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Investigation of effect of process parameters in micro hole drilling

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Abstract—This paper investigates the Micro Electric Discharge Machining (Micro EDM) of titanium wrought alloy with brass as electrode. In this research work, the effects of four parameters, namely, current, capacitance, pulse on time and pulse off time were studied upon material removal rate (MRR), electrode wear rate (EWR), diametric overcut (DOC) and taper angle (T). The objective was to study the effect of input parameter individually on the final outcome. Response surface methodology was used to design the experiments and the performance characteristics in micro drilling operation were studied. The experimental result indicate that current is the most significant factor. At high values of discharge energy MRR and EWR were found high while shape accuracy distorted by interaction of other parameters among which pulse on time and capacitance plays important role.

Keywords—Micro EDM, Material removal rate, Electrode wear rate, Overcut, Taper angle

I. INTRODUCTION

Titanium wrought alloy (VT-20) is most widely used material in aerospace industry. It has drawn special attention due to its excellent properties. It is possible to machine this material with some conventional machining processes, however the high accuracy required in drilling micro holes cannot be possible. Among non-conventional machining processes, the micro EDM drilling is the only method capable of machining VT-20 with desired accuracy.

Micro EDM is non-conventional machining process, widely used for machining electrically conductive materials, more specifically hard materials. The micro EDM has many advantages, such as non-contact with the workpiece during the machining process and ability to machine any conductive material, regardless of its hardness. Hence, it does not create any vibration during machining as compared to other conventional machining and proved effective in machining micro holes, blind holes, deep holes, inclined holes and irregular holes; because there is no microscopic force during machining [1]. Various applications of micro hole can be found like fuel injection nozzles, spinneret nozzle holes, standard defects for testing material, biomedical filters and so on [2]. Creating cooling channels in turbine blades made of hard alloys is a typical application of EDM drilling [8]. M.P. Jahan et. al [2] investigated the influence of major operating parameters on the performance of micro-EDM of WC (tungsten carbide) with focus in obtaining quality micro-holes in both transistor and RC-type generators. Hung-Sung Liu et al. [3] checked the feasibility of fabricating micro-holes in the high nickel alloy using micro-EDM. G. Kibria et. al [4] investigated micro-EDM characteristics such as MRR, EWR, DOC, T and machining time (MT) during micro-machining of through holes on Ti-6Al-4V super alloy employing de-ionized water based dielectric other than conventional hydro-carbon oil i.e. kerosene. M.P. Jahan et. al [5] introduces a simplistic analytical model to evaluate the effectiveness of low frequency work piece vibration during the micro EDM drilling of deep micro-holes. Yan et al. [6] described the characteristics of micro-hole on carbide, produced by micro-EDM using copper tool electrode and investigated the effects of various machining parameters on the quality of micro-holes. B.H. Yan et al. [7] investigated the drilling of

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precision micro holes in borosilicate glass using micro EDM combined with micro ultrasonic vibration machining. Natarajan N. et al. [8] done optimization using grey relational analysis with input parameters as current, voltage, pulse on time and pulse off time while the response are MRR, EWR, DOC and T.

II. EXPERIMENTAL SET-UP

During this study, series of experiments on the VT-20 were conducted by micro EDM of charmills robdrill to examine the effect of input machining parameters, such as current, capacitance, pulse on time and pulse off time on MRR, EWR, taper angle and overcut. In this experimental work rotary brass hollow tubular electrode of diameter ϕ 500 µm was used under servo control. The weight of workpiece and electrode was measured by denver's weight balancing device having least count 0.1 mg. An optical Microscope was used to measure the diameter of machined hole on the workpiece with.

2.1. Experimental procedure

The experiments has been conducted with four controllable factors namely capacitance, current, pulse-on time and pulse-off time. On the basis of preliminary experiments conducted by using one variable at a time approach the range of capacitance, current, pulse-on time and pulse-off time are selected. Machining parameters and their level chosen for this study are presented in Table 1.

Table 1. Machining Parameters and their levels

	-2	-1	0	+1	+2
Capacitance	0.15	0.22	0.26	0.32	0.38
Current	8	15	19	26	32
Pulse-on time	8	12	16	20	24
Pulse-off time	8	12	16	20	24

III. RESULT AND DISSCUSSION

In this study the machining parameter such as current, capacitance, pulse on time and pulse off time were studied to evaluate MRR, EWR and quality of micro holes.

3.1. Analysis of material removal rate

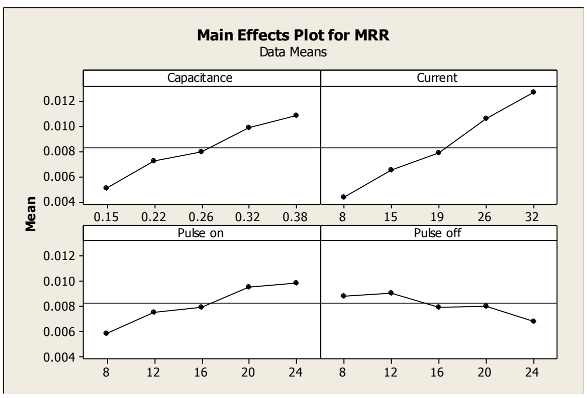


Figure 1. Main Effect Plot for MRR

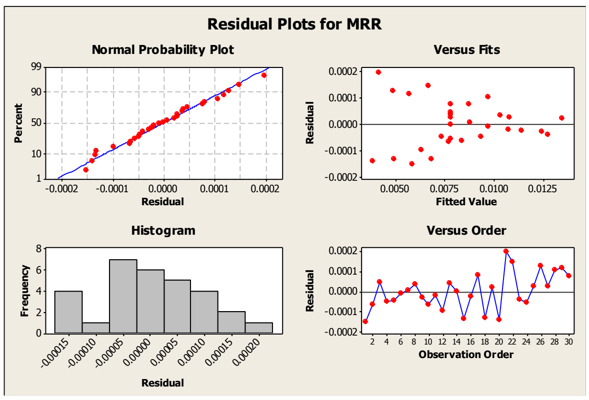


Figure 2. Main Effect Plot for MRR

The MRR is calculated as the workpiece removal weight over the machining time, which is expressed as grams per minute. Figure 1 shows that the MRR is directly proportional to the capacitance, current and pulse-on time. But the MRR is lower, whenever there is increase in pulse-off time. MRR mainly depend on discharge energy, long pulse energy results in higher MRR. Then, regression equation 1 is performed based on the results by the design of experiment software, which is shown in figure 2. Here, the MRR act as dependent variable, which has four independent variables.

MRR = - 0.00764 + 0.0256 Capacitance + 0.000360 Current + 0.000250 Pulse on - 0.000129 Pulse off … (1)

3.2. Analysis of electrode wear rate

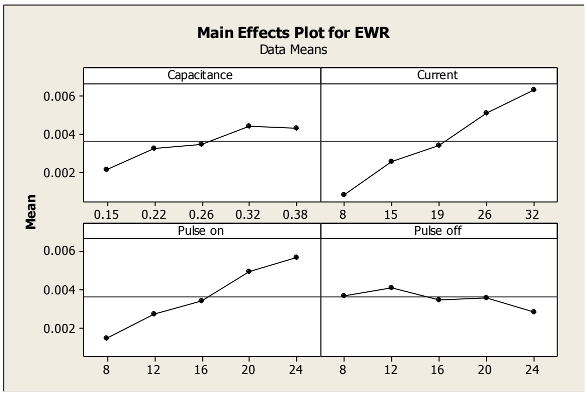


Figure 3. Main Effect Plot for EWR

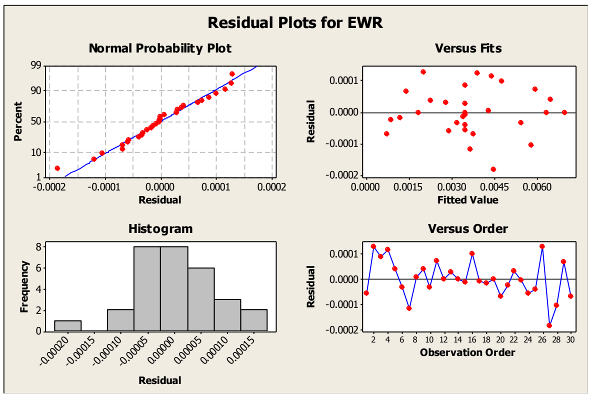


Figure 4. Main Effect Plot for EWR

EWR is calculated as the ratio of tool wear weight to the machining time, which is expressed as grams per minute. Figure 3 shows that the EWR is directly proportional to the capacitance, current and pulse-on time. However, the EWR is lower, when there is increase in pulse-off time. Then, regression equation 2 is performed based on the results by the design of experiment software, which is shown in figure 4. Here, the MRR act as dependent variable, which has four independent variables.

EWR = - 0.00707 + 0.0106 Capacitance + 0.000226 Current + 0.000273 Pulse on - 0.000059 Pulse off … (2)

3.3. Analysis of overcut

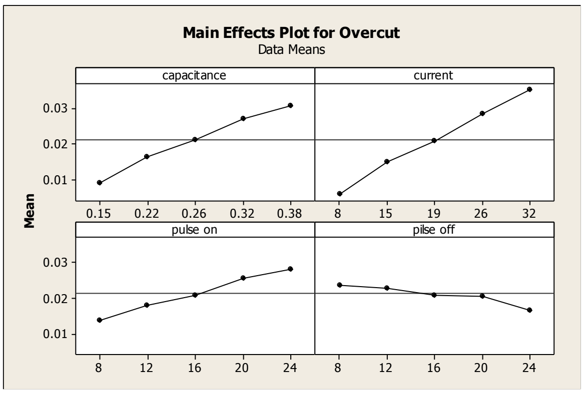


Figure 5. Main Effect Plot for DOC

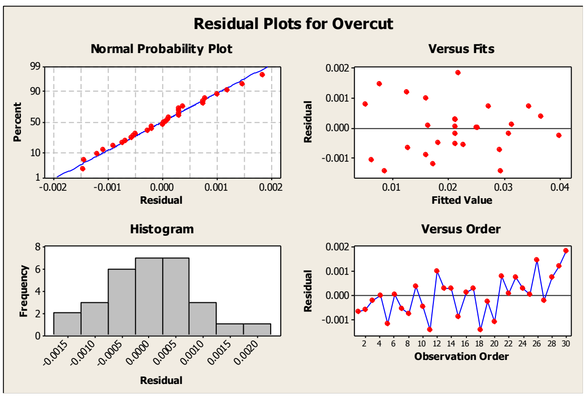


Figure 6. Main Effect Plot for DOC

It is the distance between the diameter of the machine hole and the electrode diameter. As the electrode became taper, the overcut was taken from the average of entrance and exit side of the micro-holes. Figure 5 shows that overcut is high at high current. The reason for this is increased secondary sparking with increase in discharge energy, resulted in increased diameter of machined hole on workpiece. The regression equation 3 is performed based on the results by the design of experiment software, which is shown in figure 6. Here, the overcut act as dependent variable, which has four independent variables.

Overcut = - 0.0385 + 0.0999 capacitance + 0.00120 current + 0.000926 pulse on - 0.000341 pulse off…… (3)

3.4. Analysis of taper angle

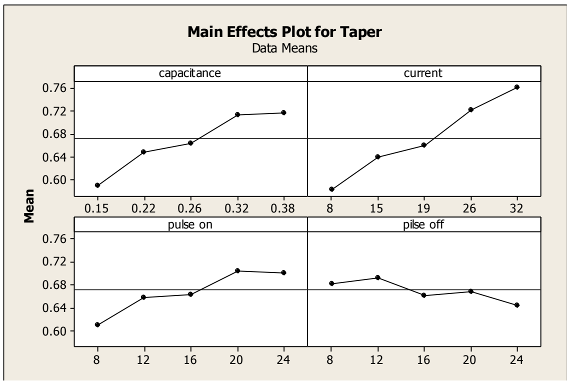


Figure 7. Main Effect Plot for taper

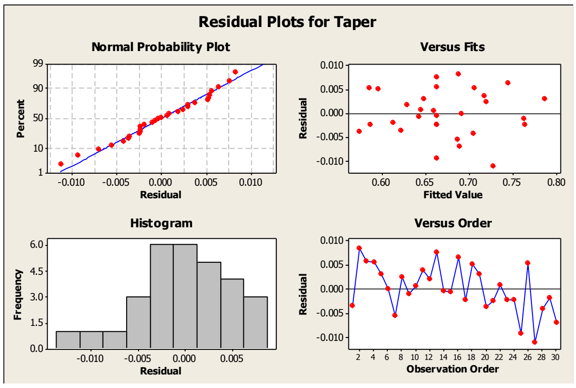


Figure 8. Main Effect Plot for taper

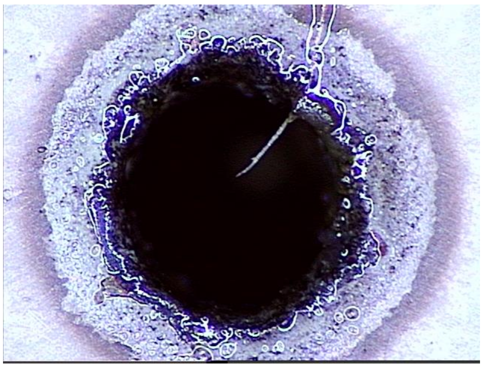
The difference between entrance and exit diameter of micro holes and angle between them, is known as taper angle. If the debris cannot be removed from the machined zone properly, it will cause secondary sparking and arching at the side walls of the micro holes. This phenomenon causes the entrance of micro hole to be larger, thus increasing the overcut and taper angle. Taper angle of micro hole is measured using equation 4. Taper is proportional to current, capacitance and pulse-on while it decreases with pulse off time as shown in figure 7. Then, regression equation 5 is performed based on the results by the design of experiment software, which is shown in figure 8. Here, the MRR act as dependent variable, which has four independent variables.

$$\Theta = \tan^{-1} \frac{(D_{top} - D_{bottom})}{2h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

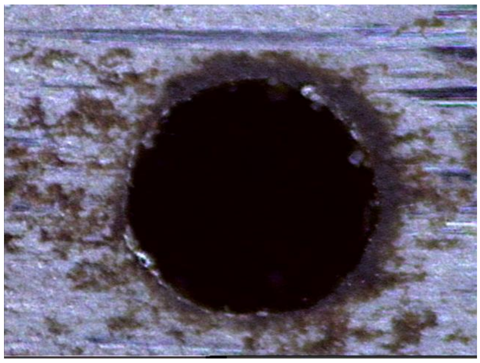
Taper = 0.312 + 0.619 capacitance + 0.00748 current + 0.00569 pulse on - 0.00279 pulse off………… (5)

IV. ANALYSIS BASED ON OPTICAL MICROSCOPE IMAGES

The effect of parameter on micro-hole shape can be observed from images of machined holes under different parametric combination. After analyzing all images, the effect of each parameter has been identified individually. Fig. 9 shows the images of machined micro holes under different parametric combination. White layer can be observed around hole that may be because of sudden contact between electrode and workpiece during machining under high current which results into unstable discharge.



a) 0.26 F/ 32A/20 µs/20 µs



b) 0.32F/26A/20 µs/16 µs

Figure 7. Hole shape at different parameter setting, using 500 µm diameter brass electrodes.

V. CONCLUSION

The micro EDM experiment were conducted on titanium wrought alloy using brass electrode. The MRR, EWR and quality of holes is evaluated. It is observed from the experimental result that machining time reduces drastically with increase in discharge energy at the same time large amount of electrons are removed from electrode surface that result into simultaneous electrode wear. Overcut and taper angle are directly proportional to discharge energy, because the debris particles re-solidify near to the edge of micro holes due to insufficient time allowed for flushing of the debris from machined zone and leads to abnormal discharges such as arcing and short circuit. It was found that current is most significant factor followed by capacitance, pulse on time and pulse off time.

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