Mechanical Micro-Drilling and Micro-EDM Drilling: A Comprehensive and Comparative Evaluation

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Abstract

Micro-electro discharge drilling (µEDM-drilling), a non-conventional micromachining processes, has already shown its advantages over conventional (mechanical) micro-drilling process in terms of machined surface quality and diversity of processing materials. µEDM-drilling is generally recognized as a process that yields to a good surface quality with a low Material Removal Rate (MRR) whereas; conventional micro-drilling has a contradictory identification. But, it is worthy to mention that the surface quality and MRR have an extensive variation in µEDM-drilling due to possibilities of a wide range of electrical and mechanical process parameters. On the other hand, conventional micro-drilling is subjected to only mechanical parameter alternation which may lead to a comparatively low deviation in surface roughness. A one to one quantitative study of different responses such as MRR, Surface Roughness and Dimensional Accuracy may fetch a justified assessment for the two processes and hence is performed in this work. Experiments for such assessment is carried out by maintaining similar machining conditions in terms of input machining parameters, tool-work material combination and dimensions.

Keywords: µEDM-drilling, micro-drilling, Surface Roughness, MRR.

1. INTRODUCTION

Mechanical micro drilling is capable of fabrication of micro holes provided that the tool has hardness greater than that of the workpiece. This process uses peck cycle in which the drill is repeatedly inserted and withdrawn from the hole which eventually leads to the creation of a deep hole [1]. The potentiality of the process can be seen by its ability to fabricate holes having diameter as small as 50µm [2, 3, 4], on materials like plastics and polymers as well as metals. Drill bits are made of hard materials ranging from HSS (high speed steel), Tungsten and other Carbides [5] to machine holes on soft metals like brass and copper.

Micro Electro Discharge Machining Drilling (µEDM-drilling), on the other hand, is electric spark erosion drilling in which the hole formation takes place as a result of recurring electrical discharges on the surface of the workpiece. The conducting tool and workpiece are separated by a dielectric which breaks down as the separation between the two are decreased to a particular value causing discharge to occur and hence melting the workpiece material. When the heat generated in electrical discharge is very high, the molten metal evaporates or else it is flushed out by the dielectric [6]. It has the capability to drill holes as small as 10 µm [7].

µEDM-drilling is generally recognized as a process that yields to a good surface quality with a low Material Removal Rate (MRR) [8] whereas; conventional micro-drilling has a contradictory identification. But, it is worthy to mention that the surface quality and MRR have an extensive variation in µEDM-drilling due to a wide range of electrical and mechanical process parameters. Electrical parameters include Voltage and Capacitance while spindle RPM and Feed rate are the Mechanical parameters. On the other hand, conventional micro-drilling is subjected to only mechanical parameter alternation which may lead to a comparatively low deviation in surface roughness. Further, µEDM drilling is a slow machining process as compared to conventional drilling. Unlike in conventional Drilling the tool wear is significant in µEDM drilling which affect MRR [9]. A one to one quantitative study of different responses such as MRR, Surface Roughness and Dimensional Accuracy may fetch a justified assessment for the two processes and hence is performed in this work through drilling micron level holes. Similar machining conditions in terms of tool-work material combination, input parameters and target feature dimensions are maintained to ensure that the comparison between the two processes is acceptable. A similar scientific way of comparison has already been adopted by Nirala and saha [10].

Single flute tungsten drill bit has been used in conventional micro drilling while µEDM Drilling was performed with a tungsten electrode of the same diameter i.e. 200µm. The workpiece used was a split plate made of brass (66% Cu) which was joined at the time of machining and separated only after the completion of the experiments similar to the one performed by Nirala and Saha [11]. A set of nine experiments (repeated twice) were performed with 3 levels of spindle RPM and feed rate (f) for both the processes keeping capacitance and discharge voltage constant for the RC circuit µEDM. Another set of experiments has been performed to analyze the effect of capacitance and discharge voltage on drilling micro-holes by RC circuit micro-EDM. In order to maintain uniformity in discharge energy, multiple number of same values of capacitors have been arranged in parallel to get uniform intervals. Experimental design was based on Taguchi's L9 orthogonal array. Responses like Machining Time, Surface Roughness (Ra), Overcut and MRR have been measured.

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2. EXPERIMENTS

The experiments are performed on DT-110i Hybrid µEDM machine (make: MIKROTOOLS). The machine has a RC type pulse generator circuit with an axis accuracy of 0.1µm. The machine is capable of µEDM, Micro turning, Micro milling and Micro drilling processes. The machining condition, including the information on materials and experimental plan, is tabulated in table 1. Spindle RPM and Feed rate are the two main effecting parameters in mechanical micro-drilling and hence considered here. In order to make a fair comparison, the input process parameters for µEDM-drilling are opted as the same, even though there are more parameters in case of EDM. The levels of these parameters are given in table 2. Table 3 and table 4 present the design of experiments (DOI) for L9 orthogonal array.

Table 1: Machining conditions

	µEDM-drilling	Mechanical drilling
Workpiece	Brass plate of 1.6 mm thick	-do-
Tool	WC rod of Ø200µm	Drill bit of Ø200µm
Target machining depth	1.5 mm	-do-
No. of experiments	18 (9 at each parametric setting, repeated twice)	-do-
Machining responses	MRR and Surface Roughness (Ra)	-do-

Table 2: Process parameters and levels

Levels	Notations	Spindle RPM	Feed rate (mm/min)
1	A1	2000	0.1
2	A2	2500	0.2
3	A3	3000	0.3

Table 3: L9 DOI Matrix for both the experiments

S.No.	Spindle RPM	Feed Rate (mm/min)
1	2000	0.1
2	2000	0.2
3	2000	0.3
4	2500	0.1
5	2500	0.2
6	2500	0.3
7	3000	0.1
8	3000	0.2
9	3000	0.3

Table 4: Design Matrix of the experiment for µEDM Drilling

S.No.	Voltage (V)	Capacitance (µF)	Feed Rate (mm/min)
1	90	122	0.1
2	95	122	0.2
3	100	122	0.3
4	90	144	0.2
5	95	144	0.3
6	100	144	0.1
7	90	166	0.3
8	95	166	0.1
9	100	166	0.2

A technique for work preparation in µEDM-drilling proposed by Nirala and Saha [10] was used in this study. According to this technique, the workpiece for µEDM-drilling is used in the form of two splits and machining is allowed to continue on the interface line of the splits. This technique makes the material removal analysis possible by analyzing the cross-sectional edges. The clamping of the splits is shown in Fig. 1 along with the other parts of machine.

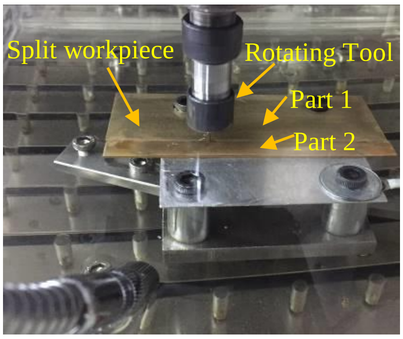

Fig. 1. Workpiece clamping

3. RESULTS AND DISCUSSION

Figure 2 shows samples of the micro holes fabricated by the two processes. The processes were evaluated based on their surface quality and MRR. Estimation of the MRR requires information on the volume removal from the workpiece and machining time. For mechanical micro drilling, the small hemispherical curvature at the bottom of the hole (shown in fig. 2) is neglected as it observed that the curvature remains unchanged at the end of all the experiments. Volume (V_{mech}), required for MRR, is estimated by the following formula given in equation 1.

$$V_{mech} = \frac{\pi}{4} D^2 h \qquad (1)$$

Here, "D" represents diameter of the hole and "h" represents depth. The curvature at the bottom neglected because almost same curvature is obtained in all the drillings and consideration of that extra amount of volume won't make any difference in the analysis as it is applicable to all holes.

For µEDM drilling, the image of the cross-section of the hole is traced with the help of Digitize software version 4.3.0. The developed spline is then revolved using the CAD software and then the volume of the hole is obtained. This technique is similar to one which is already adopted by researchers in past [10].

The machining results have been obtained in terms of MRR and surface roughness (Ra) variations at different values of spindle RPM and feed rate. Fig. 3 shows a sample Surface Roughness profile (by touch inspection) of mechanical micro-drilling whereas figures from 4 to 7 shows the MRR and roughness (Ra) variations.

Increase in MRR with feed rate is very obvious and the same can be seen in fig. 4 for mechanical micro-drilling where the MRR varying w.r.t feed rate almost linearly. But, in case of µEDM-drilling, shown in fig. 5, the relationship between these two parameters is not linear, rather, the MRR observed decreasing at high feed rate.

This could be from the fact that the RC circuit based EDM has their own discharge feed rate decided by the servo control. The feed rate provided by the user become useful only when the tool is approaching workpiece for next discharge. If feed rate is kept high by the user, eventually it is leading to a less time for the debris to come out. Improper removal of debris ultimately leads to a decreased MRR.

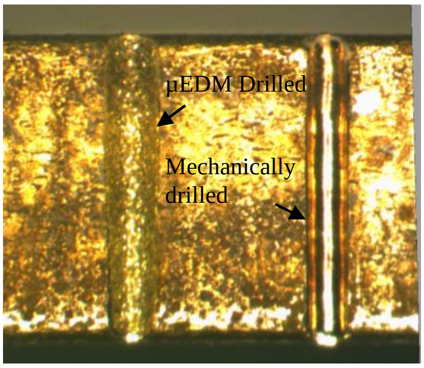

Fig. 2. Cross-section of the fabricated holes

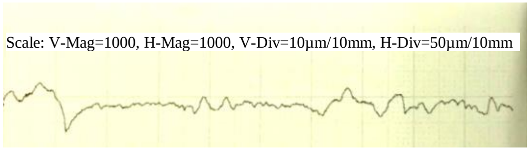

Fig. 3. Sample Surface Roughness profile of mechanical micro-Drilling

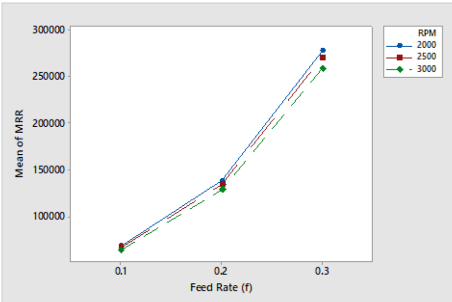

Fig. 4. Interaction plot for MRR (µm^3/min) in mechanical micro-drilling

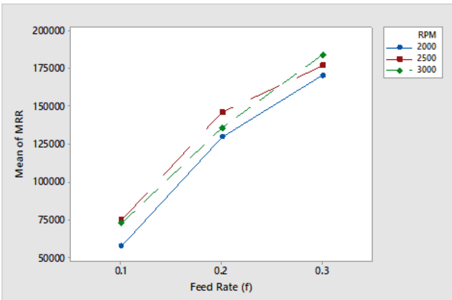

Fig. 5. Interaction plot for MRR (µm^3/min) in µEDM-drilling

The RPM has not much done on MRR in any of the machining operation. However, a close observation shows that the MRR is increasing with increase in RPM except in case of µEDM-drilling at 2500 and 3000 RPM with feed rate 0.3 mm/min.

The surface roughness, in terms of Ra value is observed to be increasing with increase in feed rate. The nature is independent of spindle RPM as it is observed increasing at all values of spindle RPM as seen in fig. 6, for mechanical micro-drilling. The reason of this increasing nature of surface roughness can be explained by the fact that the higher feed rate provides less time to the tool to perform finishing on the drilled hole. In addition, tool wear which is inherent with the process may also be affecting the surface finish as tool wear increases at higher feed rate. A similar observation is also found my researchers [12]. On the other hand, the µEDM-drilling operation leads to a decreasing nature of surface roughness w.r.t feed rate (fig. 7). The variation is not linear but it is observed in all cases of spindle RPM. The reason for the surfaces becoming smooth with increasing feed rate can only be explain with ambiguity. One reason could be the high feed rate is causing an improper evacuation of the molten material which may finally lead to a good surface finish.

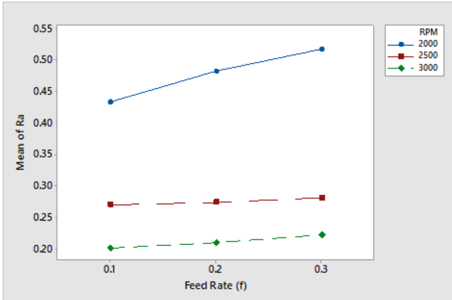

Fig. 6. Interaction plot for Ra (µm) in mechanical micro-drilling

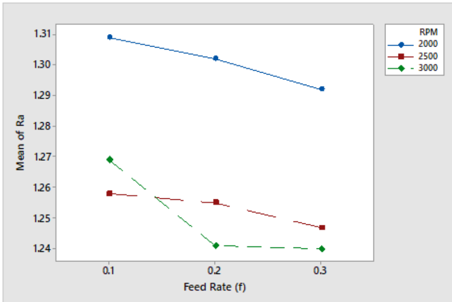

Fig. 7. Interaction plot for Ra (µm) in µEDM-drilling

In all these observations, only two parameters viz. spindle RPM and feed rate, which were the only possible common parameters between the two processes are varied. It may be now essential to know the effect of other controllable parameters of µEDM-drilling operation on the different responses. Fig. 8 represents such study incorporating also those responses which were not been considered in earlier observations. In order to perform such study, three different levels of capacitance values and voltage values are chosen to conduct experiments. These different values give different discharge energy for machining as tabulated in table 5. With increase in discharge energy machining time is observed decreasing which is very obvious. But, the slop of this decrement is not constant throughout, rather it has become very less at high discharge energies. A high value of discharge energy will melt a high amount of workpiece material for sure, but the final machining progress will be achieved only when the molten material has successfully evacuated. It has not happened so, hence leading to more machining time. All other observations such as increasing MRR, Surface roughness and Overcut w.r.t discharge energy as per they were anticipated. A special focus could be given on surface roughness variation. A high value of discharge energy eventually leads to a big crator formation which ultimately gives a poor surface finish. Large crator size, at high energy of a discharge pulse, leads to high overcut and hence observed increasing in fig. 8.

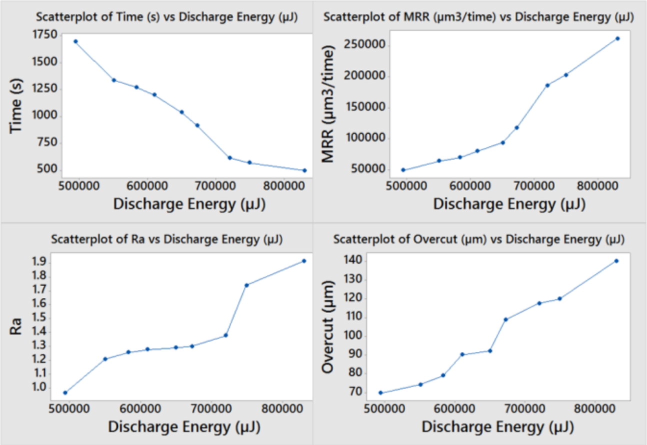

Fig. 8. Various responses from µEDM-drilling experiments

Table 5: Discharge Power in µEDM-drilling

S.No.	Voltage (V)	Capacitance (nF)	Discharge Energy (µJ)
1	90	122	494100
2	95	122	550525
3	100	122	610000
4	90	144	583200
5	95	144	649800
6	100	144	720000
7	90	166	672300
8	95	166	749075
9	100	166	830000

4 CONCLUSIONS

Upon comparison of two micro manufacturing processes for micro drilling operations many unanticipated results have been perceived. Since both the processes uses different energy source of materials removal, the characteristics of the responses are highly depending upon the parameters which are uncommon between the processes. Most of the responses, out from mechanical micro-drilling operation, are as per they were anticipated but, a lot of variation between predictions and the actuals have been seen in case of µEDM-drilling operation. For example, MRR in µEDM-drilling is not increasing with the same rate w.r.t feed rate. It is being affected by the poor debris removal and may be other contaminations in the discharge gap. The surface roughness is also found to be poor in almost all the situations in case of µEDM-drilling within the parameters under consideration. Responses such as MRR, Surface roughness and Overcut w.r.t discharge energy are observed increasing. The effect of discharge energy on MRR is observed much more than that of the feed rate. The MRR has increased to five times when the discharge energy increased by 1.6 times but it remained approximately three times when free rate increased by three times.

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