International Journal of Machine Tools & Manufacture 50 (2010) 689–697

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

journal homepage: www.elsevier.com/locate/ijmactool

Study of gas film quality in electrochemical discharge machining

Chih-Ping Cheng [a], Kun-Ling Wu [b,*], Chao-Chuang Mai [a], Cheng-Kuang Yang [c], Yu-Shan Hsu [c], Biing-Hwa Yan [c]

[a] Mechanical and Systems Research Laboratories, Industrial Technology Research Institute, Shin-Chu 310, Taiwan
[b] Department of Mechanical Engineering, Tungnan University, Taipei 222, Taiwan
[c] Department of Mechanical Engineering, National Central University, Jhong-Li 300, Taiwan

ARTICLE INFO

Article history:
Received 11 January 2010
Received in revised form
22 April 2010
Accepted 23 April 2010

Keywords:
Electrochemical discharge machining
ECDM
Gas film
Transition voltage

ABSTRACT

Electrochemical Discharge Machining (ECDM) has been demonstrated to be an alternative spark-based micromachining method for fabricating microholes and microchannels in non-conductive brittle materials. However, the mechanism for attaining accurate control of the contour shape and dimensions remains to be explored. In ECDM process, the gas film on the electrode surface is used as the dielectric medium required for discharge generation. Quality of gas film is the dominant factor that determines the machining qualities such as geometric accuracy, surface roughness and repeatability. Nevertheless, it is difficult to assess the gas film quality of ECDM. In this study, current signals and machined contours were taken as indexes of gas film quality. Experimental results showed that a stable and dense gas film could be obtained when the applied voltage exceeded the critical voltage and reached a specific level, which is called the "transition voltage" in this study. At the transition voltage, a stable electrochemical discharge activity could be generated, thus producing the smallest deviation of contour dimensions. Moreover, when the drilling process reached a certain critical depth, bubbles inside the hole could not easily escape. In order to reduce the interface energy between bubbles, a thicker gas film is formed at the hole entrance, resulting in unstable discharge performance that undermined machining results. In summary, information provided by current signals can shed light on the changes in gas film structure, which serve as useful reference for varying process parameters to achieve better efficiency and accuracy.

1. Introduction

In recent years, different kinds of non-conductive brittle materials have been extensively employed because of their excellent functions, such as high creep, chemical corrosion resistance and heat resistance. However, their hardness and brittleness pose problems to machining with high accuracy, high efficiency and high reliability. Electrochemical discharge machining (ECDM) is an alternative spark-based micromachining method for fabricating microholes and microchannels in electrically non-conductive materials [1]. ECDM processes utilize the electrode effect, which occurs when the electrode is separated from the surrounding electrolyte by the gas film formed during electrolysis.

In the ECDM process, the workpiece, tool electrode and auxiliary electrode are all immersed in an electrolyte solution, typically, an alkali electrolyte solution. The auxiliary electrode has a larger surface than the tool electrode. The two electrodes are connected to a DC power source. Electrolysis occurs when a voltage is applied between the tool and auxiliary electrode. When the applied voltage is higher than the critical voltage (typically around 30 V), electrolysis bubbles start to coalesce into a gas film surrounding and insulating the tool electrode. A high electric field of the order of 10^7 V/m is developed across the gas film [2]. Then, the discharge is generated inside the gas film surrounding the tool electrode [3]. As the workpiece lies in close proximity to the tool electrode, material removal would occur. Such material removal process is known as ECDM [1,4–7]. However, the exact material removal mechanism has not yet been established completely. There have been various theoretical and experimental investigations trying to verify that melting of the workpiece due to local heating is the main process responsible for material removal [2,6,8]. Moreover, there are several indications reported elsewhere in favor of chemical etching, which certainly play a role for material removal as well [4,9–12]. Theoretical and experimental investigations confirm this hypothesis, such as analysis of reaction products and observation of machined surface between different polarity conditions [11], comparison with model and experimental data to explain the material removal mechanism as

* Corresponding author. Tel.: +886 2 88625917; fax: +886 2 88625919.
E-mail address: klwu@mail.tnu.edu.tw (K.-L. Wu).

0890-6955/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmachtools.2010.04.012

a hybrid mechanism combining local heating and chemical etching [12]. However, it can be confirmed that machining accuracy, efficiency and repeatability are directly related to the quality of gas film [1,6,13,14].

To meet the requirements of high-accuracy and high-reliability machining, it is important to maintain a stable discharge activity by keeping the gas film structure robust. There have been many studies examining the relationship between gas film structure and characteristics of discharge performance. Raghuram et al. [15] studied the relationship between voltage and current in electrolyte of different concentrations and kinds, and suggested the existence of internal inductance and capacitance in the electrolyte. Fascio et al. [6,13] examined the changes in gas film structure with rising voltage and also divided the voltage–current curve of ECDM into five characteristic regions. Wüthrich et al. [14] used the percolation theory to explain bubble growth and bubble separation from electrodes as a stochastic process. They also used probability and statistical methods to estimate the critical conditions (critical voltage and current density). Moreover, in their later studies [16,17], they demonstrated that the thickness of gas film was the main limiting factor affecting the range of material removal. Thus, surfactant was added to enhance wettability of tool electrode, reduce thickness of gas film and improve machining accuracy. They also analyzed the current signals during gravity-feed drilling process, and evaluated the machining situations with reference changes in current signals [6]. Mailard et al. [18] used microelectrodes to drill microholes on glass by gravity-feed. Owing to variations in discharge energy density and electrolyte circulation, different contours were formed after drilling and they were divided into four main categories according to their geometrical characteristics. Han et al. [19] proposed using the side-insulated electrode to stabilize the geometry of gas film. In doing so, the regularity of discharge could be improved to enhance machining accuracy. It is known that increasing knowledge of gas film stability would facilitate and promote the application of ECDM. So far, quantitative studies on gas film stability have already been conducted. Allagui and Wüthrich [20] proposed a two-step algorithm for identifying formation of gas film and the subsequent discharges. In the first step, the functional decomposition–reconstruction principle is applied to the signal, as a denoising tool, followed by wavelet transformation of the signal using discrete approximation of Meyer wavelet. In the second step, local extrema detection by the center-clipping technique is employed to calculate the necessary random variables for describing the signal. Allagui's algorithm allows the measurement of the statistical distribution of gas film formation time, gas film lifetime and the interval between two successive gas film formations.

Nevertheless, in the literature, there have been few studies on how changes in gas film structure affect discharge performance and machining characteristics in a practical machining process. During ECDM, the gas film on the electrode surface served as the dielectric medium required for discharge generation. Therefore, quality of gas film is the dominant factor that determines the machining qualities such as geometric accuracy, surface roughness and ECDM repeatability. In general, gas film quality is characterized by its geometric regularity and structural strength (stability), which influence uniformity of spark energy and lifetime of gas film. This research aims to investigate the effects of machining parameters on gas film quality and machining characteristics. In this study, both current signals and machined contours were taken as indexes of gas film quality. In the experiments, microholes were drilled on Pyrex glass to investigate the relationship between gas film quality and machining characteristics under different parameters including applied voltage, tool rotating speed, electrolyte concentration, machining depth and tool geometry.

2. Experimental design

In this study, both wire electro-discharge grinding (WEDG) and ECDM systems were integrated on the micro-EDM worktable. Apparatuses similar to those used in [21] and [22] were adopted. Such a design allows us to carry out the entire experiment without the need of re-clamping the tool. WEDG can effectively fabricate microtools of different diameters and shapes by controlling the relative motion between the wire and tool. Fig. 1 is the schematic diagram of the ECDM experimental setup [22]. It comprised a chamber made of acrylic and fixed on the guide block. The workpiece was fixed in the chamber and then fed to reach the desired level by the gravity-feed device. The workpiece was a 500-μm-thick Pyrex glass composed mainly of SiO_2 (83%), B_2O_3 (10%) and Al_2O_3 (3%). The electrolyte used in the process was KOH solution at room temperature (about 25 °C). The electrolyte level was adjusted to 2 mm above the workpiece. A graphite of $50 \times 30 \times 5\ mm^3$ was used as an auxiliary electrode (anode). To prevent tool deformation during machining, tungsten carbide rod of 500 μm diameter was used as the tool material (cathode). The machining head with the fixed tool can be positioned relative to the workpiece by the XYZ stage. A DC power supply (0–80 V, 10 A) was employed to provide the applied voltage between the tool electrode and auxiliary electrode. The digital indicator placed under the machining chamber performed contact judgment between the tool and the workpiece and immediate surveillance of the machining depth. During the ECDM process, the current signal was monitored by a LeCroy 422, 200 MHz two-channel digital storage oscilloscope.

Prior to drilling by ECDM, the microtools were shaped to the desired geometry and dimensions by WEDG. In this study, electrodes of two different geometrical shapes, cylindrical and flat sidewall, were used, as shown in Fig. 2. Gravity-feed was adopted for the drilling process with contact force of 30 g kept between the tool and workpiece. After the machining operation, the dimensions of the machined microholes were measured by a microscope. The shape and surface morphology of the drilled microholes were observed by a scanning electron microscope (SEM).

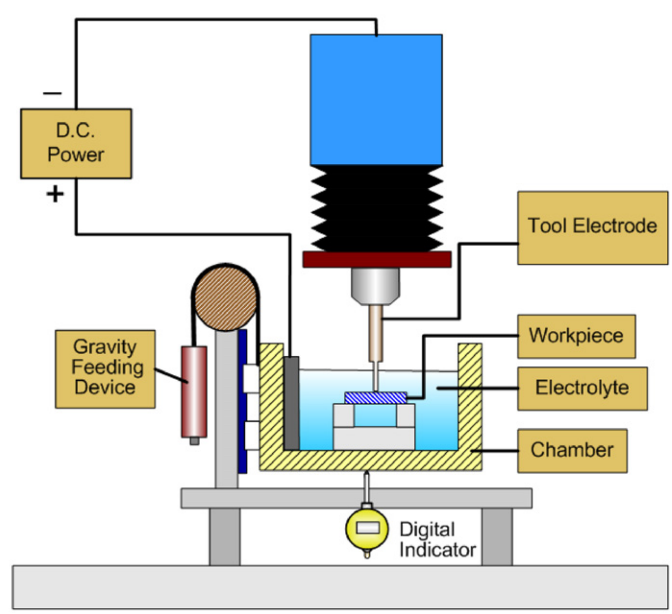

Fig. 1. Schematic diagram of ECDM experimental setup.