ELK Asia Pacific Journals – Special Issue
ISBN: 978-81-930411-8-5

DESIGN AND EXPERIMENTAL INVESTIGATION OF ELECTRO CHEMICAL DISCHARGE MACHINING OF TINY GLASS

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Abstract— Electro Chemical Discharge Machining (ECDM) is a recent innovative hybrid machining process which is combining characteristics of Electro Chemical Machining (ECM) & Electro Discharge Machining (EDM) and more suitable for non conductive engineering ceramic materials, such as ceramics, zirconium oxide, composites and silicon nitrides. In the present work, design and development of tabletop ECDM setup has been successfully completed for machining the borosilicate glass work piece. Furthermore the influence of input parameters such as applied voltage, electrolyte concentration and inter-electrode gap on output parameters like Material Removal Rate (MRR) of ECDM process. It has been observed during experiments applied voltage increases with increase of MRR but inter-electrode gap decreases with increase of MRR. It has also been obtained electrolyte concentration increases up to 250g/l with increase of MRR, beyond that values it decreases. Moreover, some preliminary observations have been investigated during machining of borosilicate glass using Scanning Electron Microscope (SEM).

Keywords— ECDM; EDM; ECM; Borosilicate glass; SEM

I. INTRODUCTION

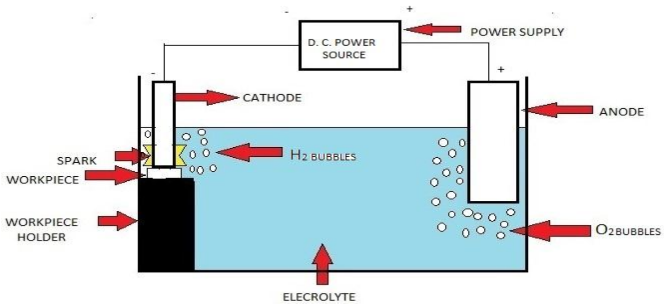
The demand of non conductive engineering ceramic materials such as Aluminum oxide, Zirconium oxide has increase day by day with the major application in mechanical, electrical, optical system or in all mechatronics system. Tinny glasses are widely used due to its unique properties like chemical resistance, transparency, non conductive very tough. Tinny glass has wide industrial applications in scientifically application, jewelry industry, medical appliance, aero space, auto mobiles, and chemical laborites. In today's scenario every organization try to increase machining quality and reduce other parameter like cost so improve the performance and get maximum profitability, so to achieve this a new hybrid process called Electro Chemical discharge machining (ECDM) process used.

ECDM process is best suited for Composite, non conductive, ceramic material, micro channel, micro gear, and also best utilization of process in Jewelry industry, Aeronautical industry and all industries where precision and accuracy required. Several researchers have been studied experimentally and theoretically the ECDM process. Laio et al [1] performed experiment and found that if the current density is increased, and there is more bubble release around the

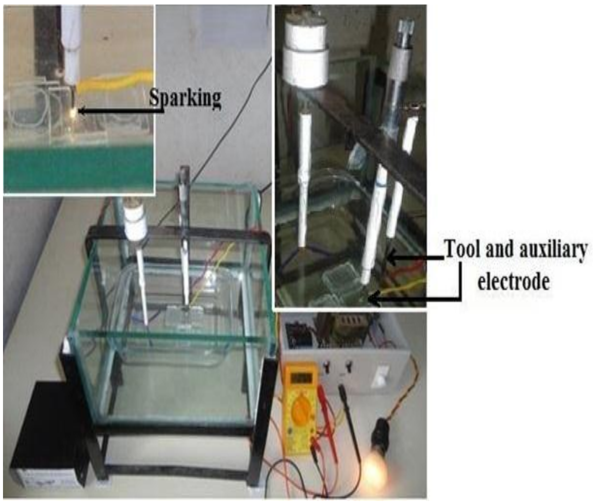
electrode as compared with that when machining in the electrolyte without SDS. **Jawalkar *et al.* [2]** found that the applications of ECDM on soda-lime glass for making shallow holes, using design of experiments, and also discussed applied voltage is the most influencing parameter. **Cheng et *al* .[3]** stated that Electrochemical Discharge Machining (ECDM) is an alternative spark-based micro-machining method for producing micro-holes and micro channels in non-conductive hard and brittle materials. **Xuan et al. [4]** investigated polycrystalline diamond (PCD) tools is used to overcome the rough surfaces that are generated by sparks in ECDM, also found that the grinding process under PCD tools reduces the surface roughness of ECDM structures from a few tens of a μm to 0.05 μm R_a. **K. Nguyen et al [5]** stated that the ECDM characteristics according to machining parameters, such as electrolyte level, electrolyte concentration, pulse voltage, offset pulse voltage, pulse on-time, pulse off-time, and tool feed rate. Based on the investigation of the machining conditions, micro structures, including micro grooves and columns, were machined on quartz material. **K. Shanmukhi et al [6]** developed the mathematical model using RBFNN during micro drilling of ECDM of silicon nitride ceramics work piece of ECDM process. They established the model with Input parameters such as applied voltage, electrolyte concentration and inter-electrode gap, and out put parameters material removal rate (MRR), radial overcut and heat affected zone. and also optimize the process parameter using genetic algorithm (GA) and particle swarm optimization (PSO) methods, finally they validated the experimental result GA-trained RBFNN (GA-RBFNN) and PSO-trained RBFNN (PSO-RBFNN) with the experimental test cases, and observed that PSO-RBFNN is better than GA-RBFNN. Some researchers also investigated that overcut is a major reason for the dimensional deviations, especially during high aspect ratio micromachining in ECDM and is explained with an analytical model and found that effect of concentration on the overcut, some researchers also develop analytical model of the gas film, involving bubble growth and departure on electrode, gas film evolution, and electrolysis characteristics. Experiments were carried out to compare models to the actual discharging phenomenon. High speed camera imaging demonstrated the formation of a gas film on the tool electrode. The range of thickness of gas film found in experiments indicated good consistency with the range of film thickness estimated from analytical models .Experiments on critical voltages and currents further revealed the characteristics of the gas fil The model considers the thermal effects on material removal for ECDM assuming a high-temperature chemical etching mechanism for the material removal. It describes the effect of electrolyte concentration as well as machining time on material removal. **C.Wei et al[8]** on their work develop a finite element based model for ECDM drilling in discharge regime. Material removal subjected to a single spark was simulated using finite element method. The drilling depth evolution in discharge regime was predicted. The model predictions were compared with experimental results for validation. **M. Coteaţa et al [9]** investigated and found that some geometrical considerations which permit to conclude that the material removal rate depends on the characteristics of the motion and on some dimensions of the elements belonging to the crank mechanism. This paper presents analytical modeling of the gas film, involving bubble growth and departure on electrode, gas film evolution, and electrolysis characteristics. Experiments were carried out to compare models to the actual discharging phenomenon. High speed camera imaging demonstrated the formation of a gas film on the tool electrode. The range of thickness of gas film found in experiments indicated good consistency with the range of film thickness estimated from analytical models .Experiments on critical voltages and currents further revealed the characteristics of the gas film in electrochemical reaction. **B. Jiang et al [10]** perform an experiment-based stochastic model for spark energy estimation .Tapered tool electrodes were fabricated by electrochemical machining (ECM) to improve the consistency of spark generation. Energy of sparks was experimentally determined and fit into a two-component mixture log-normal distribution to reveal electrochemical characteristics of tool electrodes. A finite element based model was established to correlate spark energy and the geometry of removed material as electrical energy released by spark generation transfers into thermal energy on the work piece, resulting in material removal due to thermal melting and chemical etching. Lijo Paul et al (11) The effect of process parameters of ECDM on Material Removal Rate (MRR) is studied on borosilicate glass of 0.5mm thickness plate & tungsten carbide tool. Results are obtained as MRR increases with duty factor, concentration of electrolyte and voltage also Tool wear rate is decrease with increase in concentration similarly ROC decreases with increase in voltage, concentration and duty factor.

II. FUNDAMENTAL OF ECDM

In this process of Electro chemical discharge machining (ECDM) two electrodes of different sizes are both dipped in electrolytic solution (NaOH or KOH).These two electrodes are separated by very large inter electrode distance ranging between(20mm-40mm) and constant DC high voltage is applied between them. This results in electro-chemical reactions at the metal electrolytic boundary layers and the transfer of ions in the electrolytic solution takes place. The electrochemical reactions at anode-electrolyte interface and cathode-electrolyte interface causes (i) Dissolution of anode (metal) in electrolyte solution, (ii) Evolution of oxygen gas at anode (larger surface) and (iii) Evolution of Hydrogen gas at cathode (smaller surface).Now as the voltage is increased, the current density, bubble density and their mean radius increases at cathode leading to production of gas film and discharge takes place between cathode and the electrolyte through the gas film which is seen as violent sparking. If a non-conducting work piece is placed within sparking zone then material removal takes place by melting and vaporization. The Key element of ECDM is the gas film built around the tool electrode in which the electrical discharges take place between the tool electrode and electrolyte.



Development of set up



This is a simple tabletop ECDM setup, and has been developed for machining the borosilicate glass work piece. The simple experimental setup is made by using an open type box structure made using acrylic sheet open from one side with a plastic box of appropriate dimensions serving as machining chamber glued inside it at its base connections are made by joining one end of geared DC Motor holding copper tool with cathode terminal of variable DC Power supply and joining one end of graphite rod with anode terminal of variable DC Power supply. The main component for set up are as follows:

DC Power supply

This is the most important component of ECDM apparatus supplying DC Power to the electric circuit setup between Cathode (Tool) and Anode (Graphite rod).It’s output DC voltage can be varied between (0-100V) with the help of a regulator which can be coarse or fine tuned according to requirement and it can take electric load varying between (0-5A).It also consists of Digital LED board to show numerical value of DC voltage at the time of operation and two different colored polarity terminals where red one is positive(Anode) and black one is negative(Cathode).

Cooper clip wires

These two one meter long black and red wires connect the two terminals present on the variable DC Power supply with tool and graphite rod according to the color code.

Variable speed D.C. motor

A small size DC Motor having tool holder at output whose speed can be varied between 0-100 rpm and whose voltage can be varied between 0-12V is used to hold and rotate tool of appropriate size

Variable speed DC controller

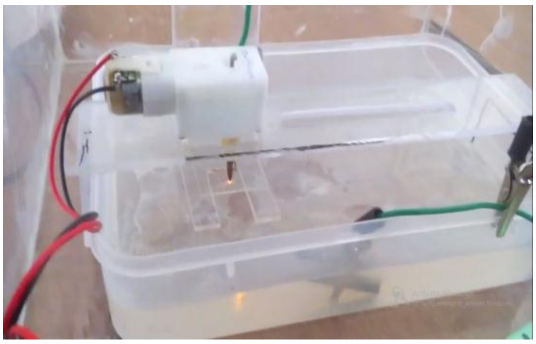
Acrylic Sheet1x1ft five Acrylic sheets are joined together using a special adhesive to make a box type structure open from one end which serves as Frame of apparatus also these acrylic sheets are cut in appropriate shape and size to make work piece holder and DC Motor holder etc.Sodium Hydroxide pellets are mixed with water to make electrolyte solution of required molarity. Borosilicate glasses of dimensions 25x35x2mm is used as work piece for machining

The tool material used is a cylindrical copper rod of diameter 3mm one end of which is grinded to appropriate dimensions (generally very thin) using a grinding machine, it is fixed inside the tool holder of variable speed DC Motor.The anode used is a Graphite rod of 8mm diameter.

Both electrodes are dipped inside electrolyte tank according to specifications and experiments are done with the dipped work piece using high value DC voltage varying between(40-70V) keeping in mind the other factors such as type and concentration of electrolyte used, cathode tool material and MRR required.

Spark Generation

In ECDM cell, electrolysis reactions take place when a DC voltage greater than the threshold value that is needed to produce the discharge. Thus producing hydrogen gas bubbles evolve. These bubbles get accumulated at the cathode tip immersed in electrolyte. Bubble generation goes on increasing, leading to combining of bubbles into a single large bubble which isolates the tip completely from the electrolyte. When an isolating film of hydrogen gas bubble covers the cathode tip portion in the electrolyte, the tip is covered by a gaseous layer. At this time a large dynamic resistance is present and the current through the circuit becomes almost zero. A high electric field in the order of 107 V/m gets generated across the cathode tip and isolated electrolyte causing an arc discharge within the gas layers covering the tip. This causes the local electric field gradient between the tool and the electrolyte interface leading to an arc discharge. At the instant when discharge occurs, a huge number of electrons caused by ionization of gas flow towards anode. Thus a large current spike flows through the highly conducting spark channel for a very short duration of time in of the order of few milliseconds. Violent sparking will be observed to take place if the voltage is increased In ECDM two electrodes of grossly different sizes where anode is the larger one and cathode is the smaller one are dipped in electrolyte solution (Sodium Hydroxide + Water). These two electrodes are separated by very large inter electrode gap and constant high DC voltage is applied between them which results in electro-chemical reactions at the metal electrolytic boundary layers and transfer of ions in the electrolytic solution takes place. The electrochemical reactions at anode-electrolyte interface causes further.



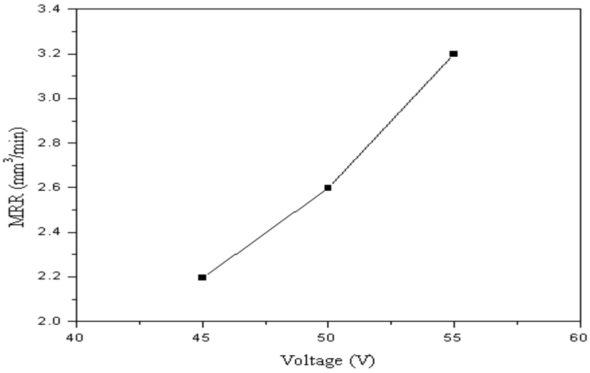
Chemical reaction taking place at anode (graphite rod) electrolyte boundary are as follows

$4(OH)^- \rightarrow 2H_2O + 2O_2\uparrow + 4e^-$ (in NaOH solution)

Chemical reaction taking place at cathode (copper tool) electrolyte boundary are as follows

$Na^+ + e^- \rightarrow Na$ (at copper tool tip)

$2H_2O + 2e^- \rightarrow 2(OH)^- + H_2\uparrow$ (at copper tool tip)



RESULTS AND DISCUSSION:

Experimental Procedures:

A complete tabletop ECDM setup has been developed successfully. Trail experiments have been conducted by varying applied voltage, electrolyte concentration and different workpiece thickness. Initial experiments were performed in borosilicate glass with graphite rod (diameter 8mm, length 55mm) as anode. The size of borosilicate glass as a workpiece was 40mm×35mm×2mm.

Each experiment was tested for about 5 to 10 min, during which applied voltage and current were recorded on a voltmeter and ammeter, respectively. Micrograph of the workpiece after machining has been studied with the help of Scanning Electron Microscope (SEM)

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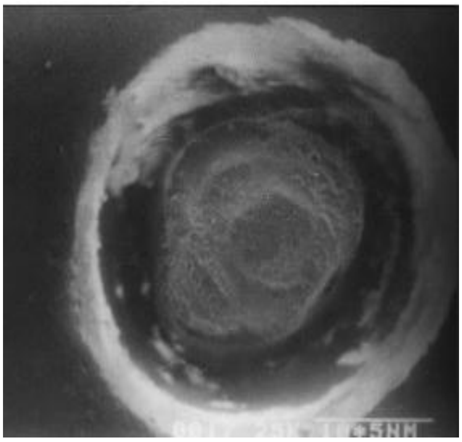


Micro graph of Borosilicateglass

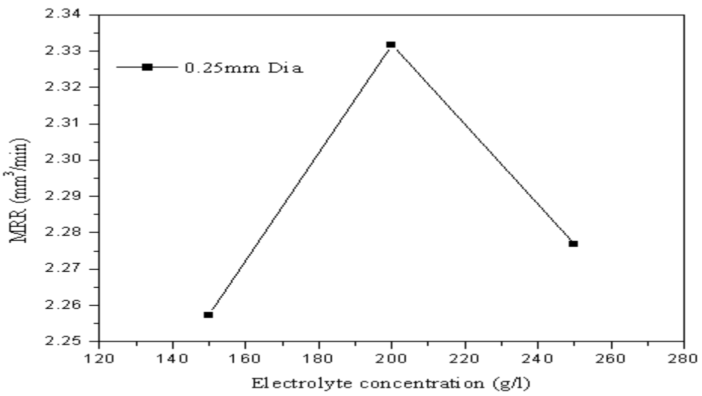
III. RESULT AND DISCUSSIONS

Effect of applied voltage on MRR:

The effect of applied voltage on MRR in ECDM process, by keeping other parameters constant is shown in Fig. 6. It is observed that MRR increases with increase in various applied voltage such as 45V, 50V and 55V. However, with the increase in voltage the electrolysis process is accelerated hence, the rate of generation of hydrogen gas bubbles is increased and consequently the rate of generation of discharge energy increases.

Effect of electrolyte concentration on MRR:

MRR increases with an increase in electrolyte concentration upto 200g/l and then starts decreasing. This is due to the fact that the specific conductance of NaOH solution increases upto 20 percent concentration, beyond which its start decreasing as shown.



Effect of electrolyte concentration on the MRR

An increase in specific conductance means increased electrolyte conductivity and consequently more current. An increase in electrolytic current would mean the accelerated electrolysis process. It would result in a greater rate of evolution of hydrogen gas bubbles at the cathode. The increased rate of formation of gas bubbles at the cathode implies an enhanced rate of sparking and hence higher MRR

CONCLUSIONS

ECDM setup has been developed in house successfully with capability to machine different non-conducting engineering materials such as glass, ceramic, zirconium oxide, composites and silicon nitrides. An extensive experimental study has been conducted to investigate the effect of the machining parameters like applied voltage and electrolyte concentration on machining characteristics such as MRR in ECDM of Borosilicate glass. Moreover, it has been observed during experiments applied voltage increases with increase of MRR and electrolyte concentration increases upto 200g/l with increase of MRR, beyond that values it decreases. Furthermore, some preliminary observations have been investigated during machining of Borosilicate glass using Scanning Electron Microscope (SEM).

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