

# Effects of pulse ON and OFF time and electrode types on the material removal rate and tool wear rate of the Ti-6Al-4V Alloy using EDM machining with reverse polarity

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**Abstract.** Electrical Discharge Machining (EDM) is an unconventional metal removal process that is extensively used for removing the difficult-to-machine metal such as Ti alloys, super alloys and metal matrix composites. This paper investigates the effects of pulse (ON/OFF) time on EDM machining characteristics of Ti-6Al-4V alloy using copper and graphite as electrodes in reverse polarity condition. Full factorial design method was used to design the experiments. Two variables (Pulse On and OFF) with three levels are considered. The output variables are the tool wear rate and the material removal rate. The important findings from the present work are: (1) the material removal rate (MRR) increases gradually with an increase of the Pulse ON time whereas the change is insignificant with an increase of the Pulse OFF time, (2) Between copper and graphite electrodes, the copper electrode is proved to be good in terms of MRR, (3) a combination of high pulse ON time and OFF time is desirable for high MRR rate in the Cu electrode whereas for the graphite electrode, a combination of high pulse ON time and low pulse OFF time is desirable for high MRR rate, (4) the tool wear rate (TWR) reduces with the Pulse On or OFF time, the rate of TWR is uniform for the graphite electrode in contrast to abrupt decrease from 25 to 50  $\mu\text{s}$  (pulse ON time) in the copper electrode, (5) In order to keep the TWR as minimum possible, it is desirable to have a combination of high pulse ON time and OFF time for both the copper and the graphite electrode.

## 1. Introduction

The importance of titanium and its alloys is increasing in commercial and industrial applications because these materials exhibit excellent properties such as exceptional corrosion resistance, high temperature strength, high strength-weight ratio and high temperatures stability [1,2]. Due to its inherent properties, Ti-6Al-4V alloys are difficult to machine. The capability to produce complex parts of titanium alloys with good quality becomes challenging. Owing to their poor machinability, it is very difficult to machine economically with conventional mechanical processes[3]. The EDM is used for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes[4]. The spark erosion process or electrical discharge machining (EDM) does not have direct contact between the electrode and the work piece which avoids vibration, mechanical stresses, and chatter during machining. Materials of any hardness can be machined as long as the material can have the property of electrical conductivity[5]. Hence, Ti-6Al-4V alloy, which is difficult-to-cut material, can be machined effectively by EDM [6]. Proper selection of the machining parameters will provide higher material removal rate, better surface finish, and lower electrode wear ratio[7]. Most of the researches have been carried out for improving the process performance and for detection optimum parameters such as pulse (ON/OFF) time and peak current with straight polarity.

Researchers found material removal rate (MRR) is greater and the relative electrode wear ratio is lower, when machined in distilled water than in kerosene [8] and also they found larger amount of debris and more micro cracks using distilled water as the dielectric. Increase in pulse energy improves the material removal efficiency but leads to increase of average thickness and micro hardness of recast layer[9]. The Electrical Discharge Machining (EDM) of Ti-6Al-4V alloy with different electrode materials has been accomplished to explore the influence of EDM parameters on the material removal rate increase, and electrode wear decreases with the increasing of pulse duration. Tools with negative polarity give higher



material removal rate (MRR), lower tool wear rate (TWR) and better surface finish. The copper electrode is beneficial on material removal rate and tool wear rate. It was acquired that discharge current, pulse duration, and pulse off time affect the MRR and TWR significantly. The present paper investigates the effect of the two machining parameters such as pulse ON time ( $T_{on}$ ) and pulse OFF time ( $T_{off}$ ) on material removal rate (MRR) and tool wear rate (TWR) by using copper and graphite electrode. Experimental investigation of machining parameters for the Ti-6Al-4V alloy has been carried out with three levels with reverse polarity i.e. work as negative polarity and tool as positive polarity.

## 2. Experimental Setup and Procedure

The experiments were performed on electric discharge machine (EDM), model CNC EDM CREATOR CR-6C (Die Sinking type) with servo-head (constant gap) and reverse polarity for electrodes. Figure 1 shows the experimental setup.



**Figure 1.** Modular stem with rectangular & circular cross section

The work piece material used for this study was Ti-6Al-4V. The chemical composition and mechanical properties of Ti-6Al-4V alloy is given in Table 1 and Table 2. The specimens were prepared with 70 mm X 30 mm X 8 mm in dimensions and then grounded in order to get good finish. The properties of tool electrodes were illustrated in Table 3. Tool electrodes were prepared with 12mm diameter 100mm in length and the facing operation was done on lathe to get the good surface finish on the faces of the rods. The EDM tank is filled with commercial grade kerosene oil which is used as a dielectric fluid. Each work piece was machined for 20 min and all experiments carried out according to the experimental plan as given in Table 4.

**Table 1.** Chemical composition of Ti-6Al-4V (% wt)

Element	C	O	N	H	V	Fe	Al	Ti
Composition (% wt)	0.02	0.160	0.0023	0.0040	4.12	0.05	6.4	Remaining

**Table 2.** Mechanical properties of Ti-6Al-4V alloy

Mechanical Property	Value
Hardness (BHN)	600
Melting point (°C)	1660
Ultimate tensile strength (MPa)	832
Yield strength (MPa)	745
Impact-toughness (J)	34
Elastic modulus (GPa)	113

**Table 3.** Electrode material properties

Material Properties	Graphite	Copper
Density (g/cm <sup>3</sup> )	1.77	8.905
Melting point (°C)	3300	1083
Electrical Resistivity (ohm-m)	1400	8.9
Hardness (HV)	7	100

**Table 4.** Experimental Plan

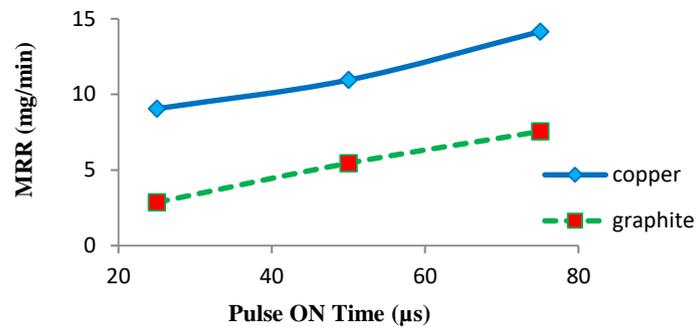
Machining conditions	Level 1	Level 2	Level 3
Discharge current	15	-	-
Pulse ON time	25	50	75
Pulse OFF time	30	60	90
Dielectric fluid	Kerosene	-	-

### 2.1 Metal Removal Rate (MRR) & Tool Wear Rate (TWR)

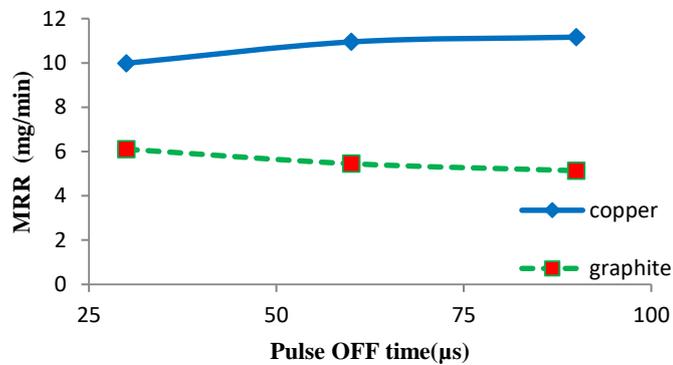
The material removal rate was measured by taking the difference in weights of the work piece and electrode material before and after machining process by using EDM. The MRR is expressed as the weight of material removed from work piece over a period of machining time in minutes. Similarly the tool wear rate was measured by taking the difference in weights of the tool material before and after machining process by using EDM. The TWR is expressed as the weight of material removed from tool over a period of machining time in minutes.

### 3. Results and Discussions

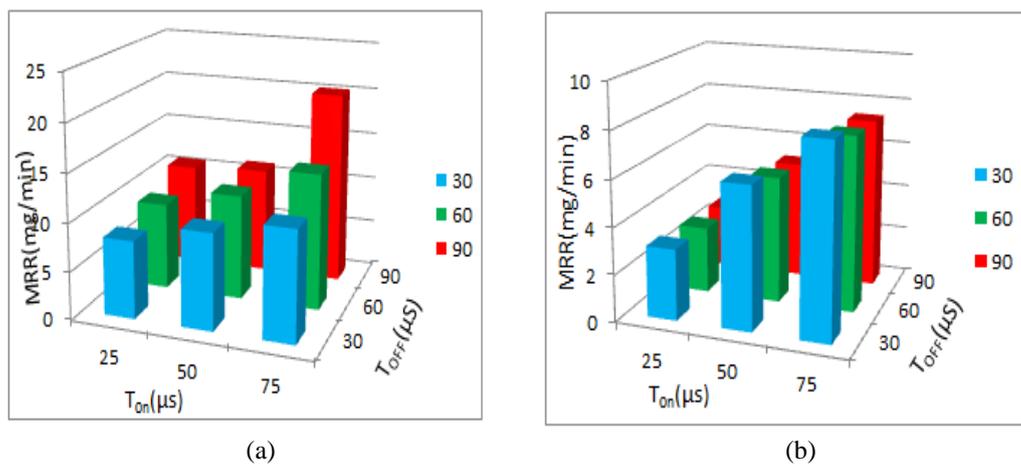
The experiments were conducted as per the plan and the results shows that the highest MRR values appeared at the higher pulse on time and at the higher pulse off time with copper electrode, and at the higher pulse on time and at the lower pulse off time with graphite electrode. From the Figure 2, it is evident that increasing in pulse on time increases the MRR with both electrodes and Figure 3 shows increasing in pulse off time very slight increase in MRR with copper electrode but slight decrease in MRR with graphite electrode. Increase in pulse pause time, decreases the spark contact time with work piece hence MRR decreases. Due to more time gap in between the successive spark will leads to less metal removal rate. From Figure 4(a) at lower pulse on time, even increase in pulse off time, MRR does not changing significantly. But at the same, higher pulse on time, the increase is more with increase in the pulse off time. From Figure 4(b), it was observed that, there is no significant effect, in case of graphite electrode. Even at higher pulse on time, the decrease in not significant. MRR with graphite electrode was less compared to the copper electrode with reverse polarity. When machining with graphite electrode in kerosene, formation of TiC, which has higher melting point temperature and carbon deposits on the electrode leads to the lower MRR. Formation of carbon deposits retard the discharge process[8]. It was observed from Figure 4(a) and Figure 4(b) that MRR increases in case of both the electrodes with the increase pulse on time. When increase in pulse on-time, the discharge energy of the plasma channel and the period of transferring of this energy into the electrodes increases. This occurrence leads to formation of a bigger molten material crater on the work piece which results in a higher MRR. In increasing on time the spark get more time to contact with the work which results in increase the MRR. The maximum material removal rate is 20.215mg/min for copper and 8.2 mg/min for graphite electrode. From this, for Ti-6Al-4V alloy the best suited electrode was copper in kerosene. Even though graphite is has good electrical conductivity but machining with graphite was not yielding more MRR.



**Figure 2.** Effect of Pulse ON time on MRR at pulse OFF time-60µs

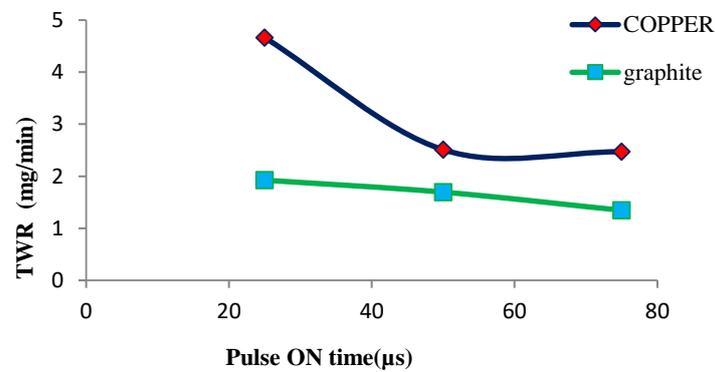


**Figure 3.** Effect of Pulse OFF time on MRR at pulse ON time-50µs

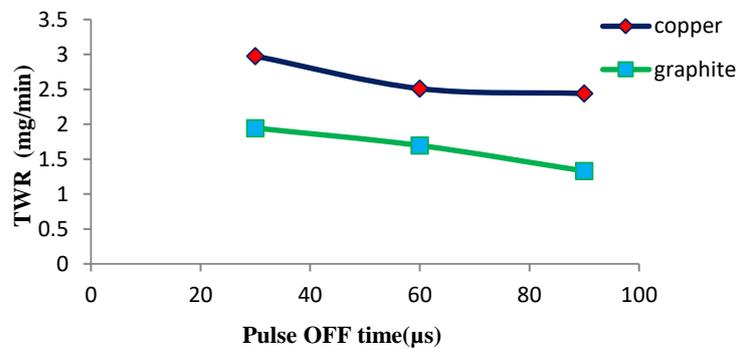


**Figure 4.** Effect of EDM Parameters on MRR with (a) copper and (b) Graphite electrode

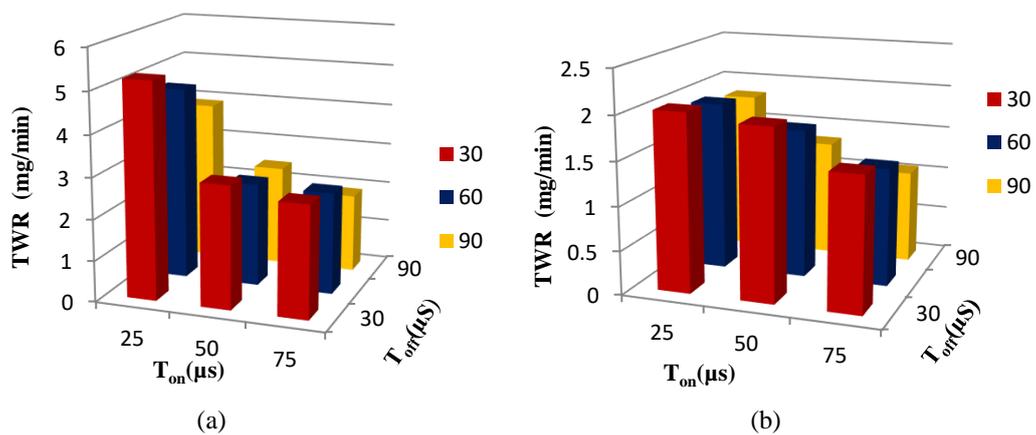
Tool wear is related to the melting point of the materials. Tool wear is affected by the precipitation of carbon from the hydrocarbon dielectric on the electrode surface during electric sparking. And also the rapid wear on the electrode edge was because of the failure of carbon to precipitate at difficult to reach regions of the electrode. The observations illustrates that the lowest TWR values appeared at the higher pulse on time and at the higher pulse off time with copper and graphite electrodes. From the Figure 5, it is evident that increasing in pulse on time decreases the TWR with both electrodes. Figure 6 shows increasing in pulse off time very slight decrease in TWR with both electrodes. Increase in pulse pause time, decreases the spark contact time with tool hence TWR decreases.



**Figure 5.** Effect of Pulse ON time on TWR at pulse OFF time-60μs



**Figure 6.** Effect of Pulse OFF time on TWR at pulse ON time-50μs



**Figure 7.** Effect of EDM parameters on TWR with (a) copper and (b) graphite electrode

Due to more time gap in between the successive spark will leads to less tool wear rate. From Figure 7(a) at lower pulse on time, even increase in pulse off time, MRR does not changing significantly. But at the same, higher pulse on time, the decrease is slight with increase in the pulse off time and at lower pulse on time we get high tool wear rates. From Figure 7(b), it was observed that, there is no significant effect, in case of graphite electrode. Even at higher pulse on time, the decrease in not significant. TWR with graphite electrode was less compared to the copper electrode with reverse polarity. It was observed

from Figure 7(a) and Figure 7(b) that TWR decreases in case of both the electrodes with the increase pulse on time. When increase in pulse on-time, the discharge energy of the plasma channel and the period of transferring of this energy into the electrodes increases. In increasing off time the spark get less time to contact with the work which results in decrease the TWR. The minimum tool wear rate is 1.91mg/min for copper and 1.06 mg/min for graphite electrode. TWR decreases with the increase in  $T_{on}$  and  $T_{off}$ . The interaction Effect on  $T_{on}$  and  $T_{off}$  decreases the TWR while increasing their levels.

#### 4. Conclusion

In this present work, the Ti-6Al-4V alloy was machined by using Electrical Discharge Machining (EDM) process with different electrode materials and different machining conditions with reverse polarity were investigated in detail. The key results from the present work are:

- The increase in Pulse ON time leads to an increase in material removal rate (MRR) and decrease in tool wear rate. With copper electrode higher material removal rate (MRR) was observed compared to the graphite electrode.
- The Increase in pulse pause time slightly decreases the material removal rate (MRR) and tool wear rate (TWR) with the graphite electrode, but in the case of copper electrode, material removal rate (MRR) increases and tool wear rate (TWR) decreases.
- From the experimental investigations, for Ti-6Al-4V alloy the best suited electrode was copper in kerosene (in reverse polarity) compared to the graphite electrode. Even though graphite has good electrical conductivity but machining with graphite was not yielding more material removal rate (MRR).

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