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Study of the effects of tool longitudinal oscillation on the machining speed of electrochemical discharge drilling of glass

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ABSTRACT

In this study, longitudinal oscillation applied to the cathode electrode during the electrochemical discharge micro drilling of glass and the effects of electrolyte flushing alteration in both discharge and hydrodynamic regimes of the process have been investigated. In this regard, numerous sets of experiments have been conducted using different vibration frequencies and amplitudes. In addition, two geometrically different tools including cylindrical rod and micro drill were used as machining electrode (cathode). In the case of cylindrical rod, two types of longitudinal waveforms including square and sinusoidal ones were applied to the tool. The experiments were resulted in a noticeable improvement in material removal rate (MRR) using square waveform and a slight improvement in the case of sinusoidal waveform. Moreover, the obtained MRR by means of vibrating micro drill has been compared with those achieved by non-vibrating one in several oscillation frequencies and amplitudes. The results showed that the vibration of the micro drill cannot further improve the electrolyte flushing and MRR in comparison with non-vibrating one because of the inherent electrolyte flushing in micro drill through its flutes which is constant in vibrating and non-vibrating cases.

1. Introduction

Electrochemical discharge machining (ECDM) is a non-conventional machining method that has been firstly introduced for glass micro drilling by kurafuji and Suda [1]. This process which has attracted extensive research interests in recent years, combines features of electrochemical machining (ECM) and electro discharge machining (EDM) with the additional advantage of machining electrically non-conductive materials. High temperature melting and thermally accelerated chemical etching enable the ECDM process to machine very hard and brittle materials including glass and ceramics in a reasonable time and cost [2,3].

As demonstrated in Fig. 1, the ECDM process takes place in an electro-chemical cell using two electrodes. The tool electrode is used as cathode electrode and a counter electrode, which is greater in size in comparison with cathode, is used as the anode electrode. The two electrodes are dipped into an electrolyte solution and connected to a D.C. power supply, consequently when a voltage higher than a critical value is applied, electrolysis in the solution starts and hydrogen bubbles grow so dense on the tool electrode (cathode) that they coalesce into a gas film. The gas film acts as an insulating layer around the tool and provide electrical potential difference between the tool and electrolyte. Consequently electrical discharges take place between tool and electrolyte. When the workpiece is in the close vicinity of the cathode, the sparks strike the workpiece and cause melting or vaporing of the struck spots and results in material removal from the workpiece [4].

Because the electrochemical discharge process is highly depended on the availability of the electrolyte in the machining zone, electrochemical discharge drilling with high aspect ratio faces various limitations. In fact, the electrolyte circulation in the machining area and debris removal from this region become highly restricted as the machining depth increases (more than around 200 μm) [5,6].

So far, different approaches have been made to improve the electrolyte circulation and debris removal and consequently achieve higher depth in the ECDM process. In general, the approaches can be divided into two main categories including applying different tool kinematics and improving the tool shape. As an instance, applying rotation to the tool has been successfully conducted by Zheng et al. [7]. In addition, applying eccentric rotation to the tool has been effectively employed by some other researchers [8]. The main

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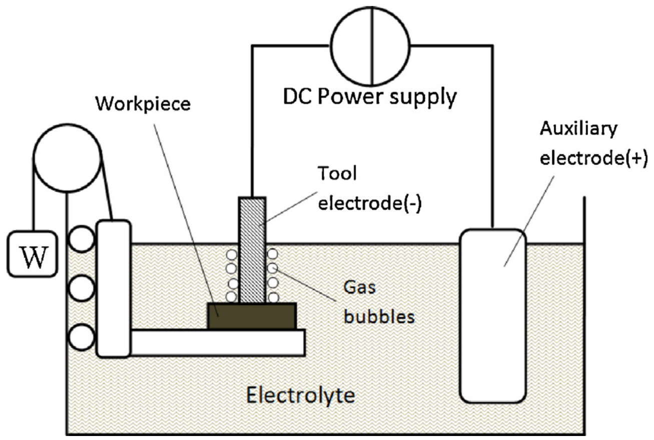

Fig. 1. Schematic view of ECDM setup using gravity feeding system.

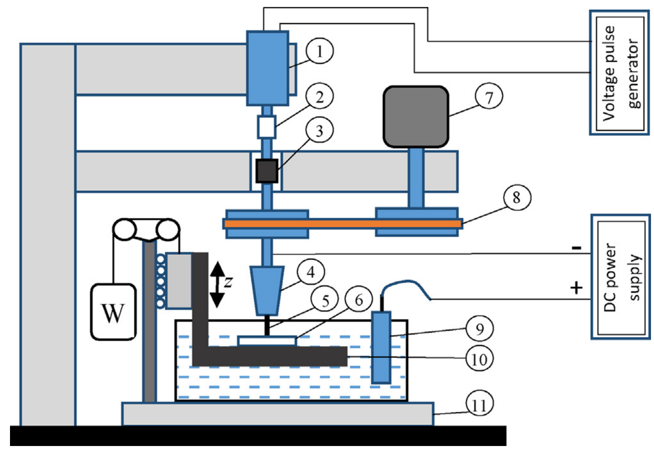

Fig. 2. Schematic view of vibration assisted ECDM setup: (1) piezoelectric actuator, (2) polymeric insulating part, (3) coupling bearing, (4) tool holder (chuck), (5) tool electrode, (6) workpiece, (7) electrical DC motor, (8) belt and pulley system, (9) counter electrode (anode), (10) workpiece holder connected to the linear guide way, (11) x–y table.

limitation of this method is the large difference between the diameter of the created hole and the diameter of the tool. In the case of geometrical improvement of the tool, spherical end tool has been successfully employed to facilitate electrolyte flow in the machining zone [9]. In another approach, Zheng et al. [7] utilized a flat sidewall tool for glass drilling which resulted in decrease in machining time and improvement of the geometry of the hole. Moreover, the electrolyte circulation has been improved using a micro drill tool instead of a cylindrical rod [10].

Regarding the tool kinematics, another potential approach which can be employed is axial vibration of the tool. This methodology has been firstly conducted by wüthrich et al. [6]. They demonstrated that applying low frequency vibration to a simple stationary cylindrical tool may reduce the machining time particularly in the hydrodynamic regime. This approach was limited to consideration of applying sinusoidal waveform to a cylindrical tool and the effects of different waveforms and tool shapes were not studied.

In this paper, the effects of applying longitudinal vibration to the two different tool shapes including cylindrical rod and micro drill are studied. The vibrations were applied in a wide range of amplitudes and frequencies and also in two different waveforms including sinusoidal and square waveforms. The effects of the mentioned parameters on the drilling speed of glass are discussed. According to the results, using vibrating tool can be considered as a proper way to enhance the material removal rate in most circumstances however it might not be true in some cases and is highly depended on the other parameters of ECDM process.

2. Experimentation method

To conduct the experiments, an electrochemical discharge drilling setup with gravity feeding system was prepared as depicted in Fig. 2. The electrolyte chamber was filled with 700 cm^3 of 25 wt.% NaOH. Soda-lime glass slides of size 75 mm × 25 mm × 1 mm were selected as workpiece. For gravity feeding system, a weight was employed to provide a 1 N contact force between workpiece and tool. In addition, a 500 μm diameter cylindrical rod and 500 μm micro drill made of Tungsten carbide were used as cathode electrode and a 304 L stainless steel plate of size 100 mm × 50 mm × 10 mm was used as anode electrode. In the case of micro drill as cathode electrode, a DC motor was used to produce the required rotation. Also a DC power supply (0–60 V, 0–5 A) was employed to apply the required working voltage.

In addition, a piezoelectric actuator was employed to apply the axial vibrations to the cathode electrode. The actuator works by means of applying pulsed voltage provided by a voltage pulse generator. Using the pulse generator, two different types of voltage waveforms were produced. In this regard, sinusoidal and square waveforms were applied to the actuator and consequently tool vibration frequencies ranging from 1 Hz to 500 Hz and vibration amplitudes ranging from 1 to 30 μm were achieved. Using a linear variable differential transformer (LVDT) the machining depth progress was monitored and stored on a PC through a data acquisition card (DAQ) with 500 Hz sampling rate.

To investigate the effects of tool longitudinal oscillation on the ECDM outputs, numerous sets of experiments have been conducted. The parameters which have been considered in this study are listed in Table 1. The mentioned parameters were tested in all levels as depicted in Table 1 in a full factorial experimentation methodology. In addition, each experiment was repeated five times and the mean value of experiment results is reported in "Section 3".

3. Results and discussion

As mentioned before, a cylindrical rod and a micro drill were used as cathode electrode in this study. The schematic diagrams of electrolyte flow in each tool are shown in Fig. 3.

Table 1
Considered parameters in the study of vibration assisted electrochemical discharge drilling of glass.

Parameter	Quantity								
Voltage pulse waveform	Sinusoidal waveform				Square waveform				
Vibration frequency (Hz)	6	10	20	25	50	100	200	400	500
Vibration amplitude (μm)	1.5	3.5	7	12	17	22	27		
ECDM voltage					33 V				
Electrolyte concentration					25 wt.% NaOH				
Tool diameter					0.5 mm: cylindrical rod/micro-drill				