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Effect of Internal Electrolyte Flushing in Electrochemical Discharge Drilling (ECDD) of Soda-Lime-Silica Glass

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Abstract

Electrochemical discharge drilling (ECDD) is a non-traditional machining technique used for drilling electrically non-conductive materials like glass, ceramics, quartz, etc. In ECDD, gravity feed is the most widely used technique to feed the workpiece. But it has certain drawbacks like consumption of space, design difficulty and less repeatability. In order to increase the efficiency and simplicity, a spring fed tool system was designed and developed to control the tool movement. By using spring fed tool system, the tool will be in contact with the workpiece throughout machining. Another major problem in deep hole drilling is the accessibility of the electrolyte at the working site for drilling holes of high aspect ratio. A spring fed tool system with internal electrolyte flushing is designed and fabricated to investigate its effect on ECDD performance. To identify the effect of electrolyte flushing on MRR, a comparison of spring fed tool system with and without electrolyte flushing were performed on soda-lime-silica glass. With the use of internal electrolyte flushing, the operating range of voltage has been increased to a maximum of 100V. This helps to deliver more energy and enhance MRR without causing any damage to the workpiece. Usual thermal cracks observed at the periphery of the drilled hole using traditional methods are found to be reduced with the application of internal electrolyte flushing. By using spring fed tool system with internal electrolyte flushing, the MRR was found to be increased by 35%.

Keywords: ECDD, Material Removal Rate, Spring feed mechanism, Electrolyte flushing.

1. INTRODUCTION

Electrochemical Discharge Machining (ECDM) is a hybrid non-conventional machining process that combines the features of Electro Chemical Machining (ECM) and Electric Discharge Machining (EDM). ECDM is first introduced by Kurafuji and Suda of Japan in 1968 for the micromachining of glass [1]. ECDM is an effective machining process for non-conducting materials like glass, ceramics, composites, quartz, etc. Nowadays, this machining process is effectively used for the micromachining of glass for producing microfluidic components, micro-pumps, micro-accelerometers, micro-reactors, micro-fuel cells and several biomedical devices. A schematic diagram of the basic ECDM process is shown in Fig. 1. In ECDM process, the workpiece is dipped in an electrolyte like NaOH, KOH, NaCl, etc. The tool-electrode tip is dipped few millimeters in the electrolyte. Commonly used tool electrodes are tungsten carbide, stainless steel, copper, brass, etc. The counter electrode (larger in size) is placed a few centimeters away from the tool-electrode. An electro-chemical cell is formed by providing a continuous or pulsed DC between the tool-electrode (cathode) and the counter electrode (anode). Electrolysis occurs at a low voltage (typically between 20 and 30 V). This result in the formation of hydrogen bubbles at the tool-electrode and oxygen bubbles at the counter electrode. As the terminal voltage increases, the formation of gas bubble and their mean radius increases due to increase in current density. This results in development of a layer of gas bubble around the tool-electrode. Beyond a critical applied voltage, the bubbles coalesce and results in formation of a gas film around the tool-electrode. The gas film acts as a dielectric and generates sufficient resistance to create high potential difference between the electrodes. As the potential difference becomes high enough for a given pair of tool-electrolyte system, electrical discharges occur between the electrode and the electrolyte. If the work-piece is placed in the discharge zone, machining takes place in the form of melting, vaporization and thermal erosion due to the heat generated by the discharges. Moreover, small amount of material is removed by chemical etching. However, ECDM has its own problems, such as limiting depth characteristic due to upward shifting of discharge zone during machining and tool size limitation while drilling a hole. In ECDD, cylindrical tools made of conductive materials are used. The range of diameter is typically from about 100 mm to a few millimetres.

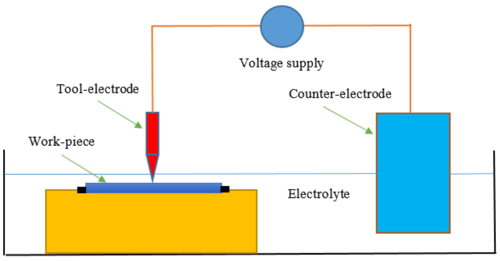

Fig.1. Schematic of ECDD

The work of Jain and Adhikary [1] provides a more detailed understanding of the ECDM process. Instead of using Cathode as a tool (with straight polarity) as it was done in the past, they used Cathode as well as the Anode as the tool interchangeably with different polarities for cutting a workpiece made of Quartz. It was observed that Reverse polarity offered higher MRR for the ECDM process as compared to Straight polarity. The principle and mechanism of the ECDM process was also

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explained by Singh and Dvivedi [2] in their study. The different variants of the ECDM process were also explained in detail along with their working mechanism and application. It was observed by Wuthrich and Hof [3] during their studies that the gas film created during machining imposed a limiting factor to reproducibility of the process. Thermal damage accompanying the ECDM process was studied by Kim et al. [4] HAZ, Overcut, surface roughness parameters etc. of micro-holes drilled by the ECDM process on Pyrex glass were studied by varying parameters such as the applied voltage pulse frequency and Duty Ratio. Their work showed that with increase in frequency and decrease in Duty Ratio, the HAZ increased. A tool electrode with a spherical end shape was used in ECDM processes at depths greater than 250µm in an attempt to improve accuracy and reduce machining time by Yang et al.[5] A gas film created due to the entry of electrolyte at the tip due to its spherical shape, resulting in efficient machining. Machining time reduced to 83 % of its original value along with a reduction in overcut. The effect of thermal conductivity of tool electrode on ECDM performance was studied by Mousa et al. [6] Their studies reported a dramatic improvement in MRR in discharge regime and a reduced MRR in the hydrodynamic regime. The effect of spherical end shaped tool electrode on MRR in ECDM was also studied by Yang et al [7]. Their studies showed that compared to conventional tool electrodes, the spherical tipped electrode exhibited higher MRR and accuracy. Longitudinal vibrations were provided to two different tool shapes used in ECDM in an effort to study their effect on MRR by Razfar et al. [8] While using a rotating micro drill as the cathode, no significant variations were oversexed on the MRR values. However, MRR increased by a magnitude of 20% with the use of a cylindrical rod and application of a sinusoidal wave form actuator voltage. Further, MRR was also observed to increase by a magnitude of 40% if a square wave form was used.

A major problem in hole drilling is the availability of the electrolyte at the machining zone for drilling holes of high aspect ratio. The deficiency in electrolyte supply at the machining zone will increase thermal cracking, which may finally lead to a significant reduction in the MRR. Wuthrich et al. used the technique of peck drilling in which the tool will be retracted at frequent intervals to allow the flushing of fresh electrolyte in to the machining zone. Another method suggested in literature is to flush the electrolyte internally through the tool electrode. This paper presents an experimental study on spring fed tool system with and without electrolyte flushing on material removal rate. A spring fed tool system with internal electrolyte flushing is designed and fabricated to investigate its effect on ECDD performance.

2. EXPERIMENTAL WORK

Soda lime glass consists of about 90% of the glass used in the world, including most windows, dinnerware, lighting products and beer bottles. Soda lime glass is made of 73% of SiO_2, 14% of Na_2O, 7% of CaO, 4% of MgO and 2% of Al_2O_3. Soda lime is not as chemical resistant as borosilicate glass. Its lower melting point and higher coefficient of expansion and contraction make it ideal for certain glass to metal operations as well as inexpensive glassware such as pipettes or plate glass.

Table 1 Properties of Soda-lime-silica-glass

Mechanical Properties	Value
Density (kg/m^3)	2520
Specific heat (J/kg K)	850
Thermal conductivity (W/mK)	1

However, those same coefficients make it unusable where high heat or great temperature fluctuations are necessary.

2.1 Tool holder fabrication

The schematic diagram of the spring fed tool system with internal electrolyte flushing is shown in Fig. 2. A pump is used for the supply of electrolyte to the machining zone. To maintain a constant electrolyte level, the inlet of the pump is connected to

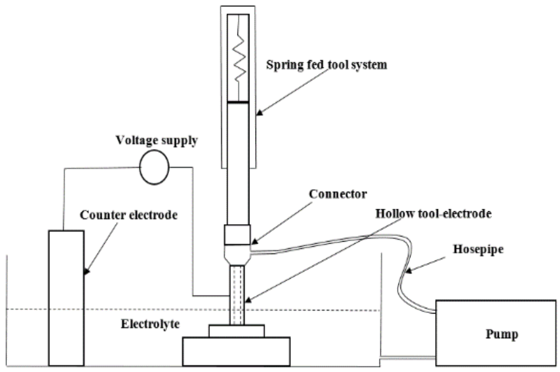


Fig.2. Schematic diagram of spring fed tool system with internal electrolyte flushing

the machining chamber. The outlet of the pump is connected to a hollow tool electrode by means of a flexible hosepipe and a connector. The experiments are conducted with the help of a CNC Router TR 203, in which the collet- nut mechanism was used to clamp the tool holder to the machine spindle. The outer diameter of the tool holder is chosen by considering the maximum diameter of the collet that is available in the ER-20 collet series (i.e. 13mm). Hence, the outer diameter of tool holder was fixed to 12.5mm. The spring holder consists of three parts, namely outer casing, inner shank, and spring. The outer casing and inner shank were first modelled in Solidworks, shown in Fig. 3. In ECDD, the entire machining is to be performed in chemical atmosphere. Stainless steel is used as the tool holder material by considering its chemical inertness. For fabricating outer cap, a stainless steel rod of 16mm diameter was turned in CNC lathe and the diameter was reduced to 12.5mm. For providing spring, the outer casing was drilled and made hollow. With the aid of Vertical milling centre, a rectangular slot was cut on the outer cap for providing locking system for spring feed. The outer diameter of the inner shank is in transition fit with the outer casing. The inner shank consists of 3 steps. This part is also made in CNC lathe. The fabricated ECDD setup with internal electrolyte flushing is shown in Fig. 4. For internal electrolyte flushing, a stainless-steel hypodermic needle of 16 gauge (1.651 mm nominal outer dia) was used. A syringe barrel was attached to the spring fed system and the tool electrode is connected to it. A submersible pump is used for pumping the electrolyte through the tool-electrode. The pump is submerged in the machining chamber containing electrolyte. A filter unit was attached beneath the pump which can remove the sludge produced during machining and prevents the tool from clogging with debris. By means of a plastic hosepipe and a connector (T joint), the outlet of the pump is connected to the tool.

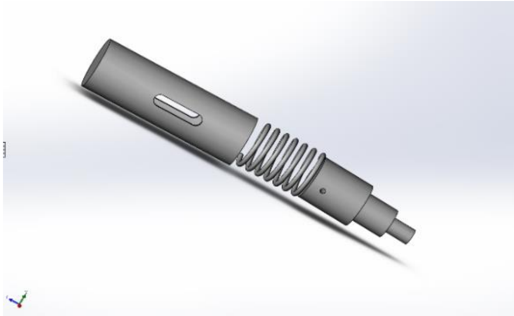


Fig. 3 Model of spring fed tool system

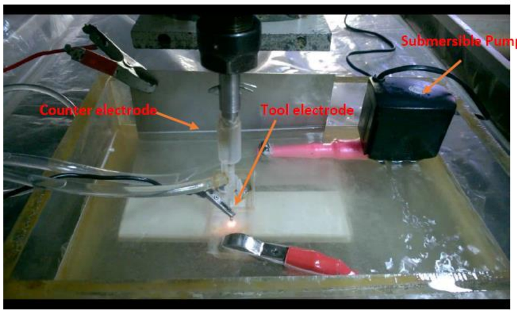


Fig. 4. Fabricated ECDD setup with internal electrolyte flushing

2.2 Experimental set up

The experiment to determine MRR with the variation in applied voltage and electrolyte concentration was conducted with the aid of a CNC Router. Soda lime silica glasses of 30x40x4 mm size were used as the workpiece. Counter electrode used was made up of stainless steel of dimension 200x150x0.8 mm.

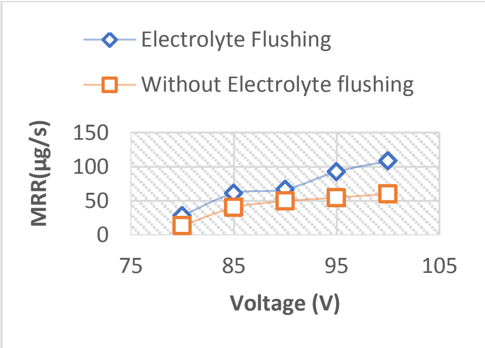
Table 2 List of process parameters

Parameters	Unit	Value
Electrolyte Concentration	M	3, 4, 5
Voltage	V	80,85,90,95,100

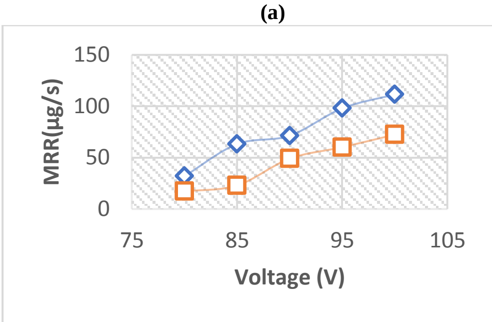
The experiments were performed in a chamber made of acrylic sheet. Due to high material removal capability, experiments were performed with KOH electrolyte. Before machining, electrolyte of different concentrations was filled to the desired level. A continous DC power supply with autotransformer and a bridge rectifier was used for the experiments. The material removal rate is measured by taking the difference of mass of the workpiece before and after machining and dividing it by time taken.

3. RESULTS AND DISCUSSIONS

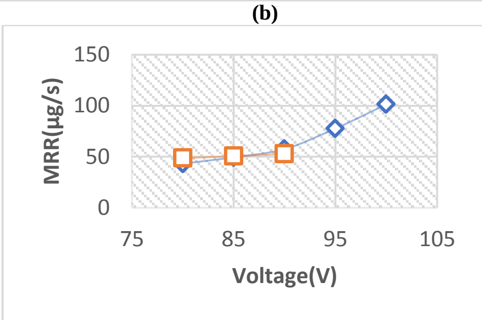
In ECDD with internal electrolyte flushing, the operating range of voltage is observed to be higher when compared with that of ECDD without flushing. Usually the critical voltage is around 30V. But with internal electrolyte flushing, sparks are observed at a minimum voltage of 78V. This is the reason for selecting high voltage values for the experiment. The comparison of MRR with and without electrolyte flushing for different voltages are shown in Fig.5. At 3M concentration, MRR obtained by electrolyte flushing is higher than that without flushing. In case of internal electrolyte flushing, with the increase of voltage from 80V to 85V there is a gradual increase



(a)



(b)



(c)

Fig.5. Voltage Vs. MRR (a) at 3M electrolyte concentration (b) at 4M electrolyte concentration (c) at 5M electrolyte concentration

in MRR. But with the increase in voltage from 85V to 90V, the rate of increase in MRR is very small. With further increase in voltage, the rate of MRR rapidly increased. At 4M electrolyte concentration, MRR increases with applied voltage for both the cases. The MRR of internal electrolyte flushing is higher than that without flushing as shown in Fig. 5(b). The MRR at 4M is higher compared to that at 3M. At 5M concentration, in both the cases MRR increases with the rise in voltage. But at the extremely high values of voltage (Beyond 90V), drilling without electrolyte flushing leads to thermal cracks and breakage of the glass workpiece. As a result, the MRR of ECDD without electrolyte flushing was not able to determine beyond 90V.

Fig. 6 shows the microscopic images of glass, machined at 4M electrolyte concentration with and without internal electrolyte flushing at different voltages. From the images, it is clear that the use of electrolyte flushing has improved the hole quality. In the case of ECDD without electrolyte flushing, more heat will be transferred to the workpiece surface. But due to the unavailability of electrolyte in the machining zone, proper flushing of the machined material does not take place. This causes a reduction in material removal rate. The large supply of

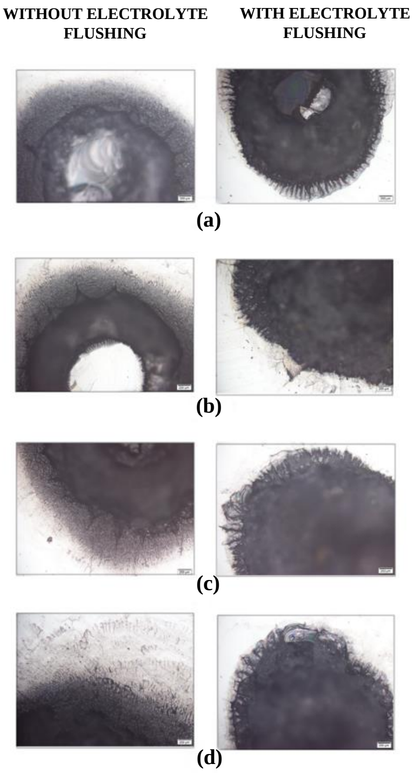


Fig. 6. Comparison of microscopic images of glass machined at 4M electrolyte concentration with and without internal electrolyte flushing (a) at 85V (b) at 90V (c) at 95V (d) at 100V

energy to the workpiece surface increases the heat affected zone. Moreover, the size of heat affected zone increases with the rise in voltage, shown in Fig.6((a)- (d)). By using internal electrolyte flushing, less energy will be transferred to the workpiece. But due to the continuous flow of electrolyte to the machining zone, the machined particle gets flushed out from the machining zone and thus an increase in MRR can be observed. In both the techniques, some microcracks are observed on the hole entrance. This may be due to the sparks occurring at the lateral surface of the tool electrode. By insulating the lateral surface of the tool electrode, lateral sparks can be avoided and thereby increases the hole quality. The effect of thermal spalling can also contribute cracks. Feather-like patterns are observed while drilling with electrolyte flushing. This feather-like pattern resembles electrolyte leaving the hole.

5. CONCLUSIONS

In this study, an experimental investigation of spring fed tool system with and without electrolyte flushing has been performed. By using spring fed tool system with internal electrolyte flushing, the MRR was found to be increased by 35%. From the microscopic images, it is observed that the use of internal electrolyte flushing has improved the hole quality. Usual thermal cracks observed at the periphery of the drilled hole using traditional methods are found to be reduced with the application of internal electrolyte flushing. With the use of internal electrolyte flushing, the operating range of voltage has been increased to a maximum of 100V. This helps to deliver more energy and enhance MRR without causing any damage to the workpiece.

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