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# Micro Electrical Discharge Machining (µEDM): Holes Drilling and Characterization of the Process Parameters

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**Abstract:** µEDM (micro-electrical discharge machining) is a process for machining conductive materials without mechanical contact; it is particularly suitable for machining hard materials. The principle consists in creating electrical discharges between a micro-tool and a workpiece, both of which are immersed in a dielectric. It is a complementary process to mechanical, laser, micro-machining techniques, and even to techniques derived from silicon microtechnology (RIE, DRIE, LIGA). However, the resolution of µEDM is limited; it depends on several electrical and physical parameters. The goal of this paper is to characterize the holes obtained by drilling using µEDM with different micro-tool diameters (Φ = 250 µm; Φ = 80 µm; Φ = 40 µm; Φ = 20 µm) for an experimental time of *t* = 2 h. The results obtained let us conclude that a large diameter micro-tool (Φ = 250 µm) leads to removing a larger amount of material ($43\times10^5$ $\mu m^3$) than small diameters: Φ = 80 µm; Φ = 40 µm; Φ = 20 µm where the removed volume is equal to $2.6\times10^5$ $\mu m^3$; $10^5 \mu m^3$; $0.4\times10^5$ $\mu m^3$, respectively. The electrode-tool diameter influences the maximum depth of the holes; a diameter of Φ = 250 µm generates a hole where the maximum depth is 170 µm while small diameters: Φ = 80 µm; Φ = 40 µm; Φ = 20 µm provide holes with a depth of 82 µm; 51 µm; 50 µm respectively. Through these experiments, we can also conclude that the lateral gap of the holes is almost constant. It is about 40 µm whatever the diameter.

**Key words:** µEDM, electrical discharges, hole drilling, amount of removed material.

## 1. Introduction

Microfabrication techniques are widely used in several applications: medical components [1], micro-pieces and molds [2], microfluidic [3], microelectronics [4], etc. They are based, generally, on mechanical or laser micro-machining techniques, or techniques from silicon microtechnology (RIE, DRIE, LIGA). µEDM (micro-electrical discharge machining) is a complementary process. It is based on the use of a cylindrical electrode-tool that runs along a predefined pattern to machine a workpiece-electrode. The two electrodes are immersed in a dielectric with a gap of a few micrometers [5]. The application of a voltage between the two electrodes leads to the generation of electrical discharges able to remove material from the two electrodes. A positive polarization helps to remove a large amount of material from the workpiece-electrode and reduces the wear of the tool-electrode [6]. For this reason, we have used this polarization during all our experiments (drilling holes).

## 2. Experimental Setup

### 2.1 Discharges Creation

During µEDM machining, a micro-plasma is created, and generates electrical discharges. These discharges remove a material from the workpiece, with the expulsion of debris from the two electrodes into the gap. The renewal of the dielectric and the approach of the micro-tool to the workpiece recreate the suitable conditions for new discharges. Fig. 1 illustrates the steps involved in creating the plasma. This phase (Fig. 1a) corresponds to the application of a voltage between the two electrodes [7] in order to create a strong electric field able to lead to a local

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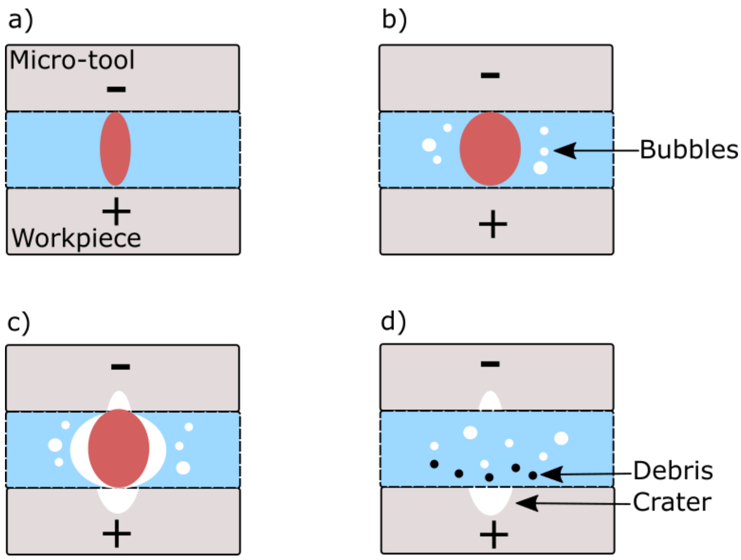



**Fig. 1 Machining steps by μEDM.**

ionization of the dielectric. During this phase, there is the appearance of streamers followed by the breakdown of the dielectric and finally the appearance of the plasma [8-11]. The development of the plasma at the gap, as well as the heating of the material and the electrode by the plasma, leads to the widening of the discharge channel, which allows the passage of a high current (Figs. 1b and 1c). The last step is the implosion of the plasma due to the dielectric pressure, then its disappearance in just few microseconds (Fig. 1d). In this phase, there is also the ejection of the removed debris and the return to the initial conditions.

*2.2 Test Bench*

In all our experiments, we use RC generator (Fig. 2a), it is based on charging of capacitor $C_c$ under a DC (direct current) voltage $V_{EE}$ through a resistor $R_c$. When the micro-tool is sufficiently close to the workpiece (sufficiently high electric field) and the dielectric is sufficiently insulating, the energy stored in the capacitor is suddenly transferred to the gap and gives a birth of series of discharges (Fig. 2b). An oscilloscope is used to record, in real time, the voltage and the current points during the plasma breakdown (discharges) for the whole machining process.

The tool-electrode, used during our machining, is made of tungsten (99.95%) [12], because it has a high melting temperature ($T$ = 3,695 ℃) [13], which reduces its wear rate during machining. Also, its good thermal conductivity allows heat to be dissipated quickly. We use stainless steel for the workpiece-electrode because it has a low melting temperature ($T$ = 1,510 ℃) [13] and a low thermal diffusivity, which allows the energy of the discharges to be diffused locally.

Before machining, we do a mechanical polishing of the workpiece, where several seed papers of different sizes are used. The goal of this step is to obtain a workpiece with a low roughness and a shiny surface.

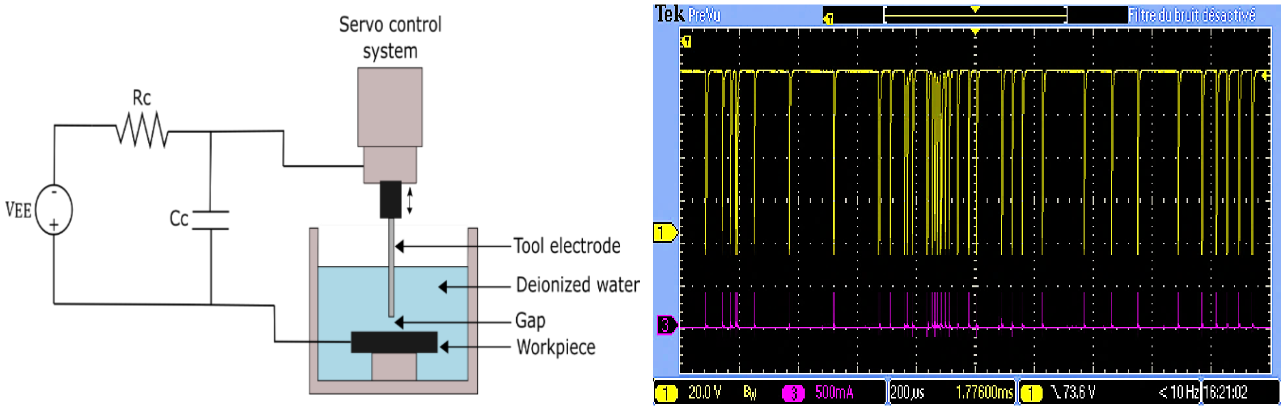
*2.3 Protocol Used in Experiments*

In order to characterize the discharges during machining, we have set up a protocol that allows:

- determining the initial gap, in order to ensure the same experimental conditions;
- determining the volume of the removed material during the holes drilling.

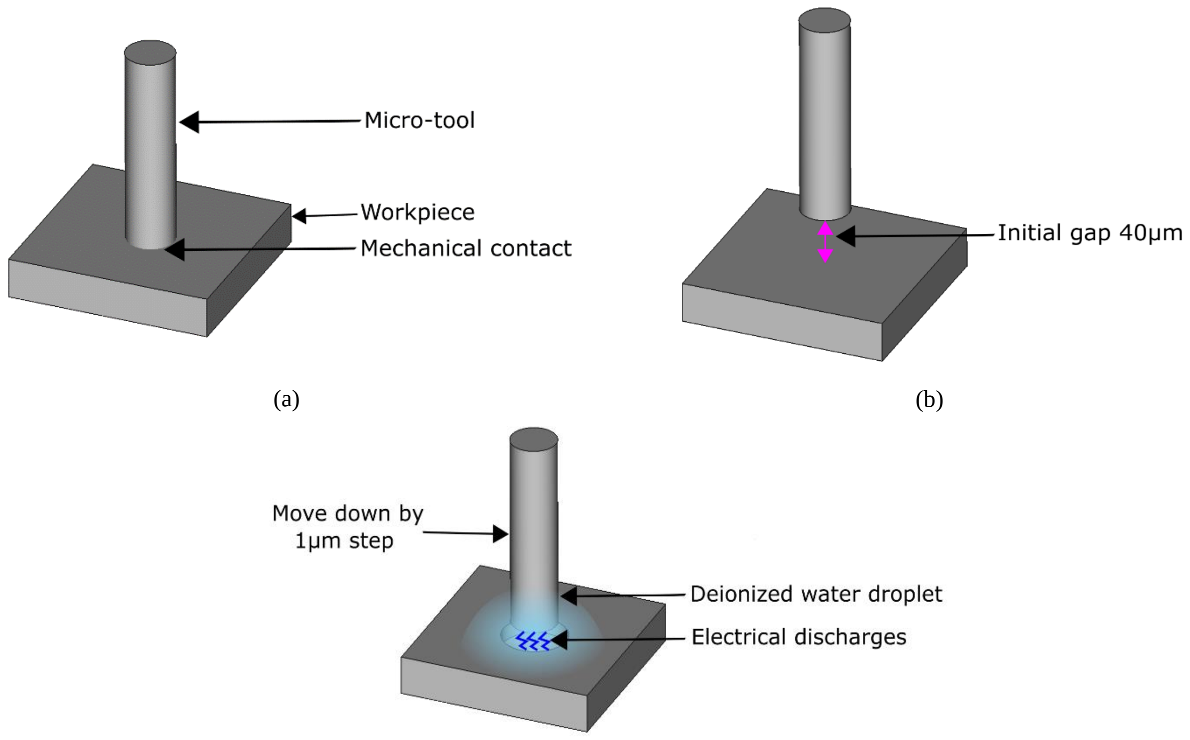
2.3.1 Gap Determination

Before starting a workpiece machining, we perform a preliminary step in order to determine the breakdown gap in specific conditions. The goal is to ensure the same gap between the two electrodes. To




(a) (b)

**Fig. 2 (a) Maching bench; (b) serie of discharges for $V_{\mathrm{EE}} = 75$ V and $C_{\mathrm{c}} = 10$ nF.**




(c)

**Fig. 3 Process of the gap determination. (a) Mechanical contact; (b) move up the micro-tool with 40 μm; (c) move down the micro-tool by 1 μm step.**

do this, we follow the steps described in (Fig. 2): (1) apply, in air, a voltage of 1 V between the two electrodes, (2) move down the tool-electrode with a step of 1 μm until a mechanical/electrical contact is detected, (3) move the tool-electrode up by a distance of 40 μm, this is the reference. At this distance, we have no discharge (no plasma creation for a machining voltage < 75 V and a micro-tool diameter Φ < 250 μm). Once the reference is determined, we apply a voltage between the micro-tool and the workpiece (example: $V_{\mathrm{EE}}$ = 25 V), we add deionized water. And we move down, with the help of a piezoelectric motor, the electrode-tool by steps of 1 μm until the creation of the plasma (breakdown or implosion of the plasma: series of discharges occur and extinguish after a few micro-seconds).

The implosion of the plasma causes a local fusion of the material on the surface of the workpiece, forming a small crater. After the implosion, the gap is no longer the same and there are no more discharges. Once the discharges disappear, we turn off the generator, and we rinse the debris with deionized water in order to evacuate the removed material and clean the tool-electrode. At the end, the micro-tool is raised for a certain distance. The experiment is repeated 3 times.

2.3.2 Calculation of the Removed Volume

In order to know the removed volume for each hole, a profilometer was used. It gives the hole's depth according to the width (Fig. 4). Eq. (1) estimates the removed volume. In order to simplify the calculation, we consider that the hole has the shape of a truncated cone.

$$V_{\text{enlevé}} = \pi \sum_{z_{\min}}^{z_{\max}} R(z)^2 \mathrm{d}z \qquad (1)$$

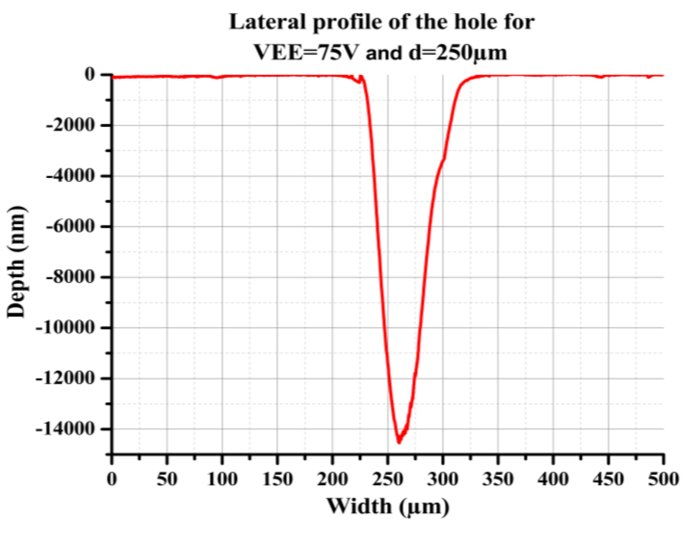
$R(z)$ is the radius of the circle, which depends on the depth $z$.

2.3.3 Lateral Gap Determination

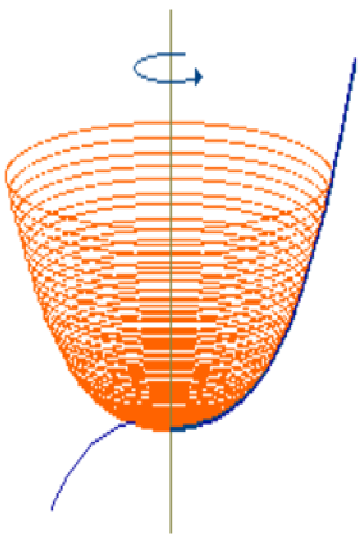
During the hole drilling, the width of the hole is greater than the diameter of the micro-tool, this problem is inherent to micro-EDM machining. The lateral gap is the distance between the micro-tool and the workpiece on each side, and it is caused by the discharge around the micro-tool. In the ideal case, the lateral gap is the same for a given crater. However, in practice it is different, as is the case in our experiments. Therefore, the machining resolution is limited and it is defined by the tool width and the dimensions of the interaction zone between the micro-tool and the workpiece. It is characterized by the dimensional parameters: lateral gap ($\gamma L$) and vertical gap ($\gamma v$) as shown in Fig. 5.

2.3.4 Machining Conditions

In order to drill holes by μEDM, the machining conditions used are summarized in Table 1.




(a)



(b)

**Fig. 4 (a) Crater profile obtained after the first pass of machining for $V_{EE} = 75$ V and $\Phi = 250$ μm, (b) The crater shape modelization.**

**Table 1 Machining conditions.**

| Electrical conditions | Geometrical and physical conditions |
|---|---|
| $V_{EE} = 50$ V | Tungsten micro-toolsdiameter: $\Phi = 250$ μm; $\Phi = 80$ μm; $\Phi = 40$ μm; $\Phi = 20$ μm |
| $C_c = 10$ nF | Steel workpiece: $20 \times 20 \times 0.5$ mm$^3$ |
| $R_c = 500$ Ω | Deionized water; gap after the first breakdown = 10 μm ± 2 μm |

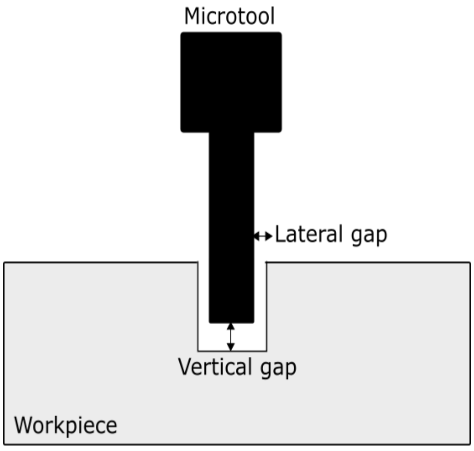



**Fig. 5 Lateral and vertical gap diagram.**

## 3. Results and Discussion

### *3.1 Drilling Holes with Different Micro-tool Diameters*

The choice of the applied voltage ($V_{EE} = 50$ V) for drilling holes is based on the results of a previous study where we have analyzed the effect of the voltage on the machining performances [14]. Compared to these voltages ($V_{EE} = 25$ V; $V_{EE} = 75$ V), the voltage of 50 V has given satisfactory results: a significant removed volume from the workpiece with lower wear of the micro-tool and little rough surface of the craters. Based on these results, we have done the hole drilling with different micro-tools diameters (Φ = 250 μm; Φ = 80 μm; Φ = 40 μm; Φ = 20 μm).

The protocol, followed during drilling, is described in Fig. 3. It is used at the beginning of each new experiment. In order to ensure the birth of new discharges: (1) a cleaning with deionized water is used after each breakdown (a series of discharges) in order to remove debris, (2) the electrode-tool is moved down by a step of 1 μm until a new breakdown is obtained. The process with the two steps is repeated until the end of the desired machining time.

Fig. 6 shows the 4 holes obtained, we note that the hole shape is circular on the surface for the different micro-tool diameters, their geometric characterization (lateral gap and depth) is presented in the following paragraphs.

### *3.2 Lateral Profile of the Obtained Holes*

In order to determine the shape and the depth of the obtained holes, we used a profilometer. Fig. 7 represents the four profiles obtained for the different

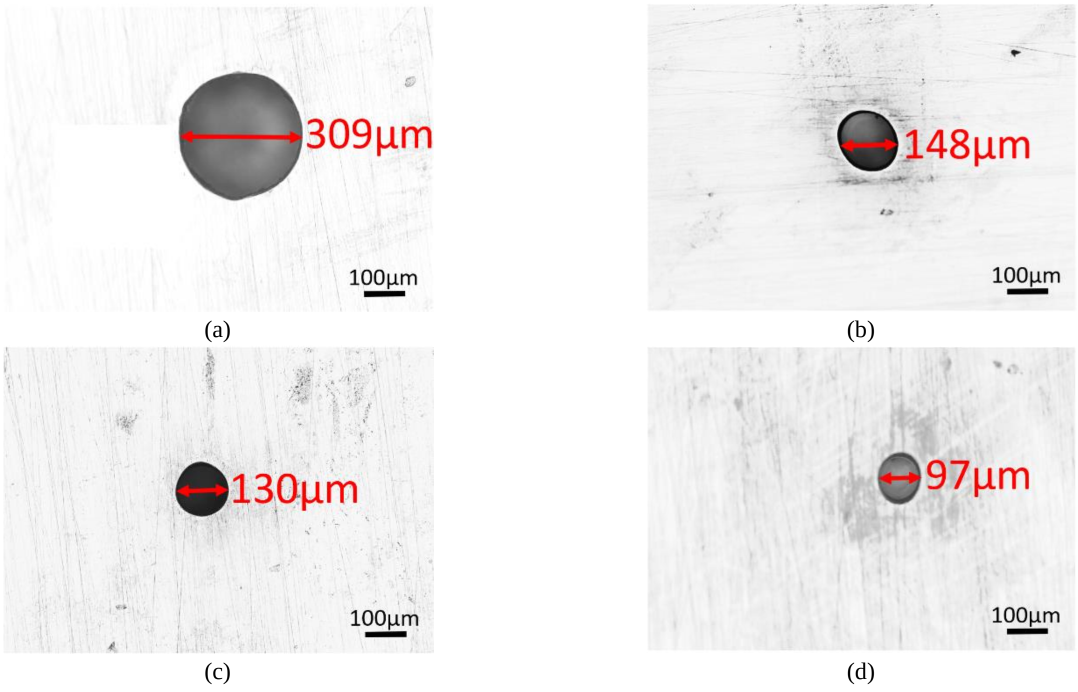



**Fig. 6 Hole drilling with different micro-tool diameters: (a) Φ = 250 μm ; (b) Φ = 80 μm ; (c) Φ = 40 μm ; (d) Φ = 20 μm.**

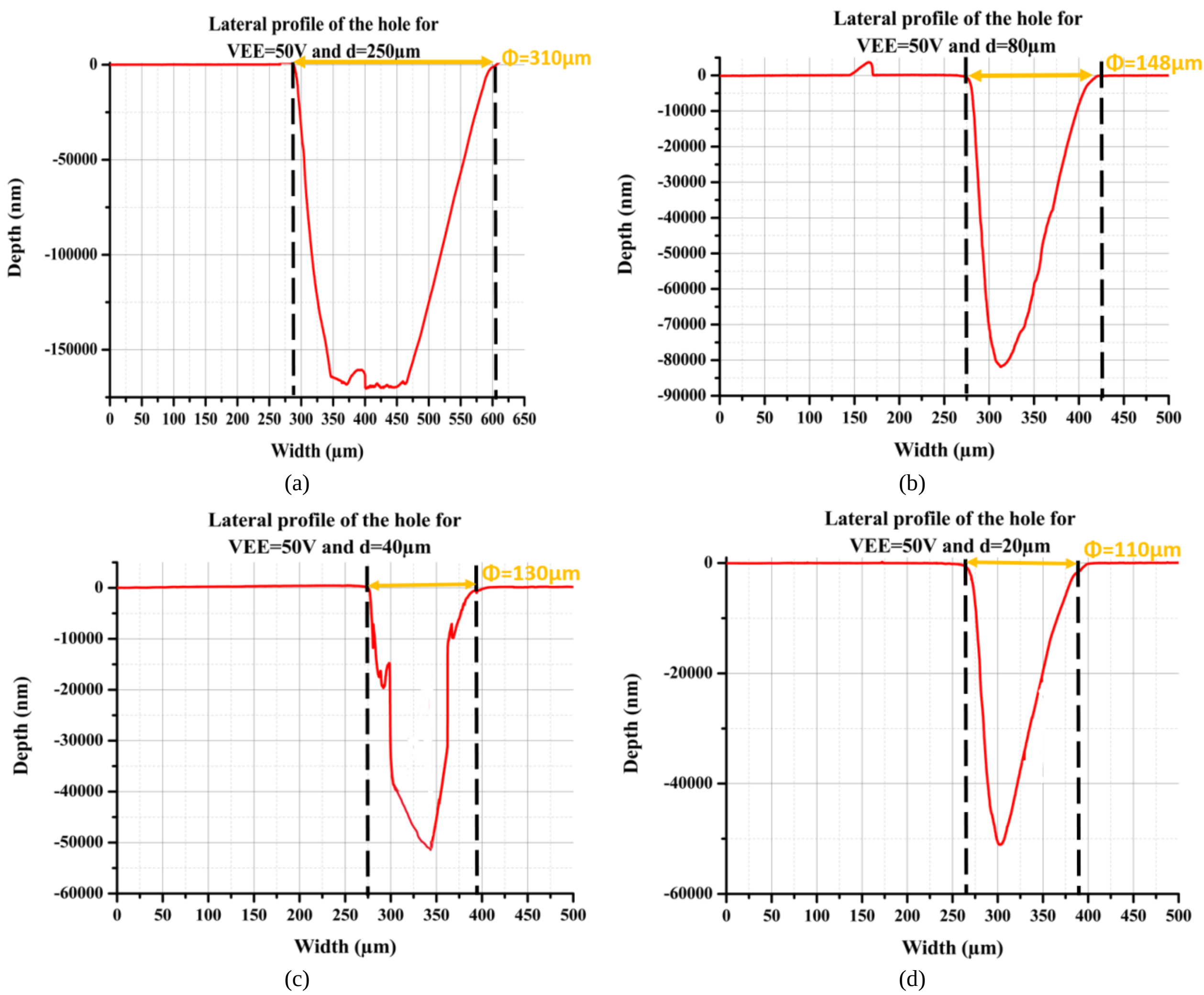



**Fig. 7 Profile of holes drilled by micro-tools with diameter of: (a) Φ = 250 μm; (b) Φ = 80 μm; (c) Φ = 40 μm; Φ = 20 μm.**

**Table 2 Characteristics of the obtained holes.**

| Micro-tool diameter (μm) | Max. depth (μm) | Lateral gap (μm) | Removed volume (μm$^3$) |
|---|---|---|---|
| 250 | 170 | 30 | $43 \times 10^5$ |
| 80 | 82 | 34 | $2.6 \times 10^5$ |
| 40 | 51 | 45 | $10^5$ |
| 20 | 50 | 45 | $0.4 \times 10^5$ |

micro-tool diameters. We can see that the micro-tool with diameter of Φ = 250 μm gives holes with a greater depth than the small diameters (Φ = 80 μm; Φ = 40 μm; Φ = 20 μm) because an important amount of material is removed. And the shape of the hole, at depth, is less conical in this case. The hypothesis is that the bottom of the micro-tool is less worn for a 250 μm wire than for small micro-tool diameters (Φ = 80 μm; Φ = 40 μm; Φ = 20 μm). In the case of a micro-tool with a diameter of Φ = 20 μm, the wear is greater, which justifies the conical shape of the hole.

### *3.3 Lateral Gap and Maximum Depth for the Different Obtained Holes*

Table 2 summarizes the geometric characteristics of the four holes. The removed volume is equal to $43 \times 10^5$ μm$^3$; $2.6 \times 10^5$ μm$^3$; $10^5$ μm$^3$; $0.4 \times 10^5$ μm$^3$

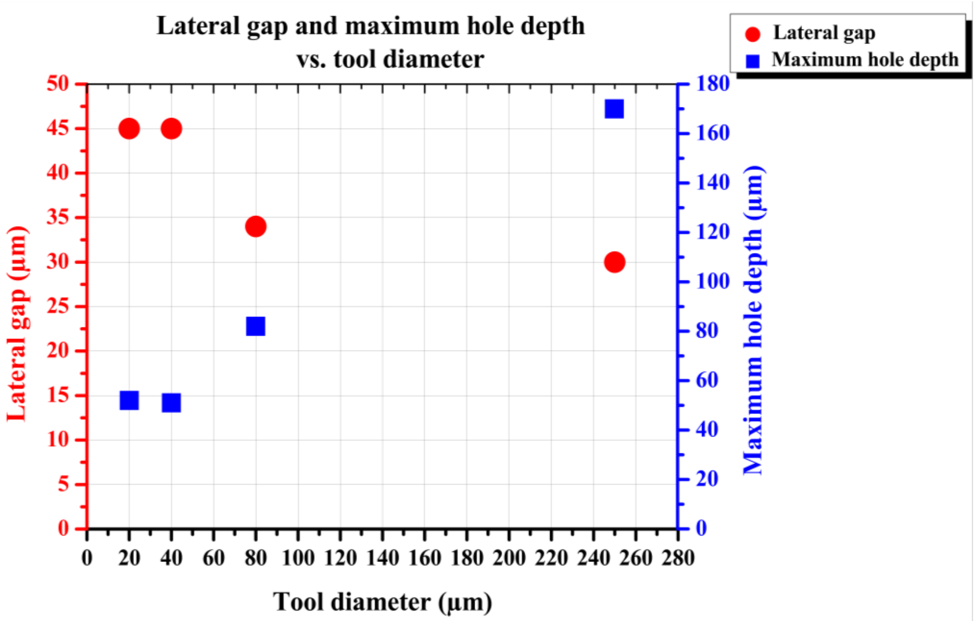



**Fig. 8 Lateral gap and maximum hole depth for the different micro-tool diameters.**

for micro-tools diameter Φ = 250 μm, Φ = 80 μm, Φ = 40 μm, Φ = 20 μm, respectively. We can see that for the hole where the micro-tool has a diameter of Φ = 250 μm, the removed volume and the hole depth are important because the facing area of the two electrodes (micro-tool/workpiece) is important, too. However, the lateral gap is larger for small diameters (Φ = 40 μm, Φ = 20 μm) compared to micro-tools diameter Φ ≥ 80 μm.

Fig. 8 represents the variation of the lateral gap and the maximum depth for the four holes obtained. As previously described, the micro-tools with a large diameter lead to removing high amount of material and even to machining deeply (170 μm for a Φ = 250 μm micro-tool) than in the case of small micro-tool diameters. Also, it can be seen that the smaller the diameter, the larger the lateral gap.

## 4. Conclusion

The holes drilling by μEDM in these conditions: an applied voltage of $V_{EE} = 50$ V and micro-tools with different diameters (Φ = 250 μm, Φ = 80 μm, Φ = 40 μm, Φ = 20 μm), gave us the correlation existing between the removed volume, the maximum hole depth and the lateral gap. This lateral gap, which is inherent to the machining method, increases when using micro-tools with small diameter. So, to reduce the lateral gap, we propose to sheath the tool-electrode in order to prevent lateral discharges inside the hole. The results of this study will lead us, in a short term, to machine channels of greater length and depth.

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