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Micro Electrical Discharge Machining (μ EDM): Holes Drilling and Characterization of the Process Parameters

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Abstract: μ EDM (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 μ EDM is limited; it depends on several electrical and physical parameters. The goal of this paper is to characterize the holes obtained by drilling using μ EDM with different micro-tool diameters ($\Phi = 250 \mu\text{m}$; $\Phi = 80 \mu\text{m}$; $\Phi = 40 \mu\text{m}$; $\Phi = 20 \mu\text{m}$) for an experimental time of $t = 2 \text{ h}$. The results obtained let us conclude that a large diameter micro-tool ($\Phi = 250 \mu\text{m}$) leads to removing a larger amount of material ($43 \times 10^5 \mu\text{m}^3$) than small diameters: $\Phi = 80 \mu\text{m}$; $\Phi = 40 \mu\text{m}$; $\Phi = 20 \mu\text{m}$ where the removed volume is equal to $2.6 \times 10^5 \mu\text{m}^3$; $10^5 \mu\text{m}^3$; $0.4 \times 10^5 \mu\text{m}^3$, respectively. The electrode-tool diameter influences the maximum depth of the holes; a diameter of $\Phi = 250 \mu\text{m}$ generates a hole where the maximum depth is $170 \mu\text{m}$ while small diameters: $\Phi = 80 \mu\text{m}$; $\Phi = 40 \mu\text{m}$; $\Phi = 20 \mu\text{m}$ provide holes with a depth of $82 \mu\text{m}$; $51 \mu\text{m}$; $50 \mu\text{m}$ respectively. Through these experiments, we can also conclude that the lateral gap of the holes is almost constant. It is about $40 \mu\text{m}$ whatever the diameter.

Key words: μ EDM, 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). μ EDM (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 μ EDM 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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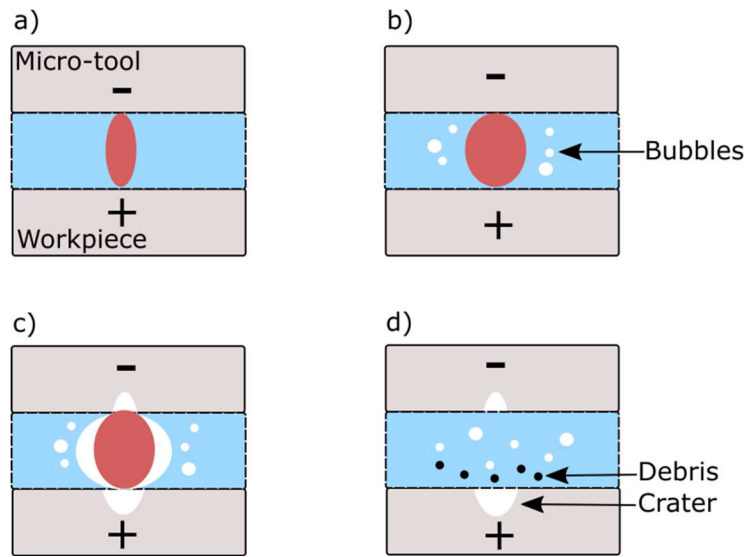


Fig. 1 Machining steps by μ EDM.

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 ($T = 3,695 \text{ }^\circ\text{C}$) [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 ($T = 1,510 \text{ }^\circ\text{C}$) [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