Influence of Different Electrode Materials during micro hole fabrication in Titanium grade 5

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Abstract

The aim of the study is to investigate the performance of different electrode materials i.e., Copper, Graphite and Platinum during micro hole fabrication in Titanium grade 5. For this purpose, Voltage (V), peak current (Ip), Pulse on duration (Ton) and Pulse off duration (Toff) are considered process variables, while Material removal rate (MRR) and Overcut (OC) are considered process responses. This paper utilizes micro-electrical discharge machining, in which thermal processing of workpieces is not affected by the mechanical properties of materials. This experiment utilizes the response surface methodology with a central composite design for carrying out experiments. The experiments were performed on a Swiss-built AGIETRON 250 die-sinking EDM machine with computer numeric control supplied by Charmilles Technologies. A commercial grade-EDM Oil (3033) was used as dielectric fluid during the experiment. It was observed that platinum as electrode material revealed higher MRR as compared to other electrode materials and graphite for lower values for Overcut (OC).

Keywords: Copper; Graphite; Material removal rate (MRR); Platinum: Pulse on duration (Ton); Pulse off duration (Toff).

1. Introduction

Electrical discharge machining (EDM) is a machining method utilizing heat for machining workpieces, controlling electric discharge sparks to cause melting, erosion and vaporization to achieve the purpose of removing material. Workpieces irrespective of any hardness can be machined using the EDM process, as long as they are electrically conductive. As a result, EDM is often used to machine high-strength or hard materials and which, if machined using traditional machining methods, would be uneconomical or suffer from imprecision [1]. According to Drozda [2], any material to be used as a tool electrode is required to conduct electricity. There is a wide range of materials used to manufacture electrodes, for instance, brass, tungsten carbides, electrolytic copper, copper tungsten alloys, silver tungsten alloy, tellurium-copper alloys, copper-graphite alloys, graphite etc. Copper is the best choice because of its facility to be highly polished. The copper-tungsten tool electrode gives a good surface finish [3]. It provides a high material removal rate and low electrode wear depending on the EDM parameter settings as compared to metallic electrodes [4]. Copper-tungsten has a much higher density than copper. This makes it the best material for a large electrode. Nickel chromium alloy (Titaniumgrade5) has a wide range of applications like chemical industry pipes, fighter plane engines, and furnace components which offer difficulty in conventional machining in hardened conditions [5]. Due to the extremely tough and thermal resistant nature, Titanium grade 5 is well known as a material difficult to cut. Shaped holes in disc fan aircraft engines, made of Ni-based superheat resistant alloy, are required to have good integrity and geometrical accuracy [6]. This kind of shaped hole is produced by EDM currently. The performance of the EDM process is determined by Material removal rate (MRR), Electrode wears (EW), Surface roughness (SR), Surface quality (SQ), and Dimensional accuracy (DA). Several Investigations have been conducted by Soni and Chakraverthi [7]. Lee and Li studied the surface quality, material removal rate, electrode wear rate, and dimensional accuracy of die steels and alloy steels in EDM [8]. The effect of the machining parameters on material removal rate, relative wear ratio, and surface roughness in EDM of tungsten Carbide has been studied using different electrode materials. It was concluded that copper tungsten yielded better results than copper and brass. Abbas et al. [9] presented the current research trends on machining and modeling techniques in predicting EDM performances. It seems that adequate investigations for different electrode materials have not been done for micro-EDM operation. In this present investigation, the effect of various electrode materials on MRR and overcut in titanium grade 5 has been analyzed. The variation of voltage, peak current, pulse on, and pulse off duration on the responses have been investigated.

2. Experimental Details:

2.1. Machine Tool

In this study, the experiments were performed on Swiss-built AGIETRON 250 die-sinking EDM machine with computer numeric control supplied by Charmilles Technologies. A commercial grade EDM Oil (3033) was used as a dielectric fluid during the experiments. An impulse jet flushing system was used to flush away the eroded material from the sparking zone This machine was used for conducting the micro-EDM experiments. This machine was energized by a pulse generator which could be switched to both transistor-type and RC-type.

2.2. Workpiece Material and Tool Material

The workpiece material used in this study was Titanium grade 5 owing to its applicability in aerospace applications. The selection of electrodes plays a vital role in die-sinking micro-EDM. In this study, three electrodes made of Copper, Graphite, and Platinum with a diameter of 0.5 mm each, respectively, were used. The electrode material's specific thermal conductivity and thermal stability (melting point) influence the machining performance significantly. Graphite as an electrode material provides a higher metal removal rate than copper with less wear. The suitable electrode polarity was selected. It was identified that the negative electrode polarity provided higher MRR and a good surface finish. Micro-EDM experiments were carried out with electrode as negative polarity and workpiece as positive. In die-sinking micro- EDM, after machining each hole the electrode was dressed using a sacrificial block of electrodes The experimental layout was based on the Central composite design. The design consisted of 30 experiments with 16(24) factorial points, eight star points to form a central composite design with α=±2, and seven center points for replication. The design was generated and analyzed using the Design expert®9.0 software package. Based on the literature survey and preliminary investigations, four significant process parameters were selected, which were source voltage (V), Peak current (Ip), Pulse on duration (Ton), Machining time (Tm), and Pulse off duration(Toff).

Table 1: Process Parameters and their levels

Process Parameters	Low	High
Voltage (V)	30	40
Peak Current (A)	8	32
Pulse on duration (µs)	20	40
Pulse off duration (µs)	30	60

2.3. Measurement of Machining Performance

2.3.1 Material Removal Rate

MRR for a micro-EDM process can be calculated by dividing the total volume of material removed and the total machining time. The measurement of diameter was done from four different positions namely horizontally, vertically, and diagonally. The average value was considered for the determination of entry as well as exit diameter. MRR was calculated considering the geometry of the micro-hole and machining time. The MRR was determined as the average volume of the material removed to the machining time and expressed in cubic millimeters per minute.

MRR=Volume of material removed/ Machining time(Tm)

Volume of material removed = $\underline{\pi h}/12(D_t^2 + D_t^2 * D_b^2 + D_b^2)$ (1)

Where D_t is the Top diameter of micro-hole

D_b is the Bottom diameter of the micro-hole.

h is the thickness of the workpiece material.

Tm is the machining time

2.3.2 Overcut

Overcut is the difference between the radius of the micro-hole and the radius of the electrode. The diameter of a hole at the entrance side was measured by scanning electron microscope. The microscopic view of micro-drilled holes measured from both top and the bottom surface of the workpiece is shown in Figure 1.

The calculation of Overcut has been determined using Equations 2. The value of OC was calculated by the diametric difference of tool as well as machined as illustrated in Figures 2 and 3 respectively.

Overcut = $(D_a – D) / 2$ (2)

$D_a = ((D_t + D_b)/2)$

where D_a is the average diameter of micro-hole produced.

where D_t is the top diameter of the micro-hole produced and *Db* is the bottom diameter of the micro-hole produced. D is the tool diameter

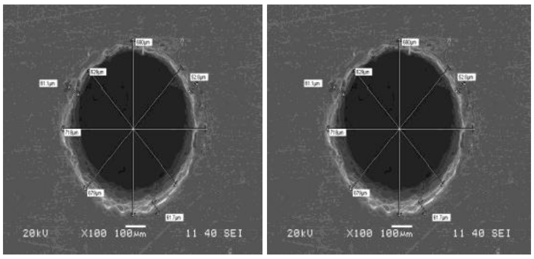

Figure 1 SEM Images of Micro Holes

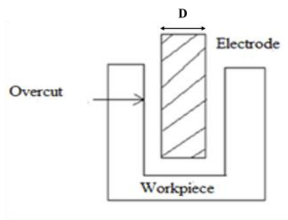

Figure 2Measurement of overcut

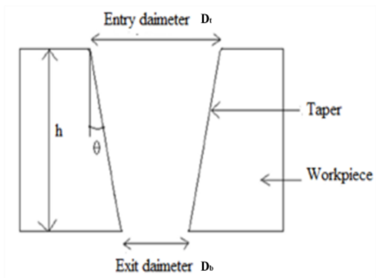

Figure 3. Measurement of Taper angle

3.1 Results and Discussion

MRR and Overcut were investigated in the fabrication of micro-hole in Titanium grade 5 using Copper, graphite, and platinum as electrode material. Further, a comparative study was also carried out to investigate the effect of process variables on process responses. In total 27 experiments have been carried. With each process parametric level (Voltage, peak current, Pulse on duration, pulse off duration) having 9 variations each, which have been plotted graphically.

3.1.1 Performance of different electrode materials on MRR

The process parameters and their levels for micro-EDM operation are given in Table1. The variation of MRR for a different combination of process parameters to voltage is shown in Figure 4 for three different electrodes. It can be observed that the MRR is maximum for platinum as electrode material followed by graphite and copper respectively. Figure 4 depicts that there is a significant rise in MRR for all three electrode materials at a voltage setting of 35 V.

However, a decreasing trend can be seen when the voltage reaches 40V. The variation of MRR for a different combination of process parameters to variation in Peak current is shown in Figure 5. Further, it can be observed that platinum as an electrode material shows maximum MRR followed by graphite and copper. It can be observed that with the increase in current settings, MRR tends to increase for platinum, while it tends to decrease for the case of graphite and copper for a maximum current setting of 32 amperes. The variation of MRR for a different combination of process parameters to pulse on duration is shown in Figure 6. Platinum as an electrode material shows the highest MRR with respect to pulse on time. The variation of MRR for a different combination of process parameters to pulse off duration is shown in Figure 7. It can be noticed that platinum as electrode material exhibits a higher MRR as compared to graphite and copper respectively.

The wear resistance of platinum electrode is very high and retains its hardness at high temperature compared to copper and graphite electrode. Because of this high form stability of platinum electrode MRR is found to be more compared to other electrodes for all combination of process parameter.

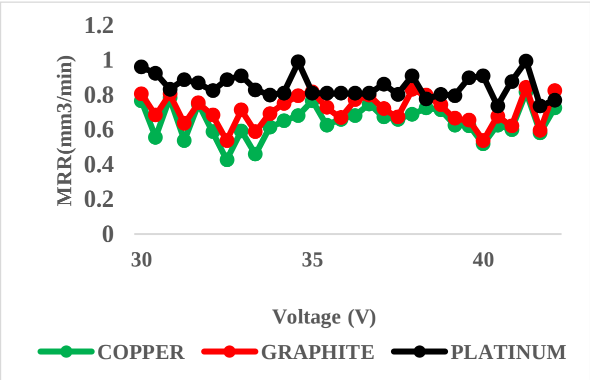

Figure 4 Variation of MRR for different electrodes with variation in voltage

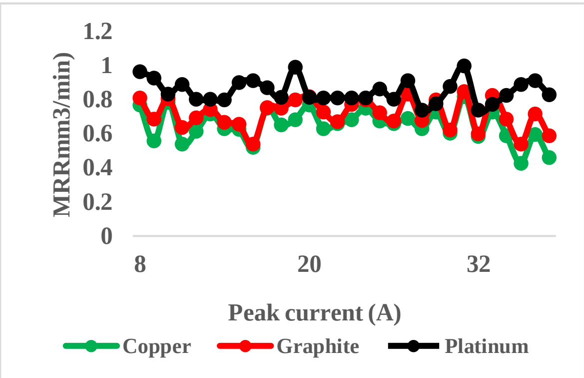

Figure 5 Variation of MRR for different electrodes with variation in Peak current

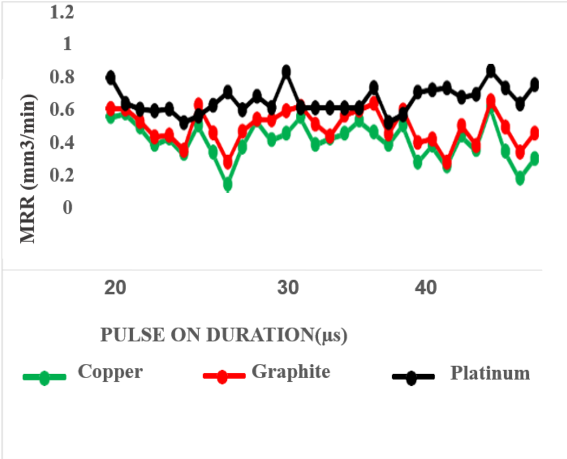

Figure 6 Variation of MRR for different electrodes with variation in pulse on duration

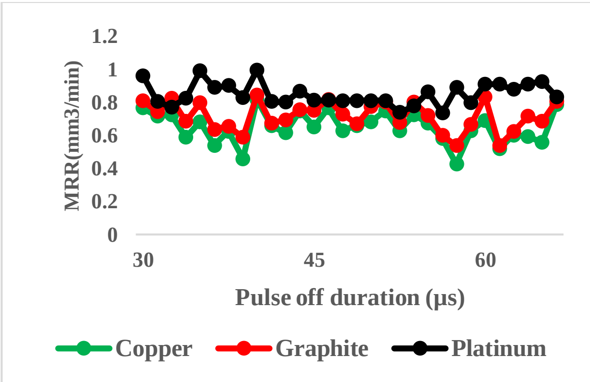

Figure 7 Variation of MRR for different electrodes with variation in pulse off duration

3.1.2 Performance of different electrode materials on overcut (OC)

The performance of various electrodes is also analyzed from the overcut point of view. During the machining process, overcut occurs due to side erosion and the removal of debris. Since overcut leads to oversizing holes, it should be as the least as possible. The variation of OC for a different combination of process parameters to voltage is shown in Figure 8. It can be seen that for the operating voltage setting of 30V, graphite depicted a minimum overcut effect, while at the operating voltage of 35 V copper showed the least overcut. It is interesting to note that at 40V platinum exhibited the least overcut. The variation of OC for a different combination of process parameters to current is shown in in Figure 9. It was observed that all electrode materials showed a nonlinear trend with irregular fluctuations in overcut values. However, copper as electrode material exhibited the least overcut during the current setting of 20 amperes while graphite showed the least overcut effect at 32 amperes current setting. The variation of OC for a different combination of process parameters to pulse-on duration is shown in Figure10. The variation of OC for a different combination of process parameters to pulse off duration is shown in Figure 11. It was observed that for pulse off duration setting of 30µs, graphite showed the least overcut but as there was a rise in pulse off duration value to 45µs, it showed a rise in overcut value.

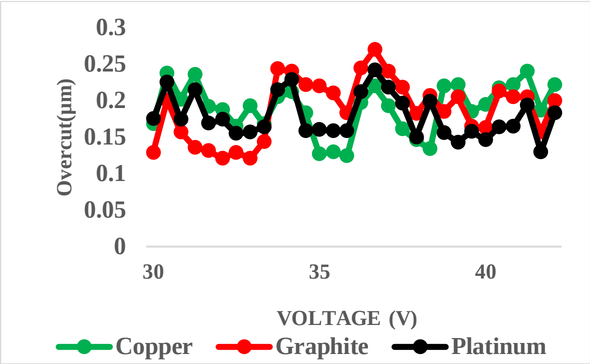

Figure 8 Variation of OC for different electrodes with variation in Voltage

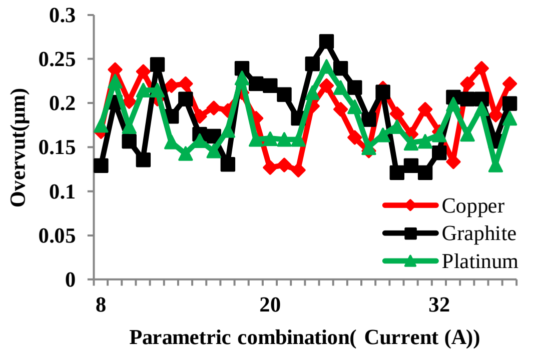

Figure 9 Variation of OC for different electrodes with variation in peak current

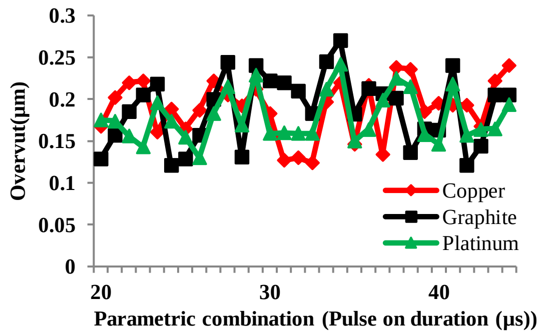

Figure 10 Variation of OC with respect to pulse on duration

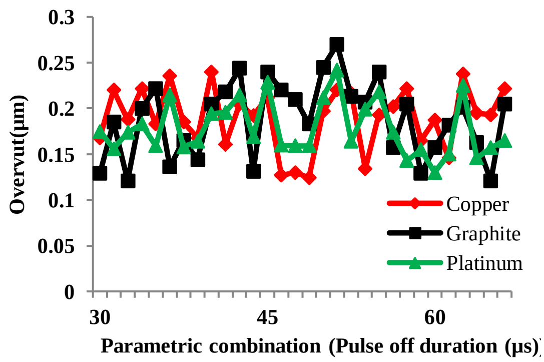

Figure 11 Variation of OC with respect to pulse off duration

The wear resistance of platinum electrode is more compared to copper and graphite. Less wear is observed in platinum wear compared to graphite and copper. Less wear was developed in platinum electrode compared to copper and graphite because of its high hot hardness and better wear resistance.

4. Conclusions

An experimental investigation was made to identify the performance of various electrodes during the fabrication of micro-holes considering Titanium grade 5 as workpiece materials. It was found that platinum followed by graphite and copper as electrode materials exhibited higher MRR, but on the other hand, platinum showed higher values of OC when compared to graphite and copper.

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