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Study of gas film characterization and its effect in electrochemical discharge machining

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ABSTRACT

Electrochemical discharge machining (ECDM) is a promising method for the machining of hard, brittle, and inert materials such as ceramics and glass. Reducing the overcut is an important requirement for the ECDM process to emerge as a viable micro manufacturing method. The gas film quality is a critical factor contributing to the machining overcut in ECDM. This study focuses on the characterization of the gas film thickness and stability in ECDM. A full factorial parametric study of the gas film was performed for the electrolyte concentration, level of the electrolyte, the distance between electrodes and time of machining. Analysis of variance of the gas film thickness and stability of the gas film along with experimental verification revealed that the overcut in ECDM is affected by both gas film thickness and stability of the gas film. A lower concentration of electrolyte, with a lower level of electrolyte above the top surface of the workpiece and a higher distance between electrodes, for a lower time of machining constitute optimal machining condition to machine holes with less overcut and less taper.

1. Introduction

The upsurge in demand for micro products in chemical, MEMS, optical and biomedical industry demands for materials with robust mechanical, chemical and optical properties. Glass has an abundance of these properties, and thus, it finds widespread application to fabricate miniature products ranging from solid oxide fuel cells to DNA array manufacturing. However, glass micro manufacturing poses critical challenges due to its brittle nature and tendency to crack. Electrochemical discharge machining (ECDM) is a promising method for micromachining of glass with minimal surface cracking and surface instabilities [1]. ECDM has also shown repeatability in high aspect ratio machining with low overcut and hence proves suitable for more complex 3D shapes [2]. For controlling the precision and reliability of machining, the behavior of the gas film and its characterization are very critical as it decides the size of the machined crater. Literature study yields theoretical model of gas film formation [3]. Experimental study of gas film formation also reveals the importance of maintaining a stable discharge activity by keeping the gas film structure robust [4].

In ECDM literature, the gas film is considered as a resistance offered to the current flow and its role in ECDM has been explained with the help of RLC circuit [5]. Later, the gas film growth and detachment was studied by a statistical approach using percolation theory which was used to study critical voltage and current density [6]. Gas film thickness was described as a critical factor affecting the accuracy of machining and furthermore, this approach was followed in next studies, where surfactants were used to reduce gas film thickness [7]. Another research approach was to use a high wettable surface tool or side insulated tool or textured tool to reduce the gas film thickness to improve accuracy [8].

However, it should be noted that the gas film behavior in ECDM is difficult to be defined based entirely on a single linear relationship as it depends on several electrochemical and physical parameters, which act in an interconnected manner. Some of these research works cited above, characterized gas film by the peak current [4,8] or by mean current [9] which may not entirely describe its nature, behavior, and shape. As gas film formation and its shape are highly stochastic in nature, the peak discharge current is likely to occur at an instantaneous condition that corresponds to the formation and breakage of a thicker gas film. Hence, a peak value is not an appropriate index to predict overcut in machining for the whole range of discharges. Also, since mean current calculations typically consider current values even when the actual discharge is not happening (for example current values during electrolysis and gas film formation), there is a need for a more accurate parameter for gas film characterization. Additionally, the combined interactive effect of various thermochemical parameters on the stability and thickness of gas film has not yet been discussed. Therefore, to gain a better understanding of the gas film behavior, its characterization through interdependent parametric experimental study is required.

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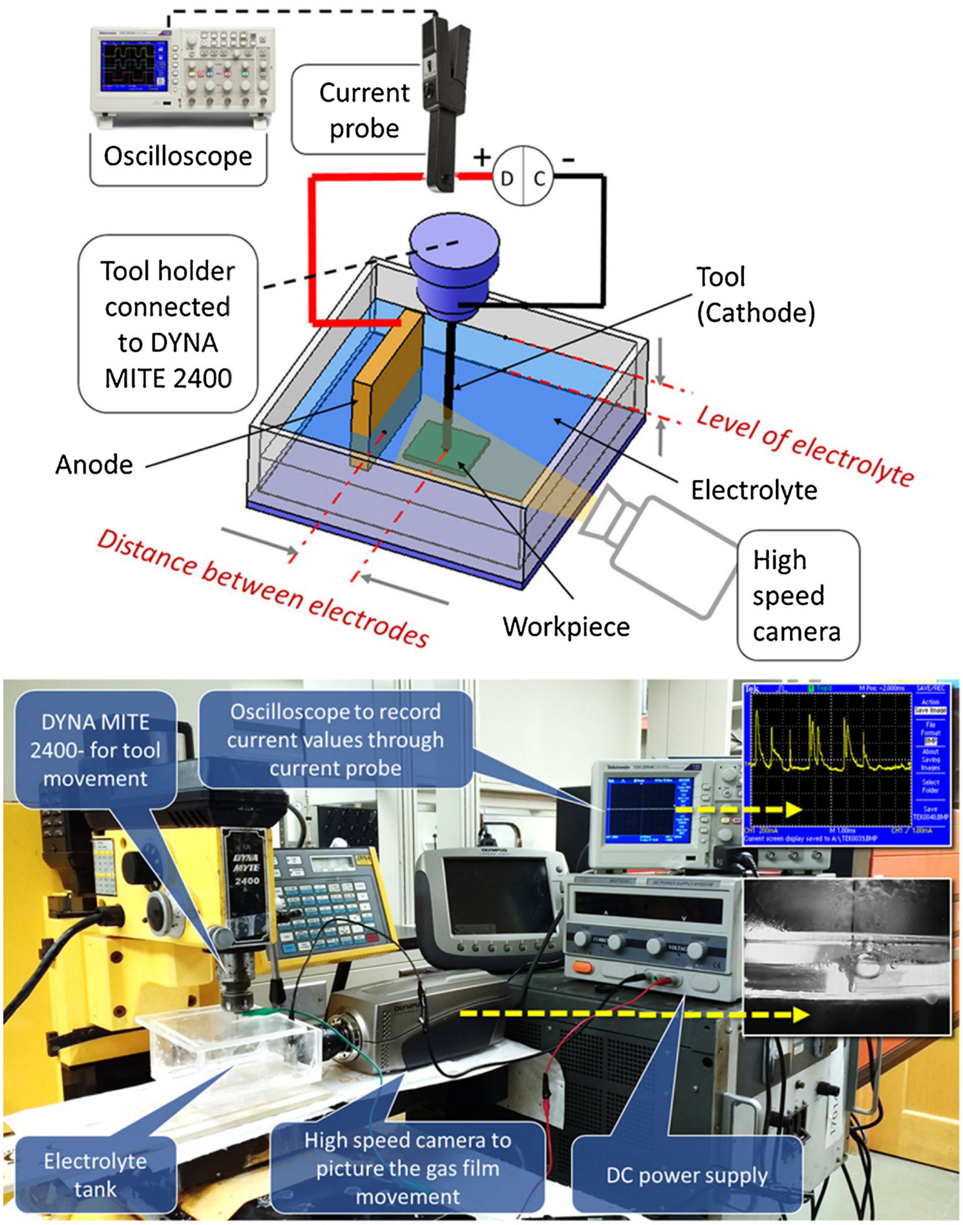

Fig. 1. Experimental setup (Top: Schematic; Bottom: Physical).

In this present investigation, a full factorial design of ECDM experiments with 4 factors and 3 levels is performed to achieve thin, stable gas film by optimizing the thermochemical process parameters using analysis of variance. The concentration of the electrolyte, time of machining, level of electrolyte and distance between electrodes are considered as variants/factors. In this study, values of electric current are recorded during the sparking interval at critical voltages and the effects of these variants are discussed considering different hydrodynamic forces acting on the gas film.

2. Materials and methods

2.1. ECDM experimentation

The experimental setup for the parametric study of ECDM is shown in Fig. 1. Experimental setup included NaOH electrolyte in an electrochemical tank that was housed on a 3-axis CNC stage, which can provide resolution of 2.5 μm in all 3 axes. 1100 μm thick Borosilicate glass was used as a workpiece material. A 300 μm diameter Tungsten tool and a tool steel block were used as cathode and anode respectively. The electrodes were washed with deionized water and cleaned in an acetone ultrasonic bath for 3 min to remove any surface contaminants and then were connected to DC power supply. A full factorial design of ECDM experiments with 4 factors and 3 levels is performed with 3 repetitions. The ECDM process parameters used in this study and their level of variations are listed in Table 1. It should be noted that the factor B: level of electrolyte considers the level of electrolyte above the top surface of the glass workpiece. A high-speed camera was used to capture pictures and videos of gas film activity for all experimental

Table 1
Process parameters with considered level of variation.

Factors	Level 1	Level 2	Level 3
A: Concentration of the electrolyte	1.5 M	2 M	2.5 M
B: Level of the electrolyte	1.5 cm	2.5 cm	3.5 cm
C: Distance between the electrodes	1 cm	2.5 cm	4 cm
D: Time of machining	1 min	2 min	3 min