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A Study on the Effect of Electrolyte Concentration on Surface Integrity in Micro Electrochemical Discharge Machining

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Abstract

Micro machining of nonconductive materials such as glass is critical as it has numerous applications in microsystems including biomedical devices, micro-reactors, micro-pumps, micro-accelerometers and MEMS. Electrochemical discharge machining (ECDM) is a promising process for the micromachining of glass. However, ECDM often inadvertently causes surface wrinkling and surface damages. This paper studies the effect of concentration of electrolyte in ECDM on the integrity of a micro machined hole surface. The study includes: analysis of surface roughness and micro-defects, microstructure by EDAX testing and hardness testing by nano indentation. It was found that lower electrolyte concentrations in ECDM enhance chemical etching that causes surface wrinkling.

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Keywords: ECDM; Surface wrinkling; Micromachining; Glass

1. Introduction

Micro machining of glass is extremely challenging due to its tendency to form surface and subsurface cracks hampering surface integrity[1]. Despite that, ever growing applications of glass in MEMS, biomedical devices, reactors and micro-sensors industry bring along with them vast demand for highly reliable microscale manufacturing [1]. This provides impetus towards advancing knowledge of surface integrity as it improves performance, reliability and durability.

Existing micro manufacturing processes for glass such as laser machining, ultrasonic machining, abrasive machining, and chemical etching produce distinct results with some persisting limitations. Laser and ultrasonic micromachining of glass causes surface cracking and leads to a poor surface finish [2]. Chemical etching etches the side walls and surface during the process and damages its quality [3]. Electrochemical discharge machining (ECDM) is a promising method for micromachining of glass [4]. Although it avoids surface cracking, it often produces surface damage by surface wrinkling which requires further research.

2. Literature Review

Well-documented literature is available in the CIRP or other publications over the past years in terms of methods to characterize surface integrity performance of micro-nano surface [5, 6]. ECDM involves chemical etching along with a thermal mechanism of machining. Effects of individual mechanisms differ with varied machining conditions [7, 8]. The effect of concentration of electrolyte in ECDM has been studied for high aspect ratio machining and higher accuracy [7, 9]. However, change in surface integrity characteristics with varied electrolyte concentration in ECDM need to be studied to understand the influence of electrolyte concentration on the material removal mechanism and resulting machining quality of ECDM. Furthermore, control over the profile of surface wrinkles may lead to novel applications such as self-cleaning surfaces [10].

3. Experimentation

An experimental setup used in this study is shown in Fig.1. 'L' shaped tool steel block was used as the anode and

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300μm diameter tungsten rod was used as the cathode. The electrodes were separated by 5 cm distance with NaOH as electrolyte. The depth of the immersed tool was kept constant by keeping volume of electrolyte constant at 5 ml. Borosilicate glass is used as substrate and elemental composition is given in Fig.6. A multimeter with 0.01mA sensitivity was connected in series to monitor current behavior. It was connected to LABVIEW interface to monitor current characteristics. The electrolyte tank was fixed to LABVIEW controlled precision micro stage of 0.01 μm sensitivity. Mitutoyo SJ-410 Profilometer was used to study the surface wrinkles on the machined part. Philips XL-30 FEG Environmental Scanning Electron Microscope (ESEM) was used to perform energy-dispersive X-ray spectroscopy (EDX) studies. Table 1 lists the experimental conditions used in this study.

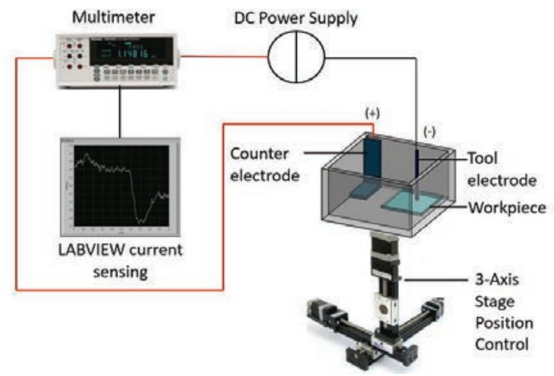

Fig. 1. Experimental setup

Table 1
Experimental parameters for machining

Process Parameter	Value
Anode	4mm thick L shaped tool steel block
Cathode	Tungsten Carbide rod 300 μm dia.
Electrolyte	1M, 0.8M,0.6M, 0.4M, 0.2M NaOH (5ml)
Workpiece	200 μm thick glass slide
Time	30 min

4. Results and Discussions

To study the effect of concentration of electrolyte, micro holes were machined with varying concentrations of 1M, 0.8M, 0.6M, 0.4M and 0.2M NaOH. Experiment for each concentration was repeated five times. The level of electrolyte was kept constant for all experiments. The critical voltage decreases as recorded in fig.2. Dominance of chemical etching at lower concentration of electrolyte machining can be shown by studying the current characteristic behaviour for varied concentration. The current behaviour along the time span of machining shows very less current for lower concentration as shown in fig.3. This is due to the reason that chemical etching is the major contributing mechanism of machining in lower concentration of electrolyte where small low current sparks at higher voltage heat the surface catalysing chemical reactions. Chemical etching mechanism becomes substantial which affects surface integrity of workpiece. The effect of change in concentration of electrolyte on the surface roughness, surface hardness and its profile is discussed in subsections below.

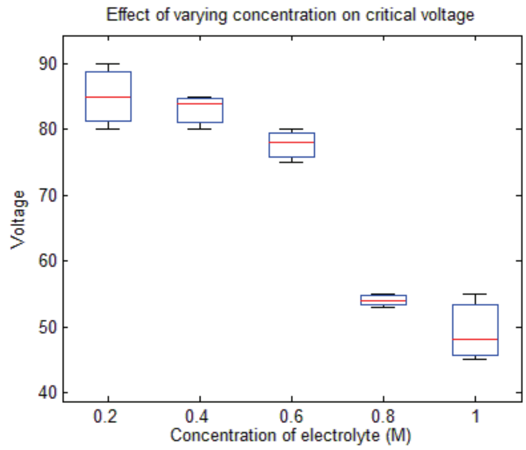

Fig. 2. Effect of varying concentration on critical voltage

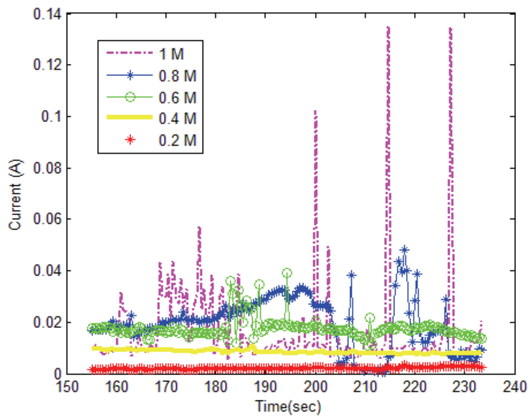

Fig. 3. Current characteristics for different conc. of electrolyte.

4.1 Effect of concentration on surface roughness

Machining with lower concentration of electrolyte was observed to produce surface wrinkling near the perimeter of hole surface as shown in fig.4. With lower concentration of electrolyte, the energy of sparks reduces which reduces machining size of hole as thermal mechanism is less effective. Whereas temperature near the machining surface is substantial enough to produce chemical etching. The fundamental mechanism of chemical etching reaction in glass has been widely studied in nuclear waste glass stability performance[11] and it has been well documented. The glass chemical etching reaction has been described in terms of mechanism, based on glass network breakdown. It takes into account surface layer formation and diffusion processes. Diffusion processes like network hydration and alkali ion exchange were ignored in previous models since their rates are faster for initial short period duration and were not considered in long period laboratory tests. However, chemical etching in the case of ECDM is for very small duration and necessitates study of these reactions. The step by step chemical etching reactions are described in Table 2.