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Comparison of Surface Features of drilled Hole Generated on Titanium Grade 5 (Ti-6Al-4V) Between Dry-micro EDM and Dry-macro EDM Using Confocal Sensor

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Abstract

Micro-Electric Discharge Machining (µ-EDM) is a method based on thermo-electric energy generated between the tool electrode and workpiece, to develop micro parts in the range lesser than 1mm. To remove harmful effects of liquid dielectric in a working environment, use of air or gases has been increasingly used to promote green manufacturing. In this present case of dry-EDM (both micro & macro), air/oxygen has been used as a dielectric medium on the Ti-6Al-4V workpiece with copper and brass tubular electrodes. Air/oxygen is fed at a pressure of 5 bar to the machining zone, through the rotating tubular electrode by maintaining a constant spark gap. The purpose of using air/oxygen at such pressure is to act as a dielectric, to remove the debris accumulated and to lower down the temperature generated in machining zone. Multi-Spark experiments (for 5 min duration) were carried out for both dry-micro and dry-macro EDM cases, using 0.5 mm and 2mm tubular electrodes of Brass and Copper respectively. Thus a comparison has been made, under the same conditions of Open Circuit Voltage V, TON & TOFF between dry Micro & Macro EDM and observing their influence on work sample (Ti-6Al-4V). The surface features of the drilled hole generated have been analyzed by the use of a confocal sensor, i.e., hole dimensions (Diameter and Depth) and the result thus obtained are compared with microscopic images of the samples.

Keywords: Dry Micro-EDM, Dry Macro-EDM, Ti-6Al-4V, Tubular Electrodes, Dielectric, Confocal

1. INTRODUCTION

With the advent of micro-manufacturing in various applications including optics, telecommunication, etc., the demand for developing small and precise components is growing at a fast pace. For obtaining the burr-free micron and sub-micron size components having a large aspect ratio, Micro-EDM is being considered as an ideal process. For machining of micro holes and for generating complex surface-features, Micro-EDM is widely used.

Micro-EDM is a non-contact type material removal process, in which discharge occurs between the tool electrode and workpiece kept at a minimal distance, usually of the order of few microns. The discharge often occurs between the two electrodes when the electric field intensity exceeds the particular value and breakdown of dielectric between the two electrodes. The discharge usually occurs at a very high rate which results in melting and evaporation of the material from both the tool electrode and workpiece. The dielectric commonly being used is Kerosene or De-ionized water in case of EDM, but due to the demerits and harmful effects to the environment of using liquid dielectric, dry environment is being preferred mostly nowadays. For maintaining the dry atmosphere between the two electrodes, compressed air or gases (mainly oxygen, nitrogen and argon) are more preferred for obtaining the high MRR, small Tool Wear Ratio, and better finish.

When machining micro-holes, the debris generated around the periphery of the hole is hard to be removed. Such debris accumulation around the periphery causes abnormal discharges and short circuits. So to avoid or prevent such abnormal conditions, better flushing techniques had been proposed by various researchers, to improve the machining performance. The tool electrode is provided with a to-and-fro mechanism to change the contaminated dielectric between the tool and workpiece. The rotary movement of the tool electrode for enhancing the pumping action of fluid had been given by Masuzawa et al.[1]. Apart from the advantage of the better pumping action of the dielectric fluid, rotary or planetary movement of the electrode has been found to be essential for the better stability of the dry-EDM process [2]. There are mainly three types of flushing techniques namely pressure or jet flushing, suction flushing and a combination of the two. For the first type of flushing method, i.e., pressure flushing, a higher pressure is usually required to flush the dielectric through the hollow electrode or through the workpiece. Secondly, the suction flushing can also be provided through the tool electrode or workpiece as it is mainly responsible for minimizing the secondary discharge and wall tapering. Lastly, combining the two techniques allows gases and eroded particles to leave the machining area and permit circulation for proper machining, thus often used in cases of molds with complex shapes. In the case of Micro-EDM, traditional flushing techniques like pressure or jet flushing and suction flushing are not desirable due to the size constraints and flexibility of using micro-electrodes (in the order of lesser than 1mm). A very high pressure used for flushing of the dielectric can reduce the dimensional accuracy due to the deflections of the micro-sized electrodes employed in Micro-EDM. Hence to reduce the arcing and short-circuiting conditions, several methodologies had been explored to improve the flushing of debris from the narrow gap of micro-EDM, which includes gravitational and magnetic field assisted micro-EDM [3,4,5].

Few researchers also proposed the vibration over the work surface which is directly attached to the transducer, and hence to influence the machining performance it has a significant effect for micro-EDM process [8]. Teimouri R. et al. showed the combined effect of rotary magnetic field and a rotational motion to the electrode, over the work surface that helps in increasing the machining performance by better debris removal from the machining zone. Sundaram M.M. et al. [11] studied the effect of various flushing techniques like utilizing the magnetic field and gravitational forces that are suitable for the case of Micro-EDM. They also studied the influence of tool materials along with the flushing techniques and their effect over the work sample to improve the machining performance. Jahan et al. [12] investigated the influence of various machining parameters on the performance of micro-EDMing tungsten carbide (WC) work

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sample in obtaining high quality micro-holes for both transistor-type and RC-based pulse generator. Yan B.H.et al. [9] performed various experiments to develop the micro-holes over the carbide surface by using the copper as tool electrode and studied the effect of various operating parameters over the quality of micro-hole generated on the carbide surface.

To remove the harmful effects to the environment by the use of liquid dielectric, the case of Dry Micro-EDM (d-μEDM) is preferred nowadays. In the case of Dry Micro-EDM, liquid dielectric has been replaced by air or gases (like oxygen, nitrogen, etc.) for machining. The role of using air or gas is to act as a dielectric, to cool the machining zone and to flush the micro-sized debris generated during machining. The rotation of tool electrode is essential for ensuring the better stability and high performance in the case of Dry Micro-EDM. Features that attract one towards usage of this technology include low tool wear rate (TWR), high surface roughness (SR) and less surface damage. However, in comparison to the conventional EDM, the significant limitations of using this technology include lower material removal rate (MRR) and lower stability of the plasma channel.

To study the effects on the surface thus obtained after machining using electrical discharge, no study has been made for in-situ geometrical measurement of drilled hole or channel, etc. In-situ measurement helps in measuring the surface features without removing the object from the machine tool because removing the part and mounting it again on the machine tool leads to various kinds of systematic errors and geometrical deviations. Thus non-contact type optical sensor is preferred to incorporate in the system for in-situ measurement of geometrical or surface features. The chromatic confocal sensor such as the one used by F.Iqbal et al. [6,7] is light, compact and mounted on the tool head for fulfilling the need for measuring the surface features obtained in the micro-EDM process, as shown in fig.2

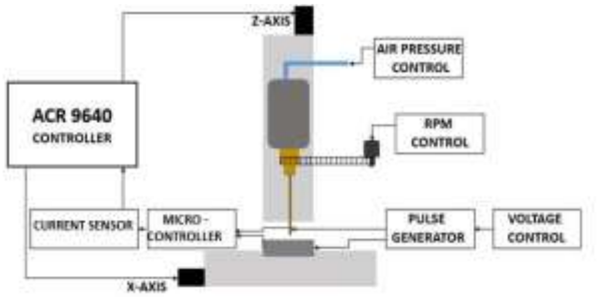


Fig. 1. Block Diagram of dry Micro-EDM Setup

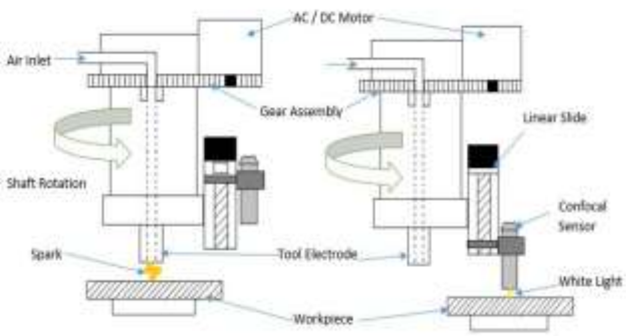


Fig. 2. In-situ Measurement by using Confocal Sensor

The present work investigates the influence of workpiece material (Titanium Grade 5 in this case), tool electrode properties and the various process parameters (T_{ON}, T_{OFF}, etc) on the surface features generated over the work sample by erosion performing multi-spark experiment for a specified duration using hollow electrodes rotating at a certain constant speed. The dielectric medium used to flush out the debris from the machining zone is compressed air which is provided through the rotating tool electrode at a particular pressure usually of the order of 4 to 5 Bar. Thus a comparison has been made between both the electrodes used under the same conditions over the Titanium Grade 5 work sample and the surface features generated after performing machining operation for a specified duration has been observed by using the confocal sensor.

2 EXPERIMENTAL METHOD & SETUP

2.1 Details of workpiece and tools used

The workpiece used is a plate of dimension 100mm X 80mm X 7mm and material as Titanium Grade 5 (Ti-6Al-4V) which have been eroded by using the copper and brass tubular electrodes of 0.5 mm and 2.0 mm diameter.

Table 1 Physical Property of Materials used as Tool Electrodes

Physical Property	Copper	Brass
Thermal Conductivity, k [W/m.K]	376	401.93
Specific Heat, c [J/ kg.K]	385	109
Melting Point, T [K]	1358	1213.15

Tool electrode is the most critical part of EDM. Brass is commonly used to form EDM wire and small tubular electrodes. Brass does not resist wear and is much easier to machine. Copper, on the other hand, have better EDM wear resistance than Brass. Copper is commonly used because of its highly conductive and stable nature. Table 1 compares the physical properties of both the copper and brass as tool electrodes.

2.2. Experimental Procedure

Dry-Micro EDM (d-μEDM) experiments have been carried out on fabricated Micro-EDM Setup whose line diagram is shown in fig.1. In all the experiments, compressed air was used as a dielectric medium which is forced out of a tubular electrode of 0.5mm and 2.0mm outer diameter at a pressure of 5 bar. The tubular electrode is gripped on a high precision collet chuck of range 0.3mm-3.0mm fixed onto the spindle which is being rotated at a speed of 60 RPM. The machining time was set and kept 5 min for each experiment respectively. However to facilitate the experimental work, following process parameters are mainly considered namely discharge current, pulse-on time, duty cycle and gap voltage.

Table 2 Process parameters and their ranges used

Process Parameters	Range
Discharge Current (Ip), A	0 - 3.5
Pulse-On Time, TON (μs)	100, 250, 500, 1000
Duty Factor	0.50
Gap Voltage (Vg), V	100, 120, 130

The experiments were carried out keeping the above parameters at specified values. The range of the discharge current for the experiments was selected from 0-3.5 A, Pulse-on time selected 100 to 1000 μs, duty cycle was kept at 50%, and the gap voltage has been selected from 100 V to 150V as per the power supply used for the experimentation. The process parameters along with their ranges have been provided in Table 2.

Table 3 Dry Micro EDM conditions

Working Conditions	Description
Tool Electrode	Cu, Brass
Tool Polarity	-ve
Dielectric Fluid	Compressed Air
Work Material	Ti-6Al-4V

For in-situ measurement, the chromatic confocal sensor is used along with the Micro-EDM tool head as shown in fig.2 to avoid any measurement error. The specifications of the confocal sensor are shown in Table 4. After performing the desired experiments, the workpiece (Ti-6Al-4V) is moved below the confocal sensor with the help of linear stage. The confocal sensor is brought closer to the workpiece surface maintaining the stand-off distance between the sensor head and work surface as 6mm. An excellent white spot can be seen on the work surface to be measured, which is hovered over the drilled hole whose specifications need to be checked. The scanning data is retrieved in the excel sheet, which then is used to determine the width and depth of the hole over the work sample.

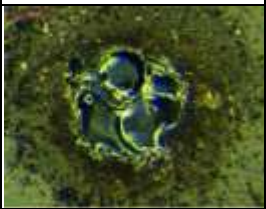
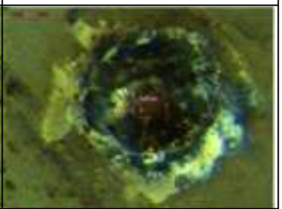
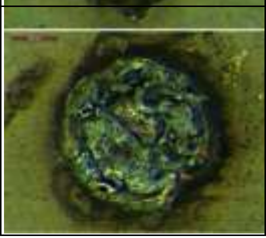
Voltage	Copper (2 mm) hollow electrode	Brass (2 mm) hollow electrode
100 V		
120 V		
150 V		

Fig. 3. Images of work sample using 0.5mm hollow electrodes under different voltage conditions

Table 4 Confocal Sensor Specifications

Parameters	**Value**
Fibe Core Dia	50 µm
Light Spot Dia	6 µm
Probe Diameter	27 mm
Probe Length	154 mm
Resolution	10 nm
Working Range	300 µm
Working Distance	6 mm

The results of the hole generated using the confocal sensor has been compared with the Leica Optical Microscope M205A at 200 µm and 500 µm resolution respectively. The images of the drilled holes obtained for both the electrodes, i.e., 0.5 mm and 2.0 mm diameter, under different machining conditions has been shown in fig. 3 and fig. 4 respectively.

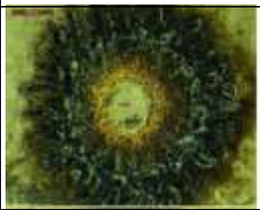
Voltage	Copper (2 mm) hollow electrode	Brass (2 mm) hollow electrode
100 V		
120 V		
150 V		

Fig. 4. Images of work sample using 2.0mm hollow electrodes under different voltage conditions

3. RESULTS AND DISCUSSION

With the help of confocal sensor, the width and the depth of the hole generated using the 0.5 mm electrode on the work sample has been compared with the optical microscope as shown in Table 5. Regarding comparison of width generated on the work sample using 2.0 mm hollow electrodes, confocal sensor could not be used as the area surrounding the spark gets accumulated by a large amount of debris as shown in figure 4, which does not allow the white light from the confocal sensor to get the accurate readings as it causes too much noise or disturbances while taking the readings. So taking the readings through the confocal sensor is not recommended as per the experiments carried out.

According to the values shown in table 5, for Brass, the width of machining increases with increase in the value of voltage. The values taken by the optical microscope lies almost close to the values taken from a confocal sensor. For the case of copper, the width of machining decreases with increasing the voltage values. As seen in fig 3, for the case of copper as tool electrode with increasing the voltage value the circular shape is more visible. This may be because of an intense electric field generated between the tool and workpiece, which allows the discharge to converge at a very narrow region. While in case of brass as tool electrode, the spark loses its intensity with increase in the value of voltage. This may be because of the fact that proper flushing is not occurring which causes the electrode to cause more arcing conditions instead of proper spark to happen. This may be seen more prominently with the brass electrode at 130V which results in the formation of white layer and distortion in the shape of the hole drilled over the work surface.

While in the case of macro-sized electrodes, the brass electrode tends to prepare the hole more accurately at the voltage of 100V & 130V respectively. At higher voltage values, the hole tends to lose its accuracy, apart from creating more debris around the hole to be drilled as shown in fig 4.

Table 5 Comparison of width generated on work sample usingconfocal & optical microscope for 0.5 mm electrode

Material & Voltage Range	Using Confocal Sensor	Using Optical Microscope
Brass ; 100 V	165 µm	207 µm
Brass ; 120 V	357 µm	412 µm
Brass ; 130 V	368.50 µm	424 µm
Copper ; 100 V	264 µm	315 µm
Copper ; 120 V	247.5 µm	289 µm
Copper ; 130 V	198 µm	247 µm

As per the results obtained, it can be said that at lower voltage values brass electrode is proving to be a better option instead of copper electrode and at higher voltage values copper predominates.

Table 6 Depth of machining carried out using 0.5 mm hollowelectrodes

Material & Voltage Value	**Depth of Machining**
Brass ; 100 V	38.64 µm
Brass ; 120 V	63.71 µm
Brass ; 130 V	92.61 µm
Copper ; 100 V	31.96 µm
Copper ; 120 V	32.54 µm
Copper ; 130 V	92.6 µm

For determining the depth of machining carried out on the work sample for the duration of 5 min on each sample using the 0.5 mm electrode has been found out by the use of confocal sensor, and as the confocal sensor could not be used due to large debris accumulation for 2.0 mm electrodes determining the depth of machining using confocal technology is not a good choice. Thus to determine the depth of machining for 2.0 mm electrodes, 3D scanning technology using the Leica Optical Microscope is being explored. The depth of machining using 0.5 mm electrodes has been shown in table 6. Also, the depth of machining increases for both the electrodes viz. brass or copper as the voltage value kept on increasing.

4. CONCLUSIONS

In this study, in-situ measurement of the drilled hole has been carried out by using the Confocal Sensor and the values thus obtained is compared with the Leica Optical Microscope. The results obtained leads to following conclusions and the future scope for the same

- To minimize the error in measurement by taking the sample from one place to other, in-situ measurement of geometrical and surface features has been preferred by the use of confocal sensor integrated with the EDM Head.
- For width measurement, both confocal and microscope can be employed, but for depth measurement confocal sensor found more suitability compared to the optical microscope as the same can measure depth at a higher frequency which is not possible under a microscope.
- To minimize the debris formation and its easy removal from the machining zone, arcing and short-circuiting conditions should be kept to a minimum. The new and modified circuit is being designed for minimizing these issues.

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