SOME TECHNOLOGICAL SOLUTIONS FOR ULTRASONIC AIDING OF MICRO-ELECTRICAL DISCHARGE MACHINING

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ABSTRACT: Ultra-miniaturization represents the major trend of technology and a permanent challenge nowadays. Due to steady increasing demand of miniaturization, further improvement of the process is required particularly concerning its capability to precisely manufacture complex structures with a smaller dimension. To facilitate high precision erosion, vibration is introduced in any of workpiece, tool and dielectric. This paper reviews the research work carried out by scientists on the effect of ultrasonic aiding of electrode tool, workpiece and dielectric liquid at micro-EDM. The paper reviews the influence of vibration frequency and amplitude on machining time – in the case of vibrated electrode at micro-EDM, the influence of ultrasonic power on MRR, TWR and hole taper – in the case of vibrated workpiece at micro-EDM, and the influence of powder concentration on MRR and surface quality – in the case of vibrated dielectric at micro-EDM. Some innovative solutions and optimization conditions are also presented aiming at technological performances at micro-EDM.
KEYWORDS: micro-EDM, ultrasonic vibration assisted micro-EDM

1. INTRODUCTION

In micro-EDM, spark gap is very narrow, in the order of a few microns, which makes the removal of debris very troublesome. The dielectric circulation and debris flushing are difficult due to narrow spark gap, which causes short-circuits, arcing and secondary discharges resulting in a highly unstable process [1-3]. If the debris are not removed efficiently from the working gap, it creates a bridge between the workpiece and the electrode (adhesion) which results in short-circuit and ceasing of the machining operation. This makes micro-EDM an unstable process and has adverse effects on material removal rate (MRR), tool wear rate (TWR) and surface quality of the machined surface [4-8]. The equations 1 and 2 are used to calculate MRR and TWR:

$$MRR = V_p / t \ [mm^3/min] \quad (1)$$
$$TWR = V_e / t \ [mm^3/min] \quad (2)$$

where: V_p – volume of material removed from workpiece [mm^3]; t – machining time [min]; V_e – volume of material removed from electrode [mm^3].

In micro-EDM, due to ineffective cleaning of the working gap, adhesion between the two electrodes frequently terminates the machining operation. Thus, even when the machining is possible, an extensive machining time is required. The two major challenges that micro-EDM faces are: ineffective flushing of the debris from the spark gap and low MRR (which is a consequence of the former).

In order to eliminate or mitigate these problems, vibrations can be introduced to the tool, workpiece or to the dielectric medium. The ultrasonic vibration (US) induces cavitation bubbles into the dielectric liquid at the spark gap, resulting in micro jets, which aids in the removal of debris from the machining zone [9]. In addition, due to the instantaneous and continuous removal of debris and circulation of fresh dielectric into the spark gap, the discharge frequency increases, which in turn increases MRR [3-7, 10].

2. EQUIPMENT FOR US AIDING

The vibration effect can be applied to the tool, workpiece, or to the dielectric liquid. Special equipment is needed in every case.

2.1 Tool vibration

Tool vibration is more difficult to apply in micro-EDM, since its diameter has several microns.

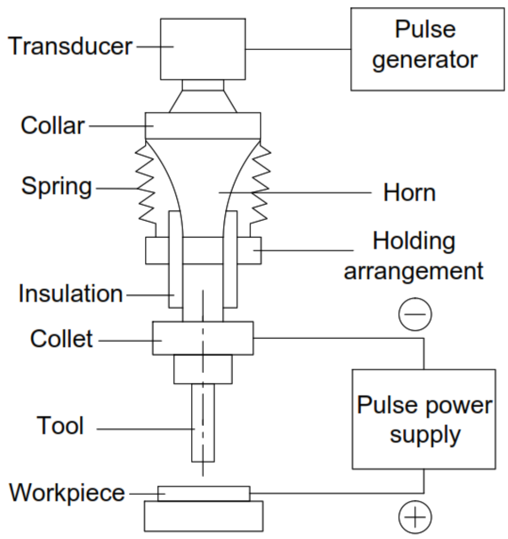

Figure 1. Example of vibration assembly for tool vibration-assisted micro-EDM [11]

The ultrasonic vibrated tool at micro-EDM setup has two main components: 1) the high-frequency vibration generator system; 2) a fixture of tool electrode holding arrangement, which is compatible with vibration assistance in order to obtain resonance frequency.

2.2 Workpiece vibration

In any circumstances, ultrasonic vibration of the tool becomes difficult due to its very small dimensions and problems related to its clamping. So vibration of the workpiece is very useful. This aims also at enhancement of flushing ability of resolidified molten metal from the vicinity of the machining zone and simultaneously changing the pressure in the narrow spark gap lead to more number of effective sparks which results in increased material removal rate [6].

One of the main advantages of workpiece vibration assisted micro-EDM is that it eliminates the need for a horn that makes the vibration system more complex - the workpiece can be directly attached to the transducer to secure the vibration as it is shown in figure 2.

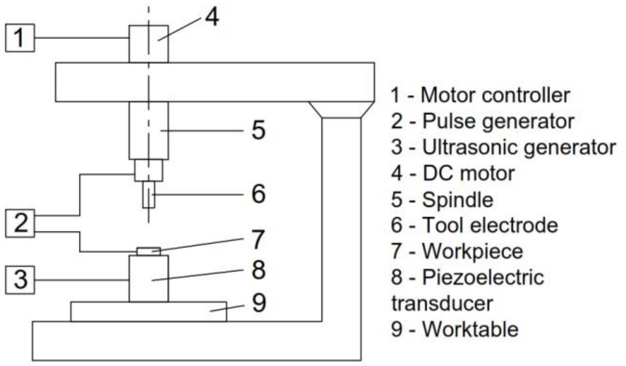

Figure 2. Example of machining with ultrasonic vibration of workpiece [11]

2.3 Dielectric vibration

Ultrasonic vibration of the dielectric fluid is a way for enhancing the removal rate of the workpiece material – figure 3. Usually, this kind of vibration is done when the dielectric fluid is infused with powder mixed electrolyte.

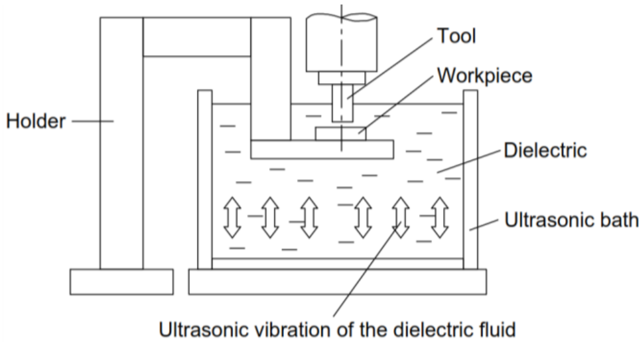

Figure 3. Example of machining with ultrasonic vibration of dielectric fluid [5]

High-frequency vibration to the dielectric fluid is done to overcome the accumulation of micro-powder particles at the bottom of the dielectric tank and to enhance the kinetic energy of tiny debris particles. This causes the debris to be removed more easily, which results in less frequent short-circuits occurring during spark discharge. Ultrasonic vibration of the dielectric fluid is more cost effective and simpler than applying ultrasonic vibration to the tool electrode or the workpiece. Commercial ultrasonic baths can be used to vibrate the dielectric fluid. Ultrasonic baths have a frequency range of of 40-45 kHz, however the value of frequency cannot be modified during machining. Another solution is to insert an ultrasonic chain into dielectric liquid, using different means [12, 13].

2.4 Some innovative equipment for micro-EDM

The equipment for ultrasonic aided electrical discharge machining of micro-slots is presented in figure 4 [13]. The main subassemblies are presented in figure 4.a. The equipment is easily assembled on any EDM machine, as it can be seen in figure 4.b, using T channels plates. In figure 4.c, some details are shown of the clamping and orientation device of the tool ultrasonic chain, achieving inclination, perpendicularity, and angular position of the tool. Similar device for workpiece is presented in figure 4.d, which accomplishes workpiece inclination and perpendicularity. In figure 4.e, the device for high pressure dielectric supply by ultrasonic cavitation is presented. The novelty of this equipment consists in: cumulating the effects produced by vibrations of ultrasonic chain including the electrode-tool and of ultrasonic chain for dielectric supply acting at workpiece level; high pressure supplying of dielectric liquid by cavitational effect produced by an ultrasonic chain that vibrates within a hopper; simultaneous inclination and rotation both of blade electrode-tool and workpiece.

The variant of equipment appropriate for deep micro-slots is presented in figure 5 [14]. It’s main subassemblies are shown in figure 5.a, the equipment being easily assembled on any EDM machine as it is presented in figure 5.d. Taking into account the susceptible deformations of blade electrode-tool during the machining process, a guide subassembly is conceived (figure 5.b), comprising basically two semi-skates with low friction coefficient, and channels for lateral flushing. The adjusting device of ultrasonic chain containing the tool is presented in figure 5.c.

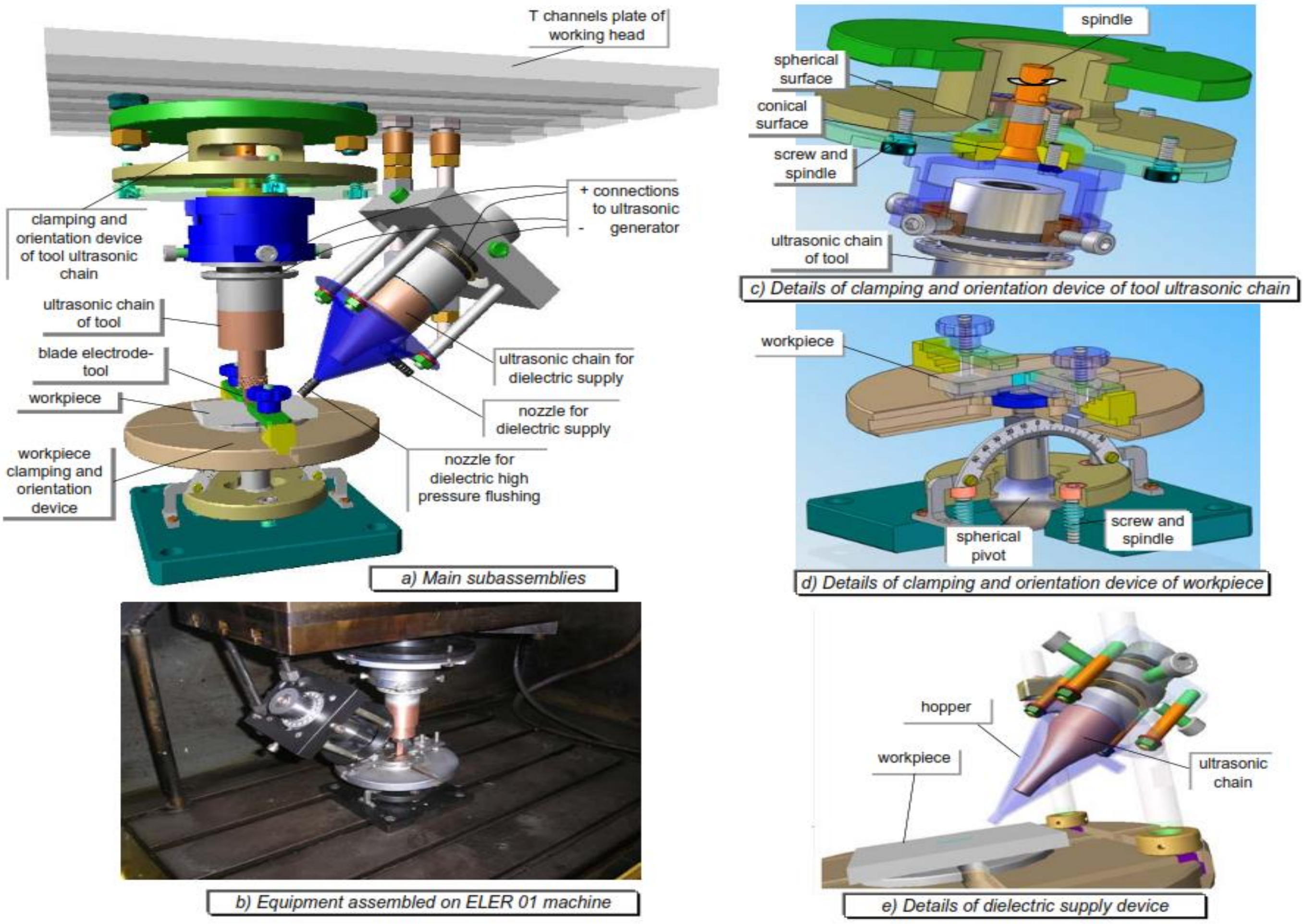

Figure 4. Equipment for ultrasonic aided electrical discharge machining of micro-slots [12][13]

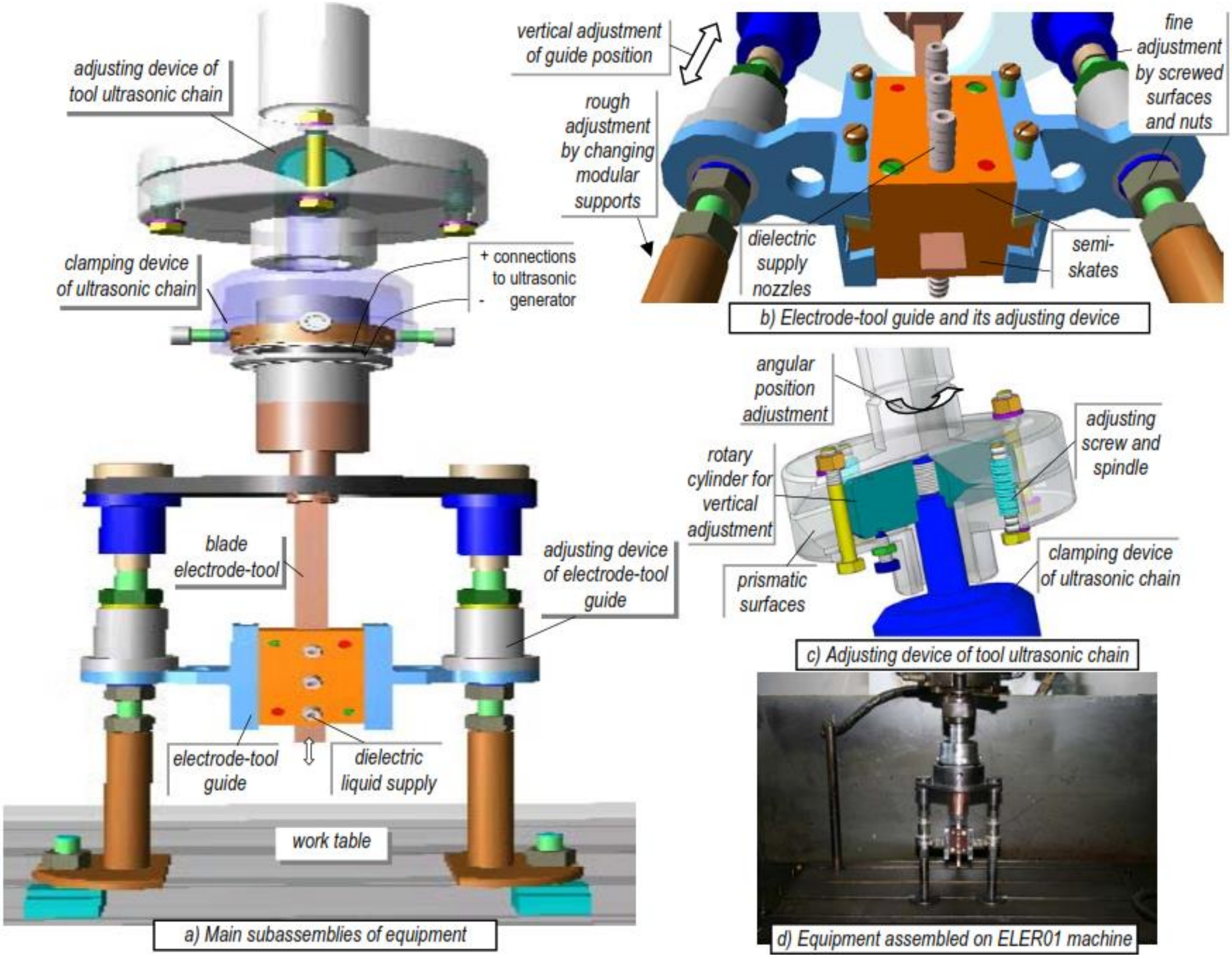

Figure 5. Equipment for ultrasonic aiding electrical discharge machining-deep micro-slots [12][14]

The construction of equipment led to some advantages: machining deep micro-slots without necessity to provide holes for dielectric flushing inside workpiece or electrode-tool; enhancement of machining precision, most of all at great depths by passing the electrode-tool through guiding assembly above or beneath the workpiece; appropriate flushing with dielectric liquid of lateral side of electrode-tool, through several flushing holes achieved inside the guiding; it assures the adjustment of perpendicularity of longitudinal axis of blade shape electrode-tool against frontal surface of machined workpiece, and angular position of electrode-tool in frontal plane of machined workpiece.

3. TECHNOLOGICAL PERFORMANCES

Applying ultrasonic vibrations to different EDM elements boosts performance, especially in micro-hole fabrication, because of its complex mechanism material removal, which achieves, beside efficient evacuation of particles from the gap, an increase of material removal from the workpiece in liquid and solid state.

3.1 Tool vibration

The influence of vibration amplitude and frequency on machining time has been studied by [7] and is presented in figure 6 and 7.

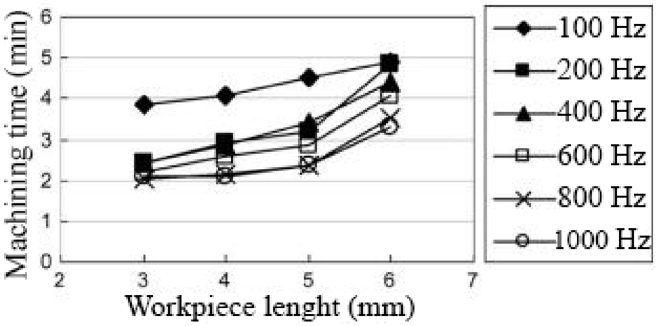

Figure 6. Effect of vibration frequency on machining time (Amplitude = 1 µm) [7]

As seen from figure 4, the higher the vibration frequency the lower the machining time, even at subsonic frequency. This is attributed to the fact that the flow of debris and recovery from adhesion are more frequent and more efficient [7], and the cumulative microjets stage occurs more frequently.

According to figure 7, the effect of vibration amplitude between 0.3 µm and 0.5 µm on machining time is marginal. For amplitude of 1 µm and 1.5 µm, there is a significant drop in machining time. It has also been observed that amplitude tends to lower the machining time, when its value is close to the value of the working gap, and lower. The authors have concluded that vibration amplitude has a minor effect on machinig time [7]. This could be explained only if the ultrasonic cavitation is fulfilled which strongly depends on cavitation real threshold [12].

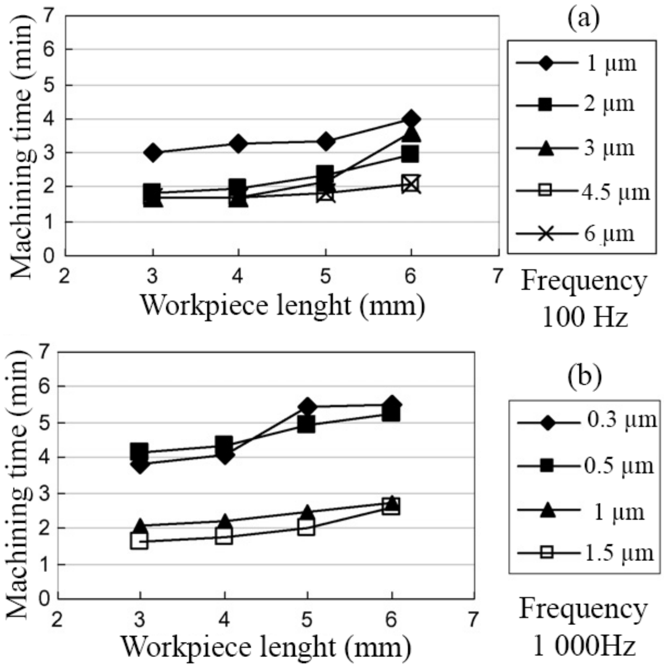

Figure 7. Effect of vibration amplitude on machining time [7]

3.2 Workpiece vibration

The influence of ultrasonic power with various gap current values on rate of material removal (MRR), tool wear rate (TWR) and hole taper (T_a) has been studied by Singh P. and others [4-5]. Hole taper is calculated using equation 3:

$$T_a = \frac{Dt - Db}{2 * t} \; x \; \frac{180}{\pi} \; t \; [°] \tag{3}$$

Where D_t and D_b are the top and bottom diameters of hole and t is the workpiece thickness. All values are in millimeters.

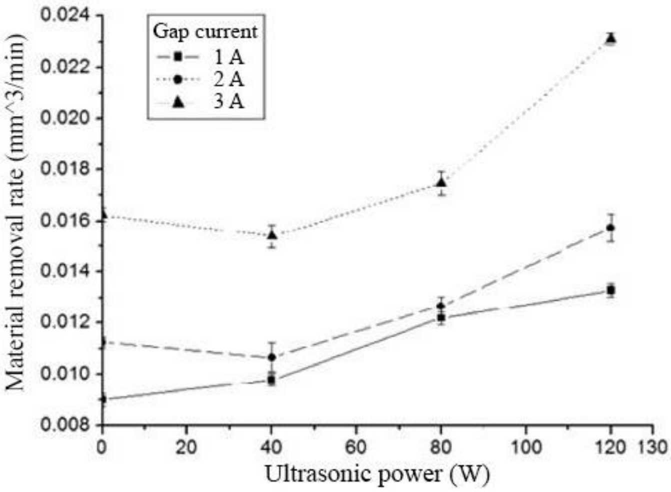

Figure 8. Effect of ultrasonic power on MRR [4]

When vibration is applied, MRR has a slight decrease at high value of gap current, and after that, it has an increasing trend (figure 8). At 1 A gap current, the MRR has an ascending trend. Which is the result of better flushing due to ultrasonic vibration. At high value of gap current, and low ultrasonic power (<40 W), MRR slightly decreases followed by an ascending trend once the value of 40 W is surpassed. The slight decrease is due to high number of short-circuits and secondary discharges - low ultrasonic power (<40 W) does not provide sufficient flushing within the spark gap.

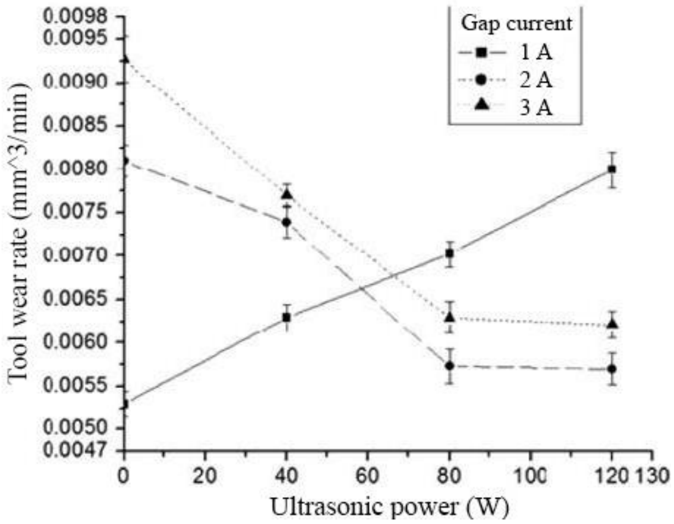

Figure 9. Effect of ultrasonic power on TWR [4]

As seen in figure 9, TWR increases at low value of gap current and decreases at high value of gap current with increase in ultrasonic power.

As ultrasonic power increases, the vibration amplitude increases, resulting in more material being pumped out of the spark gap, which reduces short-circuiting, arcing, and secondary discharges, consequences of efficient dielectric flushing - TWR exhibits a descending trend at high value of gap current.

However, at low value of gap current, TWR increases continually, because of very narrow spark gap, debris being very difficult to remove, even at ultrasonic power of 120 W.

Figure 10 shows that hole taper (T_a) decreases with increasing ultrasonic power and exhibits similar trends for all gap current values, except 1 A. As ultrasonic power increases, the amplitude of vibration also increases which leads to better flushing of debris from the working gap, resulting in a decrease in hole taper.

At 1 A gap current, T_a has an ascending trend. This happens due to narrow machining gap (because of low discharge current) which facilitates the accumulation of debris at the sides of the working gap which then leads to a large number of secondary discharges, thus the increasing trend of hole taper. Even at ultrasonic power of 120 W, the debris are poorly evacuated.

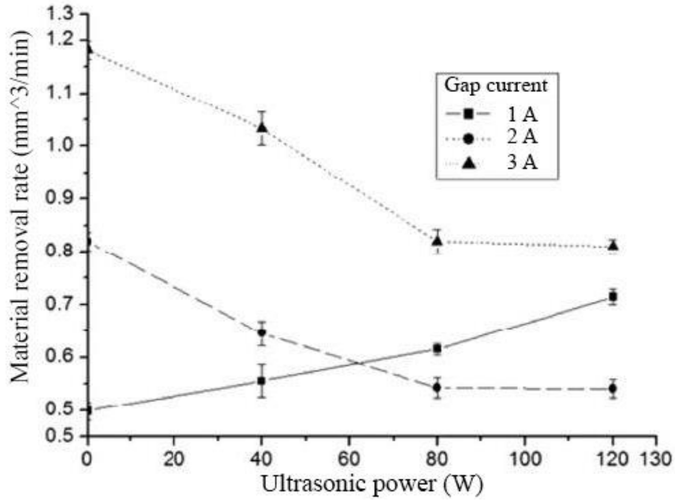

Figure 10. Effect of ultrasonic power on hole taper [4]

3.3 Dielectric vibration

The influence of ultrasonic vibration induced in dielectric liquid with powder with different levels of concentration were studied by [5, 6, 15].

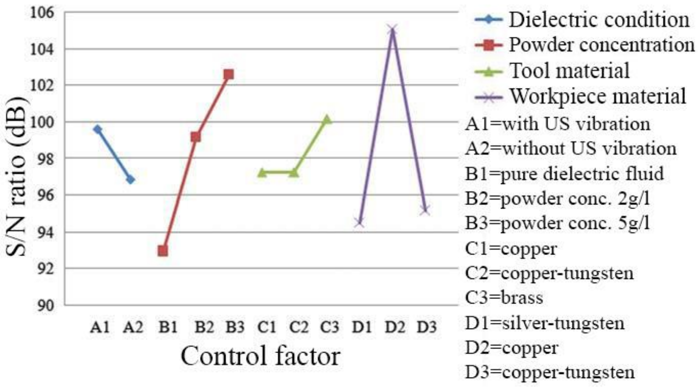

Figure 11. Results (S/N ratio = higher is better) [5]

S/N – Signal to Noise ratio, is used as an objective function for optimizing process parameters [5].

Figure 11 shows that the ultrasonic vibration of dielectric fluid increases material removal rate. Ultrasonic vibration of the dielectric fluid is used to provide better distribution of powder in the dielectric fluid – especially in the spark gap, and to avoid the powder from accumulating at the bottom of the bath. As the ultrasonic vibration originates from the bottom of the bath, powder doesn't accumulate there. The material removal rate is increased, due to the powder as it flows in the spark gap, improving the stability of the process. Ultrasonic vibration of the dielectric fluid reduces the chance that debris form a bridge between electrode and workpiece (adhesion); less adhesion occurrence results in MRR increase.

As can be seen from figure 12, material removal rate (MRR) is bigger when ultrasonic vibration is applied to the dielectric medium, compared to a process without ultrasonic vibration.

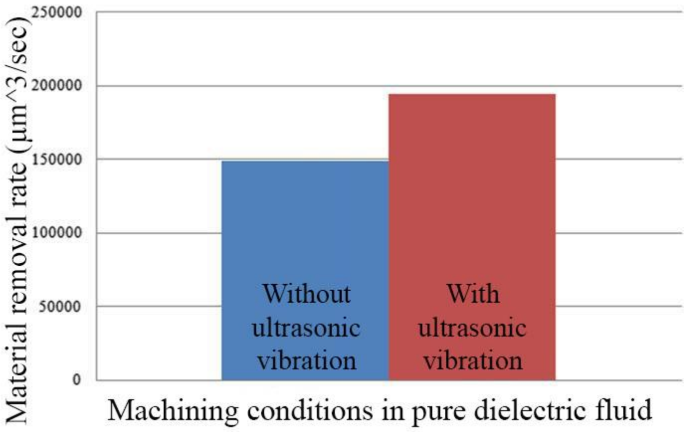

Figure 12. Comparison of material removal rate for Cu as workpiece and brass as tool electrode for machining condition in pure dielectric fluid [5]

Figure 13 shows that a concentration of 5 g/l results in the highest material removal rate. The semiconductor property of MoS_2, increases the overall conductivity and decrease the strength of the dielectric fluid, resulting in wide spark gap between the tool electrode and the workpiece [6, 15]. A bigger spark gap eases the evacuation of debris, and lessens the chances for short-circuits, hence less time is lost backing off the workhead.

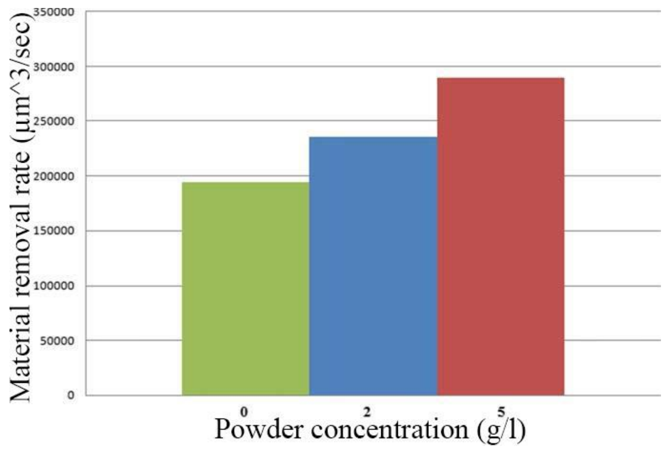

Figure 13. Comparison of material removal rate for Cu as workpiece and brass as tool electrode for machining condition in different concentrations of powder [5]

According to the study, suspended micro-powder accelerates the increase in the frequency of sparks during machining and causes a higher material removal rate. The higher material removal rate may also be caused by: the explosive effect of the discharge that pushes away the powder which impacts the workpiece, the density of MoS_2 being high enough to give a strong particle impact [5], and by the low thermal conductivity of MoS_2 which stores heat longer when impacting the workpiece [5]. The addition of powder in dielectric fluid leads to a significant difference in quality of the machined surface.

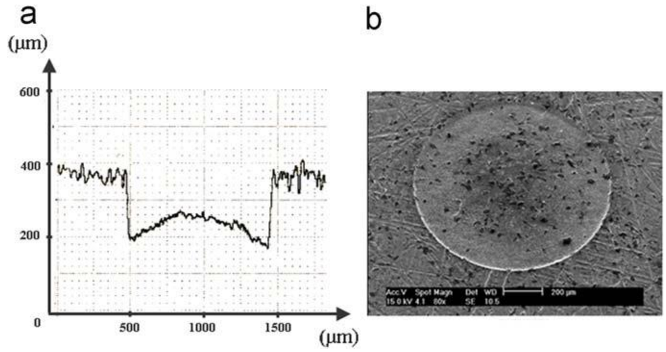

Figure 14. Profile of Cu-W surface with brass as the tool electrode obtained by μ-EDM processing, using pure dielectric fluid: (a) depth profile and (b) machined surface image [5]

Figure 14a shows the depth profile resulting from μ-EDM machining in pure dielectric which doesn’t have a flat surface at the bottom of the hole, instead it has an inverted V shape which is the result of debris stagnation and adhesion at the center of the machined hole. Also large black spots (carbon) are present, as it can be seen in figure 14b. The use of micro-powder produces a flat surface, due to efficient debris evacuation. Black spots in the center are absent – also due to efficient evacuation of debris, as shown in figure 15 a and b.

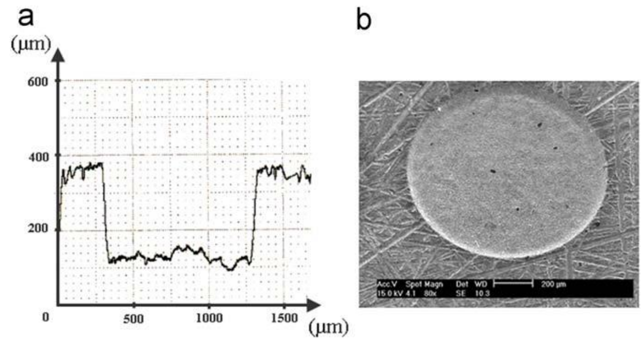

Figure 15. Profile of Cu-W surface with brass as the tool electrode obtained by μ-EDM processing, using MoS_2 powder with ultrasonic vibration of dielectric fluid and a powder concentration of 2 g/l: (a) depth profile and (b) machined surface image [5]

3.4 Optimisation of Working Parameters

To obtain, favourable working conditions, to increase the quality of the machined surface, and TWR, increase MRR, certain conditions need to be met [12]: (1) Minimisation of flushing pressure and pause time t_o. Pause time influences the number of discharges within an oscillation period; (2) Short time pulses must be used when working with negative polarity and relaxation pulses, with produces flat craters, resulting in low surface roughness. In order to not damage the crater’s rim – they are very sensitive to cavitational shock waves, the power supply of ultrasonic chain has to be 30% lower than that used for commanded pulses, which produce deeper craters; (3) When using positive polarity, long time commanded pulses must be utilized; they must be located within stretching semiperiod; on the contrary, when negative polarity is used, short commanded pulses must be used inside compressing semiperiod; (4) Carbon depositing layer is favoured by long time pulses and intensification of cavitational effect through increasing power supply of acoustic chain; this is in contradiction with condition (2); therefore an optimum must be found experimentally, depending on real working conditions; (5) Machining high carbon steels alloyed with Ni, Cr facilitates tool protection by carbon depositing.

4. CONCLUSIONS

The present paper focuses on the effect of ultrasonic vibrated electrode, workpiece or dielectric medium on MRR, TWR, hole taperness (T_a) and surface quality. There is an improvement in machining performance of micro-EDM when vibration is applied to one of the three main elements: tool, workpiece or dielectric fluid. Tool vibration is difficult to apply due to its fragility, and workpiece vibration is preferred as the setup is more simple and compact and does not require a mandatory booster or a horn. The vibration of the dielectric fluid also improves the performance and quality of the process, and it has an even simpler design, requiring only an ultrasonic bath, which can vibrate at frequencies bigger than 20 kHz. A ultrasonic chain can also be used to vibrate the dielectric medium, which can be inserted in the dielectric liquid in the vicinity of the working zone. Higher frequency in all cases gives better machining performance, while the amplitude is recommended to be less than the value of the spark gap. To produce cavitation, acoustic pressure must be greater than the cavitation threshold (depends on real conditions) [12], which is essential for technological main parameters improvement.

5. REFERENCES

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