EXPERIMENTAL INVESTIGATION ON ELECTRICAL DISCHARGE MACHINING OF TITANIUM ALLOY USING COPPER, BRASS AND ALUMINUM ELECTRODES

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Abstract

In the present study, an evaluation has been done on Material Removal Rate (MRR), Surface Roughness (SR) and Electrode Wear Rate (EWR) during Electrical Discharge Machining (EDM) of titanium alloy using copper, brass and aluminum electrodes. Analyzing previous work in this field, it is found that electrode wear and material removal rate increases with an increase current. It is also found that the electrode wear ratio increases with an increase in current. The higher wear ratio is found during machining of titanium alloy using a brass electrode. An attempt has been made to correlate the thermal conductivity and melting point of electrode with the MRR and electrode wear. The MRR is found to be high while machining titanium alloy using brass electrode. During machining of titanium alloy using copper electrodes, a comparatively smaller quantity of heat is absorbed by the work material due to low thermal conductivity. Due to the above reason, the MRR becomes very low. During machining of titanium alloy using aluminium electrodes, the material removal rate and electrode wear rate are only average value while machining of titanium alloy using brass and copper electrodes.

Keywords: EDM, Electrode wear rate (EWR), Material removal rate (MRR), Taguchi method, Wear ratio (WR).

1. Introduction

Many researchers have conducted experiment on electrical discharge machining (EDM) process owing to its based industrial application, particularly in machining high strength steel, tungsten carbide and titanium alloys [1-5]. Tosun and Ozler [6]
have worked on optimization for EDM process parameters with multiple performance characteristics. Electrical Discharge Machining is achieved by applying a succession of discrete discharge between electrode (cathode) and an electrically conducting workpiece, separated by small gap and the total set up is immersed in dielectric fluid. The gap between tool and workpiece known as spark gap, is maintained between the tool and workpiece to cause the spark discharge. Shankar Singh et al. [7] proposed, hole making process that has been long recognized as one of the most important machining. Many researchers like Debabrata Mandal et al. [8], Kesheng Wang et al. [9], Ho and Newman [10], Krishna Mohana Rao et al. [11] have carried out experimental works and used many algorithms and methods with an aim to optimize material removal rate (MRR), electrode wear rate (EWR) and surface roughness while machining titanium alloy. Shankar Singh and Khan [7, 12] carried out some investigation on electrode wear and material removal rate during EDM of steel using graphite, brass, copper and copper tungsten electrodes. Some researchers have developed mathematical model to optimize the electrode wear (EW), MRR and surface roughness [13, 14].

The titanium alloy which is used for making some components on aerospace, biomedical applications and in many corrosive environments [14-18]. From the literature survey, no creditable works were conducted while machining of titanium alloy in EDM process by using multiple material electrodes [19]. In this research work, electrode materials like copper, brass and aluminum were taken for machining of titanium grade 2. The electrical discharge machining has been conducted with these electrodes and analysis has been made on electrode wear, SR and MRR. Consequently, an attempt has been made to analyses the influences of thermal conductivity and melting point of multiple material electrode and workpiece materials on MRR, EWR and wear ratio.

2. Experimental Details
The experiments were conducted by using a die sinking electrical discharge machine made in India with a capacity of 15 A as maximum current rating. The die sinking EDM setup is shown in Fig.1. The workpiece, titanium alloy, is in the form of strip. The workpiece was connected to positive terminal and cylindrical copper, brass and aluminium electrodes, was connected to negative terminal of the DC power supply. The electrodes were prepared by using CNC lathe with good the surface finish, which is turn affects the surface finish of workpiece. Kerosene was used as dielectric fluid with a pressure of 0.2 kg/cm², and side flushing technique.
was used to conduct all the experiments. The weight of the electrode and workpiece were measured before machining and after machining by using a China made SHIMADZU BL series electronic weight with an accuracy of 0.001 grams for every trial run. The surface roughness was measured by using a Japan made MITUTOYO SJ-201P profilometer. Roughness is measured at three different randomly selected locations and average \(Ra\) values have been considered.

Fig. 1. View of test position equipped with SPARKONIX EDM machine.

In this research work, electrodes used were in the form of cylinder with 10 mm length and 6 mm diameter. The major properties of the electrode material are shown in Table 1. The workpiece materials used in the present study were titanium Grade 2 alloy and its chemical composition of titanium alloy and major properties are shown in the Table 2 and Table 3 respectively.

<table>
<thead>
<tr>
<th>Table 1. Major properties of electrode materials.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode material</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Copper</td>
</tr>
<tr>
<td>Brass</td>
</tr>
<tr>
<td>Aluminum</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Chemical composition of the Titanium Grade 2.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>99.2</td>
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</table>

<table>
<thead>
<tr>
<th>Table 3. Major properties of Titanium Grade 2.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workpiece material</td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>Titanium alloy</td>
</tr>
</tbody>
</table>
3. Design of Experiments

In this work, the Taguchi approach has been used to design the experimental parameters. Taguchi has standardized methods for each of these DoE application steps. The Taguchi approach can reduce the number of experiments required to obtain necessary data for optimization. Therefore, DoE using Taguchi approach has become a much more attractive tool for those who attempt the optimization of any system [14, 15]. A total of three parameters namely current, pulse on time and pulse off time were chosen for the controlling factor, and each parameter was designed to have three levels, namely small, medium, and large, denoted by 1, 2 and 3, as shown in the Table 4.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Current</td>
<td>A</td>
<td>4</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>B Pulse on time</td>
<td>µs</td>
<td>200</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>C Pulse off time</td>
<td>µs</td>
<td>10</td>
<td>20</td>
<td>40</td>
</tr>
</tbody>
</table>

4. Result and Discussions

As per the experimental results, the size of the crater is found to increase with an increase in current there by decreasing the surface roughness. The calculations of the MRR and electrode wear were based on the measurement of machined volume and percentage weight loss, respectively.

4.1. Discharge current against material removal rate

Figure 2 shows the effect of discharge current on MRR for the titanium alloy workpiece material. It is observed that, in case of brass electrode the MRR increases with increase in the discharge current. The aluminum electrode produces moderate increase in MRR with increase in the discharge current, where at the copper electrode does not produce any significant increase in the MRR due to increase in the discharge current. However, the increased MRR was found during machining of titanium grade 2 using brass electrodes. Comparatively low thermal conductivity k of brass as an electrode material does not allow the absorption of much of the heat energy, and most of the heat is utilized in removal of material.

![MRR vs. current](image-url)
4.2. Effect of melting point of workpiece material and thermal conductivity of workpiece material

Since, EDM is thermal erosion process, the amount of material removal or material removal rate should be a function of melting point of the workpiece material. Also, the heat generated from the arc in the EDM process concentrates in a small portion of a workpiece material and it is dissipated through the workpiece material. Due to this reason, MRR is also a function of thermal conductivity of the workpiece material. The MRR is directly proportional to melting point \((Tm)\) of the workpiece material and inversely proportional to thermal conductivity \((k)\) of the workpiece material. Therefore, it is attempted to correlate the MRR with \((Tm/k)\) the workpiece material. The plot between MRR and \(Tm/k\) is given in Fig. 3. From the experiments MRR of titanium alloy has been taken, the MRR of tool steel have been taken from the work of Shankar Singh [7], and the MRR of mild steel and aluminum has been taken from the work of Khan [12]. From Fig. 3 it is seen that the MRR decreases exponentially with respect \(Tm/k\) of the workpiece material.

4.3. Discharge current against electrode wear rate

Figure 4 shows the variations of electrode wear rate with discharge current. It is observed that, in case of brass electrode, the electrode wear increase with increase in discharge current, where in both aluminum and copper electrodes have minimal wear. For example, during machining of titanium at \(I_p\) of 8 A, the wear of copper and aluminium electrode is 0.004 g/min and 0.022 g/min respectively.

![MRR vs. Tm/k of the workpiece material](image1)

**Fig. 3.** MRR vs. melting point of workpiece material and thermal conductivity of workpiece materials.

![EWR vs. current](image2)

**Fig. 4.** Variation of electrode wear rate with discharge current.
The electrode wear for brass electrode is 0.119 g/min. This is due to the fact that the thermal conductivity ($k$) of copper and aluminium (391 W/m-K and 227 W/m -K) is almost 2.5 and 1.7 times higher than of brass (159 W/m-K). This facilitates rapid heat transfer through the body of copper and aluminium electrodes compared to brass electrodes. It can also be noted that melting point ($T_m$) of copper (1,083 °C) is higher to that of brass (990 °C) that causes less melting point and wear of copper electrodes.

4.4. Discharge current against surface roughness

Figure 5 shows the effect of discharge current on surface roughness for the titanium alloy. It is observed that aluminum gives low value of surface roughness at high discharge current on titanium alloy, whereas, brass and copper electrodes results in poor machined surface at high currents. Because of the reason that the higher MRR of copper electrodes is accompanied by larger and deeper craters, resulting in a greater surface roughness.

![Surface roughness vs. current](image)

**Fig. 5. Variation of surface roughness with discharge current.**

4.5. Discharge current and pulse on time against wear ratio

The relationship between wear ratio WR (ratio of volume of material removed from electrode to the volume of material removed from the workpiece) with $Ip$ and pulse on time is illustrated in Figs. 6, 7 and 8. It is observed from the graph, that the wear ratio increase with increase in $Ip$ and pulse on time. This shows that high current and pulse on time causes more material removed in electrode than that of the workpiece. A stronger spark is produced at a higher current there by producing more heat. Since the electrode is relatively smaller than that of workpiece, the heat get accumulated in it resulting in high temperature and consequently high electrode wear, where in case of workpiece, heat is easily dissipated through it owing to its massive size. The heat generated during a spark is absorbed by the workpiece, electrode, dielectric fluid and the machine part. For best results, most of the heat should be absorbed by the workpiece than that of the electrode. If the thermal conductivity of the electrode is high, then the accumulation of heat in electrode is less resulting is less electrode wear. Due to the above reason, less wear ratio is obtained while machining titanium alloy using aluminum and copper electrode than that of brass electrode.
Fig. 6. Relationship between WR with current and pulse on time for brass electrode.

Fig. 7. Relationship between WR with current and pulse on time for copper electrode.

Fig. 8. Relationship between WR with current and pulse on time for aluminum electrode.
5. Conclusions

By analysing the results of the experiments on titanium grade 2 with different electrode materials, the following conclusions are arrived at:

- Higher MRR is obtained using brass and aluminum electrode.
- The MRR, EWR and SR increased when the current increased.
- Brass electrode offer high electrode wear while aluminum and copper electrode offers low electrode wear.
- It is also observed that the thermal conductivity of electrode material plays a major role in electrode wear. Copper electrode undergoes less wear compared to brass electrode because higher thermal conductivity facilitates rapid heat transfer through the body of the electrode.
- It is also absorbed that the higher melting point of electrode material will be the lower electrode wear.

An attempt has been made to correlate \((Tm/k)\) of various workpiece material which machining by using copper, brass and aluminium electrodes. It is found that the MRR decreases exponentially with respect to \((Tm/k)\) of the workpiece material.

In future, this analysis will be made on EDM and micro-EDM by using different electrode and workpiece materials. Because, only limited works were carried out in this area.

References


