Influence of Span 20 Surfactant and Graphite Powder Added in Dielectric Fluid on EDM of Titanium Alloy

Murahari Kolli and Kumar Adepu

Abstract—This paper describes an experimental study to evaluate the effect of Span20 surfactant and Graphite powder (additives) added to the dielectric fluid on the machining characteristics of the Titanium alloy using Electrical Discharge Machining (EDM). Variation of material removal rate, surface roughness and tool wear rate with respect to the variation in discharge current is evaluated. Comparison is made between the performance characteristics of the Titanium alloy with and without additives added to the dielectric fluid in the machining process. Increase in Material Removal Rate (MRR) and decrease in Tool Wear Rate (TWR) and Surface Roughness (SR) were observed, when the material is machined with additives added in the dielectric fluid compared to the machining of the alloy without additives added in the dielectric fluid. The Scanning Electron Microscope (SEM) photograph observed that the recast layer thickness is low and on the machined upper surface less micro cracks and craters are formed. Energy Dispersive Spectroscopy (EDS) analysis also indicates that some amounts of material were transferred from electrode to workpiece.

Keywords---Span20 surfactant, Graphite Powder, EDM, Titanium Alloy

I. INTRODUCTION

NOW a days Ti-6Al-4V alloy has increased applications in aerospace, marine and automobile industries, because of their high strength-to-weight ratio, high temperature stability, good corrosion resistance and excellent metallurgical, physical and mechanical properties. Machining these alloys would be a problem due to their low toughness and low thermal conductivity and high chemical reactivity with the materials to be machined therefore conventional machining of Ti–6Al–4V, results in higher machining cost. Thus Electrical Discharge Machining (EDM) was adapted as one of the non conventional machining to machine Ti–6Al–4V alloy [1]. EDM is an extensively used in industry for processing of difficult to machining materials and complex shapes with reasonable exactitude. EDM is a wide accepted machining technique used for all types of conductive and non conductive materials including metals, metallic alloys, and graphite, composite and ceramic material in the past few decades.

EDM is an advanced machining process, which is widely used to produce finished parts through the action of an electrical discharge of short duration and high discharge current intensity between the tool and work piece. The basic phenomenon of EDM is the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in the dielectric fluid. The insulating effect of the dielectric is important in avoiding electrolysis of the electrodes during the EDM process. A spark is produced at the point of smallest inter-electrode gap by a high voltage, overcoming the strength of dielectric breakdown strength of the small gap between the cathode and anode at a temperature in the range of 8000 to 12,000 °C, erosion of metal from both the electrodes (tool and workpiece) takes place. The numerical control monitors the gap conditions (voltage and current) and synchronously controls the different axes and the pulse generator. The dielectric liquid is filtrated to remove debris particles and decomposition products [2].

Chen et al. [3] attempted machining characteristics of Ti–6Al–4V with kerosene and distilled water as the dielectrics. They found that MRR is greater and the Relative Electrode Wear Ratio (REWR) is lower, when machining in distilled water rather than in kerosene. A larger amount of debris and more micro cracks were also found when using distilled water as the dielectric. Lin et al. [4] exhibited an experimental investigation of the machining characteristics of titanium alloy (Ti–6Al–4 V) using a combination process of EDM with Ultrasonic Machining (USM). The EDM and USM machining mechanisms were integrated to improve the machining efficiency and accuracy. They concluded that combination of EDM/USM process can increase MRR, the thickness of the recast layer decreases and the discharge efficiency will be improved from the experimental results.

Hascalik et al [5] compared performance of copper, graphite and aluminum electrodes while EDM of Ti-6Al-4V. It has been found that SR is increased due to decomposition of recast layer on the surface, surface micro-cracks, debris and melted drops. Recast Layer Thickness (RLT) increases with increase in discharge current and pulse on duration. Surface cracks are not developed when aluminum and graphite electrodes are used for lower discharge current. In case of copper electrode, the tendency of developing surface cracks is observed for all the process parameters. MRR, SR and TWR are increased with increase in process parameters. MRR is higher in case of graphite electrode; it is medium in case of copper electrode and lower in case of aluminum. SR is lower in aluminum electrode compared to other electrodes.

DOI: 10.9756/BJIEEMS.4820
Jabbaripour et al [6] investigated effects of process parameters on MRR and TWR and various aspects of surface integrity such as surface topography, crack formation and RLT. It has been observed that MRR increases as the pulse on time increases, but its effect is less as compared to current and voltage. The TWR also increases as the pulse on time increases but at higher pulse on time, TWR is not affected considerably. TWR decreases as the current is increased. Azad et al [7] optimized multiple performances of micro-EDM process parameters for a set of target performances when Ti-6Al-4V is EDMed. They were observed that the most influential factors are voltage and current in the optimization of single quality characteristics. These factors are not influential in multiple quality characteristics. The predicted optimum condition has been verified experimentally.

Tzeng and chen [8] investigated various powders like SiC, Cu, Cr and Al added into dielectric fluid effect on the surface quality of EDMed SKD-11. They observed that mixture of Al powder into the dielectric fluid significantly decreases the thickness of the recast layer and SR on the workpiece. Wong et al [9] studied the near mirror finish phenomenon in EDM on different powders mixed into the dielectric fluid of SKH-54. They applied three kinds of powders including graphite, silicon and molybdenum sulfide. There was found that by changing the type of powder, powder concentration, and powder size, different qualities are resulted in the same input machining parameters, this attributes that the selection of suitable powder in powder mixed EDM process is critical issue.

Kung et al. [10] studied the effect of four process parameters of powder concentration, particle size, current and pulse on time on the performance characteristics of material removal rate and tool wear ratio, during machining of tungsten carbide, applying aluminum powder. They examined that by increasing powder concentration, the MRR is increased and after a certain limit, the increase of concentration leads to reduction of MRR and also by increasing the particle concentration, tool wear ratio is decreased and after that by increasing the concentration, TWR is increased. Jeswani [11] conducted experiments on graphite powder added to kerosene, results are indicated that increasing the material removal rate and reduced the tool wear rate. When graphite powder 4gm/lit mixture into dielectric fluid, his observed significantly reduction the breakdown voltage with higher discharge frequency. Kibria et al [12] conducted experiments and compared the effect of various dielectrics such as kerosene, de-ionized water and mixing of B4C powder in kerosene and the de-ionized water during micro-hole machining of Ti-6Al-4V using EDM. It has been noticed that MRR and TWR are more using de-ionized water than kerosene. When B4C powder mixed dielectrics are used, MRR increases with de-ionized water, but TWR decreases with kerosene. It has also been observed that the RLT is less in case of de-ionized water as compared to kerosene.

Wu et al [13] investigated on the effect of surfactant and aluminium powder added into the EDM dielectric to obtain dispersion effect by reducing the agglomeration of aluminum powder. They concluded that surface roughness and recast layer is significantly reduced at low concentration of powder and surfactant. Wu et al [14] explored the influence of surfactant on the characteristics of EDMed on SKD 61. In this process parameters like discharge current, pulse duration, open voltage and gap voltage on their performance characteristics are MRR, SR, TWR and RLT. They concluded that proper machining conditions are selected, increasing the machining efficiency.

Surfactant has been widely used in daily life and industries due to its characteristics of easy dispersion, solubility and wetting effect. It is needed in various products ranging from cosmetic, detergent to industrial additives. There were many chemical engineering-related research papers discussing the application of surfactant [15]. However, it is rarely used in die-sinking EDM. The use of low concentration of surfactant in EDM resulted in increased MRR, SR where as RLT and TWR are decreased. Where as in high surfactant concentration in EDM resulted in higher SR, RLT and TWR with decrease in MRR [2009]. Similarly, by adding low concentration of graphite powder to dielectric fluid can improve the efficiency of machining significantly. But if too high concentration of graphite powder is added to dielectric fluid reduces the machining efficiency, due to agglomerate of powder particles and abnormal discharges are occurred in the machining zone [8-9,17]. The above observations and pilot experimental results, when individually addition of high concentration of graphite and surfactant respectively into the dielectric fluid degraded the machining efficiency and increased the machining time.

From the surfactant and graphite powder related very scarce literature is available on the EDM of Titanium alloy. In this work in order to increase the machining efficiency and to reduce the machining time, both higher concentrations of graphite and surfactant were added into the dielectric medium for the EDM of Titanium alloy. Variation of material removal rate, surface roughness and tool wear rate with respect to the variation in discharge current is evaluated. Comparison is made between the performance characteristics of the alloy with and without additives added in dielectric fluid in the machining process. Furthermore, RLT, EDX and surface topology where analysed in both dielectric condition. i.e., with and without additives.

II. EXPERIMENTAL SETUP

Experiments were conducted on an EDM 50 FORMATICS machine attached with self made dielectric tank shown the Figure 1. Spark Erosion 450 EDM oil is used as the dielectric fluid for machining, which is used in die-sinking machines for high machining speed and good surface finish. Additives (Surfactant 4gm/lit and Graphite powder 14gm/lit) are added in various amounts into EDM oil, by continuous stirring in order to maintain uniform distribution. The homogenous mixer of dielectric fluid is pumped in to the machining region using side flushing. The mechanical properties and chemical composition of Titanium alloy is given in Table 1 and 2. The cylindrical Electrolyte rod of diameter 14.00 mm and density 8.91g/cm$^3$ is used as tool electrode. Electrolyte Copper electrode is used which is very low cost and easily available,
the electrode face is turned and polished using a very fine grade emery sheet before conducting each experiment. The work pieces are cut to size of 100 mm X 50 mm X 5 mm and their surfaces are further polished to a surface finish (Ra value ≈ 1 µm) using emery papers before conducting experiments. The weight of the workpiece and the electrode tool was measured using a digital weighing balance (Manufacture CITIZEN) before and after the machining to calculate the MRR and TWR respectively. Surface roughness of the machined work pieces was measured using Handysurf equipment. The ranges of each factor were taken based on the capability of the machine and preliminary experiments were conducted. The concentration of the additives (Span20 surfactant and graphite powder (size 20-30 µm)) is added from 4.0 gm/lit and 14.0 gm /lit and the experimental conditions are considered as mentioned in Table 3. Topographic observation through the EDM surfaces were performed using a VEGA3TESCAN (TESCAN, CZECH REPUBLIC) Scanning Electron Microscope (SEM).

Table 1: Chemical Composition of Ti-6Al-4V

<table>
<thead>
<tr>
<th>Property</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (HRC)</td>
<td>32-34</td>
</tr>
<tr>
<td>Melting point (°C)</td>
<td>1649-1660</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>4.43</td>
</tr>
<tr>
<td>Ultimate tensile strength (MPa)</td>
<td>897-950</td>
</tr>
<tr>
<td>Thermal conductivity (W/m°K)</td>
<td>6.7-6.9</td>
</tr>
<tr>
<td>Specific heat (J/kg/K)</td>
<td>560</td>
</tr>
<tr>
<td>Mean coefficient of thermal expansion 0-100 °C/°C</td>
<td>8.6x10⁻⁵</td>
</tr>
<tr>
<td>Volume electrical resistivity (ohm-cm)</td>
<td>170</td>
</tr>
<tr>
<td>Elastic Modulus (GPa)</td>
<td>113-114</td>
</tr>
</tbody>
</table>

Table 2: Properties of Ti-6Al-4V

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Al</th>
<th>V</th>
<th>N</th>
<th>O</th>
<th>Fe</th>
<th>H</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>Max</td>
<td>6.0</td>
<td>4.0</td>
<td>0.003</td>
<td>0.149</td>
<td>0.0</td>
<td>0.011</td>
<td>Balance</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Experimental Settings

<table>
<thead>
<tr>
<th>Working parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work piece material</td>
<td>Ti-6Al-4V</td>
</tr>
<tr>
<td>Size of work piece</td>
<td>100 mm X 50 mm X 5 mm</td>
</tr>
<tr>
<td>Electrode material and size</td>
<td>Electrolyte copper</td>
</tr>
<tr>
<td>Size of electrode</td>
<td>≥ 14 mm X 70 mm (length)</td>
</tr>
<tr>
<td>Electrode polarity</td>
<td>+ve (reverse polarity)</td>
</tr>
<tr>
<td>Dielectric fluid</td>
<td>Spark erosion 450 EDM oil Additives + EDM oil</td>
</tr>
<tr>
<td>Discharge open voltage</td>
<td>110 V</td>
</tr>
<tr>
<td>Discharge gap voltage</td>
<td>65 V</td>
</tr>
<tr>
<td>Flushing pressure</td>
<td>0.75 MPa</td>
</tr>
<tr>
<td>Machining time</td>
<td>30 minutes</td>
</tr>
</tbody>
</table>

A. Material Removal Rate

Figure 2: Material Removal rate Vs Discharge Current

The effect of discharge current on material removal rate with and without additives are (surfactant 4gm/lit and graphite powder 14gm/lit) added in the EDM oil shown in Figure 2. It is observed that, with addition of additives the MRR is increased compared to without additives. The increase MMR following these is the causes. Additives added in EDM oil plays an important role, it easily suspends in EDM oil and reduces the surface tension of sediment particles and also equally distribute the graphite particles [14]. Also, during the discharge process, the surfactant may produce oxidation, which can result in the explosion. This advance density of discharge energy, improves the discharge force and enhance the erosion of material [13], which results in enhancing the discharge energy channel diameter and hence an increases in the crater diameter and depth, which attributes to higher material being evicted from the work piece.

B. Surface Roughness

III. RESULTS AND DISCUSSION
Figure 3: Surface Roughness Vs Discharge Current

The effect of discharge current on surface roughness with and without additives (surfactant 4gm/lit and graphite powder 14gm/lit) are added in the EDM oil shown in Figure 3. During the discharge process, the discharge current will locally produce high density of energy and produce explosive mix gases, which produces large craters, void and deteriorate the workpiece surface. It is observed that, with addition of additives the SR is decreased compared to without additives. Better surface finish obtained by the additive addition is due to the following causes.

- It is mainly due to effect of the properties such as electrical resistivity, thermal conductivity, particle size, particle density and concentration of powder and surfactant [8].
- In PMEDM process electrically charged conductance powder are added in the plasma channel and leads to decrease in the insulating strength of fluid.
- Surfactant reduces the surface tension and increase the conductivity of the dielectric [13].
- The enlarged and widened discharge channel reduces the electrical density on the machining zone and thus produces shallow craters and lower surface roughness [17].

C. Tool Wear Rate

Tool wear rate is defined as the weight difference of electrode before and after machining in particular time. The change of TWR verses discharge current is depicted in figure.4.

![Figure 4: Tool Wear Rate Vs Discharge Current](image)

From figure.4 it is the evident that TWR increases with increase in discharge current. If the discharge current is increased, the amount of sediment particles concentration becomes high. The additives are (surfactant and graphite powders) added in to EDM oil disturbs the adherence of carbon nuclides attached to the surface of the electrode and slightly reduced the tool wear [17]. Without additives added in the EDM oil increase in the TWR is due to production of ions during ionization in EDM oil when additives are added. These ions hit the tool electrode with high momentum and energy and cause rapid erosion of the tool electrode.

D. Surface Topography

Figure.5 (A) and (B) are the SEM photographs of the titanium machined samples. Globules of debrises, melted drops, micro cracks and craters of different sizes are formed on the machined surface of Titanium alloy when dielectric fluid with and without additives are added with variation of the discharge current. It is clear that the machined surface with additives added to the EDM oil is smoother compared to without additives. In the EDM process, without additives added to dielectric fluid, it is observed that most of the cracks, surface pits and holes are existed on the surface and its topography seems to be more unequal and non-uniform. This issue is verified by the measured surface roughness which is found to be high. When additives are added to the dielectric fluid, it is observed that the machined surface is most uniform and equal, the surface density of pits, holes and cracks are relatively less compared to without additives [16].

![Figure 5: SEM Micrographs of Machined Surface Topography](image)

(A) Without Additives (B) With Additives

E. Recast Layer Thickness

The heat affected zone produced by the EDM process constitutes an upper layer known as white layer or recast layer followed by phase transformation zone and conversion zone. Apart from it, the melted material at the substructure is quickly cooled by dielectric fluid and solidified on the surface of the work piece to form a recast layer. Recast Layer Thickness (RLT) is observed in SEM micrographs of EDMed samples with and without additives added to the dielectric fluid as shown in Fig. 6 (a) and (b). The recast layer thickness is found to be small and uniform for the machined surface done with additives compared to without additives. When additives are added into the dielectric fluid the discharge gap and plasma zone slightly increases, that effects the spark density and impulsive forces which equally distributes the energy of powder particles on the machining zone. Therefore with a greater plasma channel overpressure lesser molten material is retained and available to form overlapping recast resulting in reduction in recast layer thickness [19].

Also, high temperatures (8000-12,000 °C) are observed within the machining zone when dielectric fluid without additives added, results in the formation of high carbon and tar particles, which in turn reduce the conductivity of dielectric fluid [18]. The particles produced are accumulated on the material surface of the machine zone and these sediment particles cannot be easily removed from the zone and these form an adhesive bonding between the electrodes, so that, it causes melting of sediment particles and form a thick recast layer on the machined surface [13, 11 and 19].
IV. CONCLUSION

Based on the experimental results conclusions can be summarised as follows.

- The MRR, SR and TWR shows increasing trend with increase in the discharge current.
- Compared to without additives added, the additives added in EDM oil, results in the higher MRR and lower SR and TWR.
- By adding additives in the EDM oil, small recast layer was formed on the machined surface compared to without additives added in the EDM oil.
- When additives are added to the dielectric fluid, it is observed that the machined surface is most uniform and equal. The surface density of pits, holes and cracks are relatively less compared to without additives.
- EDX analysis also indicates that some amount of material is transferred from electrode to workpiece.

ACKNOWLEDGMENTS

The authors would like to thank the authorities of National Institute of Technology-Warangal, Mishra Dhatu Nigam Ltd Hyderabad- India for providing the material.

REFERENCES


