

A STUDY ON THE HIGH ASPECT RATIO MICRO HOLE DRILLING USING ULTRASONIC ASSISTED MICRO- ELECTRO DISCHARGE MACHINING

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ABSTRACT

Unique features of micro electro discharge machining (micro EDM) include its ability to machine hard and brittle materials and absence of mechanical contact force for the machining of fragile components. Therefore, micro EDM has emerged as one of the predominant complementary micro machining technology with applications in diverse industries such as biotechnology, aeronautical, automotive. However, to achieve high aspect ratio (>10) micro hole drilling, micro EDM needs to overcome inherent problems associated with debris removal as accumulated debris causes arcing and hence hinders the machining process. This paper presents the experimental results of ultrasonic vibration assisted micro EDM. Using this method, drilling of high aspect ratio (micro holes in austenitic stainless steel with an aspect ratio of 20) has been achieved in this study. Another benefit of ultrasonic vibration is that the savings in machining time. It is also noticed that the ultrasonic vibration causes some shape distortion and produces rougher machined surface.

Keywords: deep hole drilling, micro EDM, ultrasonic vibration

1. INTRODUCTION

Microengineering technologies have been extensively developed in recent years. There has been a considerable development in micro manufacturing technologies to attain the different mold features. Micro EDM in particular is an important micro manufacturing process because it is unconstrained by the hardness or material strength of the material being machined. One major reason for its wide implementation is that there is no direct contact of the electrode and the machined component; hence no contact forces are induced during the machining process.

The demand for high aspect ratio micromachining is ever increasing. Specific examples include micro-chemical-reactors and micro-heat-exchangers, made of metals and ceramics [1]. Deep hole drilling with an aspect ratio above 10 is a formidable task for any micromachining process. In micro EDM this is due to the problems associated with debris removal. Accumulated debris cause arcing and hence hinders the machining process. To overcome this difficulty in achieving high aspect ratio holes, debris has to be effectively removed

from the inter-electrode gap. However traditional methods such as pressure flushing and suction flushing are not applicable to micro EDM due to the dimensional constraints.

The work in this paper aims at drilling of high aspect ratio micro holes in austenitic stainless steel using ultrasonic assisted Micro EDM. Introduction of ultrasonic vibration causes phenomena such as acoustic streaming and results in better debris removal [2]. The effect of process parameters, especially that of vibration and discharge energy and feed rate under these conditions on the depth of machining and machining time were studied. Quality of the machined feature namely the shape of the machined hole and the roughness of the machined surface were also studied.

Following section presents the literature review on the ultrasonic assisted micro EDM. The experimental details, results and discussion about the effects of the machining parameters and conclusions are presented in the subsequent sections respectively.

2. LITERATURE REVIEW

The beneficial effects of tool/workpiece vibration in EDM are known for over a decade. Masuzawa et al. introduced tool withdrawal and 2D vibration (sinusoidal motion of tool) to an EDM process for machining deep holes to increase the flushing effect [3, 4]. Ghoreishi and Atkinson have reported that a combination of rotary and vibratory movements (vibro-rotary) of electrode produces higher material removal [5]. Kremer et al applied ultrasonic vibrations (20 KHz) to the tool to achieve process improvements [6, 7]. They have reported that the process stability improved due to better slurry circulation caused by the pumping action of the electrode. Moreover, the pressure variation in the gap, caused by the ultrasonic vibration, improved the MRR as larger pressure drop causes lesser resolidification of molten metal. Kozak et al have reported that the MRR in ultrasonic assisted macro EDM is maximum when ultrasonic frequency was matched with the EDM pulse frequency [8]. Murti and Philip have identified cavitation (nucleation, growth and burst of gaseous bubbles), ultrasonic field forces (radiation force, Stoke's force, Bernoulli's attraction) and acoustic streaming as the factors having pronounced effects in ultrasonic assisted EDM. Their finding is that the debris formed in ultrasonic assisted EDM is solid (rather than hollow) with higher sphericity. It is reported that there is evidence of collision of particles in the form of dents, splats, attached satellites and cracks [9]. Zhang et al utilized the combined effect of EDM and ultrasonic machining to machine conductive ceramics by replacing the pulse generator in EDM by a constant DC source and ultrasonic tool vibration [10,11]. Guo et al reported an increase in cutting efficiency, decrease in surface residual stress and reduced probability of rupture of wire with an application of ultrasonic vibration in wire EDM [12,13]. Similarly the introduction of ultrasonic vibration in micro EDM has been reported to improve the process performance [2,14-16].

3. EXPERIMENTAL WORK

The experiments were conducted using the commercial Panasonic MG-ED72W micro EDM. An ultrasonic vibration system having a peak power of 45 W was used in the experiments.

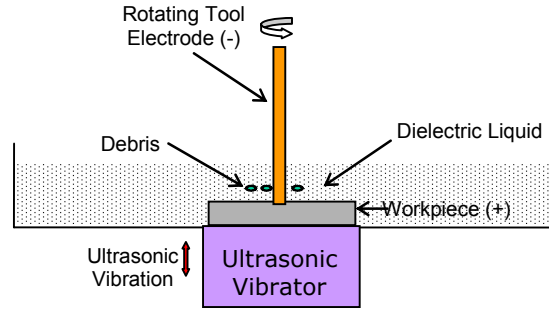


FIGURE 1. Schematic Experimental Setup.

The work piece was ultrasonically vibrated as shown schematically in the figure 1. The amplitude of the vibration was found to be approximately 6 μm . The experimental conditions used are given in Table 1.

TABLE 1. Experimental Conditions

Work material	Stainless steel (2 mm in thickness)
Tool material	Tungsten-carbide
Tool diameter	90 μm
Capacitance	1000, 3300 (pF)
Voltage	80, 110 (V)
Programmed feed rate	5, 10, 15 ($\mu\text{m}/\text{sec}$)
Ultrasonic frequency	41.616 (KHz)
Amplitude of vibration	0, 6 (μm)

All experiments were conducted with programmed hole depth of 3000 μm . The actual feed of the tool electrode was noted for every 5 minutes starting from the point of the first spark. The readings were noted until a through hole is drilled or in some cases where the tool electrode stops penetrating further because of the accumulation of the debris. Time taken to drill particular length were also recorded with uniform interval which will help in knowing the machining time for desired hole diameter and depth. It was noticed that drilling 2 mm deep through hole was possible with ultrasonic vibration of the workpiece. The geometry of the machined holes were studied using an optical microscope. The surface roughness was measured by contact method using XP - 2 stylus profilometer.

4. RESULTS AND DISCUSSION

The effects of different process parameters on the performance of ultrasonic vibration assisted micro EDM are discussed in this section.

4.1 Effect of Ultrasonic Vibration

Since the measurement of actual depth machined in a high aspect ratio micro hole is an extremely difficult task, feed (an indicator of machining depth) is compared in Table 2. The overall feed achieved with the assistance of ultrasonic vibration was higher than that without vibration for all process parameters used in this study.

TABLE 2: Feed Achieved

Process Parameters (Capacitance, Voltage, Feed rate)	Overall Feed Obtained Without Ultrasonic Vibrations	Overall Feed obtained With Ultrasonic Vibrations
3300 PF, 110 V, 15 μm	2724.8 μm	3000 μm
3300 PF, 110 V, 10 μm	2719.2 μm	3000 μm
3300 PF, 110V, 5 μm	2412.3 μm	3000 μm
1000 PF, 80 V, 15 μm	1784.1 μm	2678.9 μm
1000PF, 80V, 10 μm	1542.8 μm	2600 μm
1000 PF, 80 V, 5 μm	919.9 μm	3000 μm

Another benefit of using ultrasonic vibration is the reduced machining time as shown in fig 2.

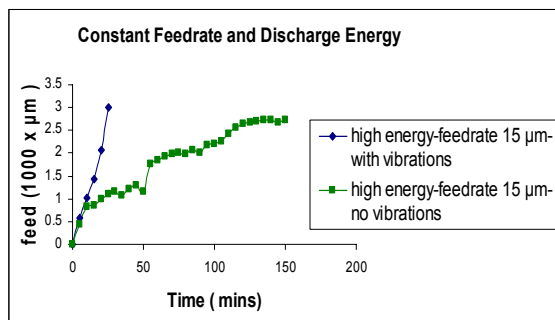


FIGURE 2. Effect of vibrations : Feed Vs Machining Time

4.2 Effect of discharge energy

The effect of discharge energy is shown in fig 3. The depths reached using the high discharge energy with and without vibration are always greater when compared to the low

discharge energy. With 3300 PF capacitance and 110 volts drill through holes could be drilled with all the three feed rates provided the work piece was subjected to vibration.

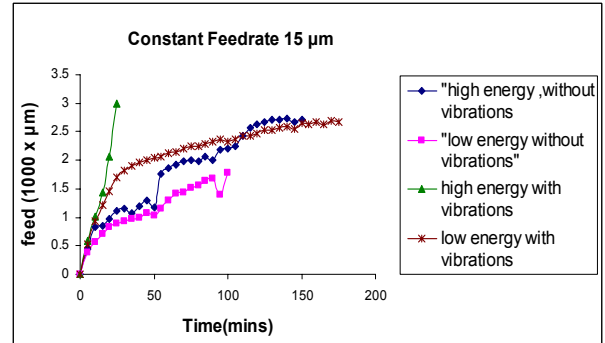
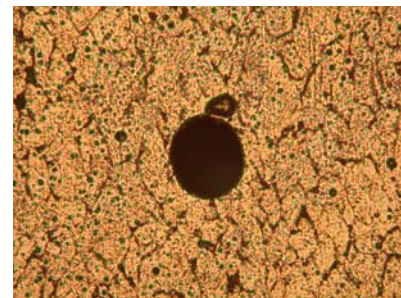


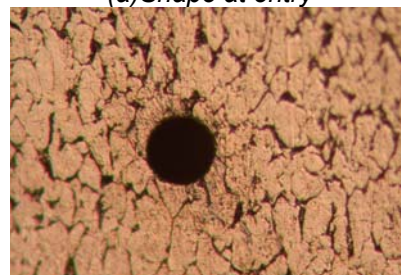
FIGURE 3. Effect of discharge energy on the depth reached

4.3 Hole geometry

Shapes of the top and bottom of a through hole machined with ultrasonic vibration are shown in fig 4. It can be observed in fig 4(a) that the hole geometry on the upper side of the work piece is a little distorted compared to the one on the lower side of the work piece. This suggests that vibration causes some wandering of initial drill location. However this is restrained with further drilling probably by dielectric oil in the confined space in the inter electrode gap of the hole. Fig 4 (b) shows improved geometry at the hole exit.



(a) Shape at entry



(b) Shape at exit

FIGURE 4 Hole geometry

4.4 Surface Roughness

The surface roughness values of the spark eroded surfaces with the different machining conditions were measured using XP - 2 stylus profilometer and are listed in Table 3.

TABLE 3. Surface roughness values

Process Parameters (Capacitance, Voltage, Feed rate)	Roughness values Without vibrations (R_a) μm	Roughness values With vibrations (R_a) μm
3300 PF, 110 V, 15 μm	0.03	0.17
3300 PF, 110 V, 10 μm	0.06	0.08
3300 PF, 110 V, 5 μm	0.08	0.09
1000 PF, 80 V, 15 μm	0.06	0.07
1000 PF, 80 V, 10 μm	0.13	0.14
1000 PF, 80 V, 5 μm	0.06	0.11

Since the ultrasonic vibration facilitates better dielectric liquid circulation at the inter electrode gap, the amount of resolidifying material will be lesser than that without vibration. Hence the craters produced are deeper and as a result the surface is rougher. This is confirmed by the observation that the peak to valley surface roughness measurement (R_t) is 3.7 μm and 2.09 μm respectively for the surfaces machined with and without vibration.

5. CONCLUSIONS

The performance of ultrasonic vibration assisted micro electro discharge machining of austenitic stainless steel is presented in this paper. It is clear from the experimental results that ultrasonic assisted micro EDM has the potential for deep hole drilling. An aspect ratio of 20 has been achieved in the machining of micro holes in austenitic stainless steel in this study. Another benefit of ultrasonic vibration is that the savings in machining time. It is also noticed that the ultrasonic vibration causes some shape distortion and produces rougher machined surface.

6. ACKNOWLEDGEMENT

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