Increasing the Performance of EDM Process Using Tool Rotation Methodology for Machining AISI D3 Steel

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Abstract

Electric Discharge Machining is one of the most accurate unconventional manufacturing processes used for cutting or creating intricate shapes in very hard or difficult-to-cut, electrically conducting materials. The adoption of tool rotation methodology increases the material removal rate by increasing the spark efficiency and effective debris clearing.

The experiments have been performed on AISI-D3 Steel. Results show that the tool rotation phenomenon significantly improves the average MRR and surface finish by 41% and 12% respectively. Moreover, the final surface is more uniform in structure with less number of microcracks and thinner recast layer as compared to the stationary tool EDM.

Keywords: Electric discharge machining (EDM); Material removal rate; Scanning electron microscope (SEM); AISI D3 steel.

1. Introduction

Electric Discharge Machining (EDM) is an acclaimed process for the machining of geometrically complex or hard and electrically conducting materials which are difficult to machine by any other conventional machining processes.

The EDM process originated around 1770 when the erosive effects of the electric discharges (sparks) were being studied by an English Scientist Joseph Priestly. Since then the developments started in the EDM process and for the first time in the year 1930, electric discharges were used to machine metals and diamonds, this process was then called as the “spark machining or arc machining”[1].

B. R. Lazarenko and N. I. Lazarenko, two Russian Scientists in the year 1943 during the Second World War, did pioneering work on this process. They introduced the concept of resistor-capacitor (RC) circuits and also defined the capacitor charge energy in the EDM process [2]. These days advanced EDM machines equipped with adaptive control monitoring systems can be operated round the clock [3].

Nuclear, automotive and aeronautical industries are among the leading users of very hard alloys for machining purposes. EDM is used to machine such alloys easily with a high level of accuracy. The discharge current is the most influential parameter which affects the material removal rate (MRR), whereas the pulse on-time highly affects the electrode wear rate [4, 5].

The primary drawbacks of this process are its low MRR and poor surface finish. In the recent past people have adopted various methodologies to overcome these flaws by using powder mixed dielectric solution, vibration assisted machining etc. Tool rotation methodology has been a good alternative to overcome these drawbacks, but in the past years there has been very less use of it. The present work highlights the increment in the performance of the basic EDM process by using the tool rotation methodology. The material removal rate and the surface integrity analysis have been carried out on the AISI D3 steel specimens (5 mm in thickness) using rotating copper tool (10 mm in diameter) on the EDM for
drilling purpose. The circularity of the obtained geometries has been checked using a shadowgraph.

1.1. Working Principle

The EDM system consists of two electrodes, i.e., the cathode (tool) and the anode (workpiece) and other components like power supply, servo system, reservoir, pump filter etc. as shown in Fig. 1. The power supply creates a potential difference between the two electrodes and in the inter electrode gap (IEG) the dielectric acts as a charge conducting medium. As soon as the circuit becomes complete, an electric spark occurs between the two terminals which cause the surrounding electrode material to melt. The material gets removed in the form of very fine particles from the workpiece at a controlled rate. The dielectric flushes away the material from the melt cavity when the tool electrode moves up during the on-time.

![Fig. 1. Schematic diagram of Electric Discharge Machining Process](image)

1.2. Process Mechanism

The basic mechanism of the EDM process involves the melting and vaporization of the electrode material due to the high-intensity electric spark produces in the IEG. Due to the high thermal energy of the spark the material gets melted and the molten material present in the melt cavity is being carried away with the flush of the dielectric. The process involves repeated discontinuous sparks between the workpiece and the tool, submerged in the dielectric fluid [6]. The spark temperature is high enough to melt materials of any hardness. This temperature can reach as high as 20000 °C [7].

The volume of material removal per discharge is approximately around $10^{-6}$ to $10^{-3} \text{ mm}^3$ and the MRR is around 2 to 400 mm/m\text{m} [1]. The accuracy level of the parts produced by the EDM process is good. We can also say that EDM can also be tagged as a shape reproduction process, which involves the tool electrode form to be mirrored in the workpiece [8]. With the increase in the input current, the value of MRR increases and simultaneously the value of tool wear rate (TWR) also increase, resulting in higher Ra value of the machined surface, i.e., rougher surface at higher values of the input current. The tool rotation methodology in the EDM process provides better MRR and surface finish as compared to the stationary tool EDM process [9].

1.3. Process Characteristics:

The EDM process has the following main characteristics:

(a) The process can be used for machining any electrically conducting material in the required form, irrespective of its hardness and other physical properties.
(b) The process can be used for creating intricate shapes in the workpiece which are difficult to create using the other conventional process.
(c) The exact tool shape can be replicated in the workpiece with high accuracy level.
(d) Thermal properties of the workpiece play a major role in the MRR during the EDM process.
(e) During the process the workpiece and the tool are never in contact with each other, they are separated by a small inter-electrode gap.
(f) The tool also needs to be conducting in nature so as to complete the circuit for the flow of current.

2. Experimental Set-up

The experimental set-up used for the present study is shown in Fig. 2. It includes the Electronica Z-axis Numerical Control (EZNC) EDM and a rotary tool arrangement mounted on it. The motorized set-up for providing rotary motion to the tool electrode was fabricated and mounted on the ELEKTRA 5535-EZNC EDM.

![Fig. 2. EDM with rotary tool set-up](image)
the MRR is substantially increased with a slight change in TWR. Moreover, by setting the proper direction of rotation the arc can be restricted to get the desired steepness at the edges [10].

Table 1. Technical features of the rotary EDM set-up

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motor Type</td>
<td>Permanent Magnet Direct Current</td>
</tr>
<tr>
<td>2</td>
<td>Voltage</td>
<td>120 Volts</td>
</tr>
<tr>
<td>3</td>
<td>Poles</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Speed</td>
<td>0 to 3000 RPM</td>
</tr>
<tr>
<td>5</td>
<td>Power</td>
<td>240 Watts</td>
</tr>
</tbody>
</table>

The Technical features of the rotary EDM setup are given in Table 1 and Table 2 shows the different experimental parameters used during the study.

Table 2. Experimental Parameters

<table>
<thead>
<tr>
<th>S. No</th>
<th>Input Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Current</td>
<td>10, 15, 20 and 25 Amperes</td>
</tr>
<tr>
<td>2</td>
<td>Voltage</td>
<td>75 Volts</td>
</tr>
<tr>
<td>3</td>
<td>Ton</td>
<td>150 µm</td>
</tr>
<tr>
<td>4</td>
<td>Toff</td>
<td>58.33 µm</td>
</tr>
<tr>
<td>5</td>
<td>Polarity</td>
<td>Positive</td>
</tr>
<tr>
<td>6</td>
<td>Tool rotation speed</td>
<td>0 and 1000 RPM</td>
</tr>
<tr>
<td>7</td>
<td>Feed rate</td>
<td>0.88 mm/sec</td>
</tr>
<tr>
<td>8</td>
<td>Dielectric</td>
<td>EDM oil (Paraffin oil)</td>
</tr>
</tbody>
</table>

Experiments were performed on AISI D3 tool steel metallic flats, of 5mm thickness with a copper rod as a tool electrode having 10 mm diameter. Fig. 3 shows the machined workpieces using the rotary EDM process.

Fig. 3. AISI D3 Tool Steel workpieces after machining

There are four sets of experiments (a, b, c and d), every set has two experiments, the first one using the stationary tool EDM and the later one with the use of the rotary tool EDM. A uniform rotational speed of 1000 RPM has been used during the machining, as on this value of tool rotation the MRR value is optimum. Experiments in the set (a) have been performed on uniform input current of 10 amperes, similarly for the sets (b), (c) and (d), 15, 20 and 25 amperes of uniform input current has been used respectively at a feed rate of 0.88 m/sec.

For ensuring that there is no eccentric movement of the tool, strict perpendicularity has been maintained during the experiment. For tool concentricity during rotation, a dial gauge of accuracy 1µm is used, which showed a maximum deflection of 10 µm during the experimentation. The ovality test for the workpieces has been made using a shadowgraph machine to ensure that the holes produced by the rotary tool EDM process are completely circular and accurate in diameter.

3. Performance Analysis

3.1. Material Removal Rate:

In EDM process, the MRR depends upon the input parameters like the discharge current, electrode polarity, pulse condition, machining medium etc. The material with a low melting point will have a higher MRR and, as a result, a rougher surface. The material removal takes place while the bubble is expanding, i.e., while the pressure at the discharge point is decreasing. It happens just after the discharge duration when the generated bubble is expanding and no debris particle is removed while the bubble is contracting [12]. With the help of tool rotation a maximum MRR of 12688 mm$^3$/min. can be achieved [10]. The tool rotation apart from increasing the MRR reduces the possibility of overcuts during the EDM process [11].

The experimental values obtained for the MRR during the rotary tool EDM process are given in Table 3. The calculation of MRR has been made by using the following method:

\[
MRR = \frac{W_i - W_f}{T_m} \quad (1)
\]

Where,
- \(W_i\) = Initial workpiece weight (g),
- \(W_f\) = Final workpiece weight (g),
- \(T_m\) = Machining time (min).

For equation (1), the workpiece weight was measured using a digital weighing machine and the machining time was recorded using a digital stopwatch.

Table 3. MRR for rotary and stationary tool EDM process

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Current (A)</th>
<th>MRR (g/min) with rotary tool at 1000 RPM</th>
<th>MRR (g/min) with stationary tool at 0 RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>0.0795</td>
<td>0.0401</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>0.1429</td>
<td>0.1029</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>0.2067</td>
<td>0.1837</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>0.2730</td>
<td>0.2436</td>
</tr>
</tbody>
</table>

Fig. 4. Comparison of rotary and stationary tool EDM in terms of MRR
As per the experimental results shown in Fig. 4, it is evident that the MRR during the rotary EDM process is always greater than the stationary tool EDM process. This happens because of the rotation of the electrode, which promotes frequent clearing of the debris from the melt pool. As a result, fresh workpiece surface is exposed to the tool after the debris is cleared away from the cavity. So the spark intensity becomes better as there is no more leftover debris in the IEG. Therefore, the tool rotation causes significant improvement in the MRR during the EDM process.

3.2. Surface Integrity Analysis

The surface integrity analysis has been done with respect to the following three factors:

(a) Recast Layer: These are the layers which get settled on the workpiece surface after the machining process is over. They comprise of the workpiece material, tool material and the decomposed carbon from the dielectric. Since it consists of tiny particles which are solidified on the surface of the material at high temperature, therefore, the hardness of these layers is more than the hardness of the base material. SEM images in Fig. 5 (a) clearly show the recast layer deposited over the AISI D3 steel surface after rotary and stationary tool EDM. It can be clearly seen from the figure that the rotary tool EDM has very thin recast layer as compared to the stationary tool EDM. The average recast layer thickness in the case of rotary EDM process is around 2 to 25 µm, which is almost half of what we achieve in the stationary tool EDM process [9].

(b) Surface Micro-cracks: These cracks are present on the primary surface of the workpiece after machining. They occur on the surface once the resettled material on the surface gets solidified and during the process get cracked at various places. SEM images of Fig. 5 (b) shows the micro-cracks for rotary and stationary tool EDM. We can observe that the surface obtained through rotary EDM has very few cracks as compared to the surface obtained through the stationary one.

4. Results and Discussion

The experiments and analysis performed for machining the AISI D3 steel using tool rotation methodology give us the following inferences:

(a) The average improvement in the MRR by using the tool rotation methodology comes out to be 41% (ranging from 98.25% to 12.06%), as shown in the Fig.4. It also shows that for each of the four set of experiments the rotary tool EDM yielded better MRR than the stationary one.

(b) The recast layer thickness also gets reduced by using the rotary EDM process.

(c) The tool rotation caused uniform machining of the surface which resulted in a uniform surface with fewer micro-cracks as compared to the stationary tool EDM.

(d) The surface roughness during rotary tool EDM also improves by around 12%.

With all these advantages the rotary EDM process proves to be a high-performance process and it can be adopted by the manufacturing industries to increase their productivity.

References