An Experimental Study of Machining of Glass by Non-Conventional Machining Process

Ravi Gupta and Mahavir Singh

***Abstract*—Electrochemical Discharge Machining is a type of non-conventional machining process which is used to machine non conducting material with high accuracy and zero residual stress. Electrochemical discharge machining has been accepted as a highly modern technology in micromachining. In this research, an effort has been done on micromachining of soda lime glass. The Process Parameters used in this research are Voltage, Electrolyte Concentration, electrode gap and ratio of area of electrode. Taguchi technique has been used to optimize the process parameters. A confirmation Experiment was also carried out to verify the experimental observation. ANOVA analysis has been done to find the contribution of input parameters. Material removal rate has been examined by varying these process parameters at different levels.**

***Keywords*— ECDM, micromachining, MRR, S/N Ratio**

I. Introduction

Electrochemical discharge machining is a non-conventional machining process typically suited for machining of brittle and non-conducting materials. This is a hybrid machining process of EDM and ECM, in which material removal occurs by material dissolution through electro-chemical action and thermal draining away of material through electrical discharge phenomenon.

In this process the machining is done by the combination of these two machining process. Electrochemical discharge machining (ECDM) is considered as hybrid machining method. ECDM is a proven process for micro machining and chemical etching of non-conductive materials, which are difficult to process by conventional and other non-conventional techniques like EDM and/or ECM. ECDM phenomenon, where in the area of the anode was 100 times the area of cathode. The electrodes were immersed in a suitable electrolyte and voltage was provided across the electrodes. As the voltage increased, some hydrogen bubbles at the cathode and oxygen bubbles at the anode started to form. The further increase in voltage increased the density of bubbles and their mean radius and these bubbles coalesced into gas layer.

In ECDM process, the discharge occurs when applied voltage increased beyond the critical voltage (voltage at which discharge begins and is around ~ 28ºC). The discharge occurrence is a complex phenomenon and various researchers has discussed and proposes theory to control discharge in ECDM. The current become zero due to increase in dynamic resistance that we cause by the generation of the hydrogen gas bubbles. The short duration of current produces which make electrons to bombard on the work piece and temperature of work piece increased and temperature can be decreased by the quenching process and hence discharge is shown as a discrete phenomenon.

The principle is explained in the figure 1 below

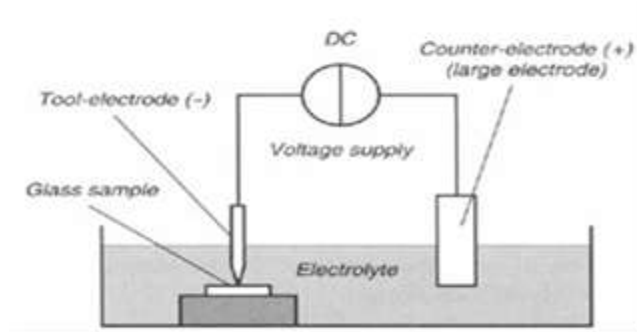

Fig 1-Schematic View of ECDM Process

The work piece is dipped in an appropriate electrolytic solution usually sodium hydroxide or potassium hydroxide. A constant DC voltage is applied between the machining tool or tool-electrode and the counter-electrode. The tool-electrode is dipped a few mm in the electrolytic solution and the counter-electrode is in general a large flat plate. The tool-electrode surface is always significantly smaller than the counter-electrode surface. The tool-electrode is generally polarized as a cathode, but the opposite polarization is also possible. When the cell terminal voltage is lower than a critical value called critical voltage, typically between 20 and 30 V, traditional electrolysis occurs. [1]

Hydrogen gas bubbles are formed at the tool-electrode and oxygen bubbles at the counter-electrode depending on their polarization and the electrolyte used. When the terminal voltage is increased, the current density also increases and more and more bubbles are formed. A bubble layer develops around the electrodes .The density of the bubbles and their mean radius increase with increasing current density. When the terminal voltage is increased above the critical voltage the bubbles coalesce into a gas film around the tool-electrode and produce the discharges between the tool and the surrounding electrolyte.

Machining is possible if the tool-electrode is in the near vicinity of the glass sample. During machining the local

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temperature can increase to such an extent, resulting in heat affected zones or even cracking. The different cathode and anode reaction takes place as soon as an appropriate potential is reached between the inter electrode gap of the machining zone [1]

Reactions at the cathode (or tool)

(i) Plating of metal ions

$$M^+ + e^- \rightarrow M$$

Where M represents any anode material

(ii) Evolution of hydrogen gas.

$$2H_2O + 2e^- \rightarrow 2(OH)^- + H_2\uparrow$$

Reaction at anode (auxiliary electrode)

(i) Dissolution of metal ions in the electrolytic solution

$$M \rightarrow M^+ + e^-$$

(ii) Evolution of oxygen gas at the auxiliary electrode

$$4(OH)^- \rightarrow 2H_2O + O_2 + 4e$$

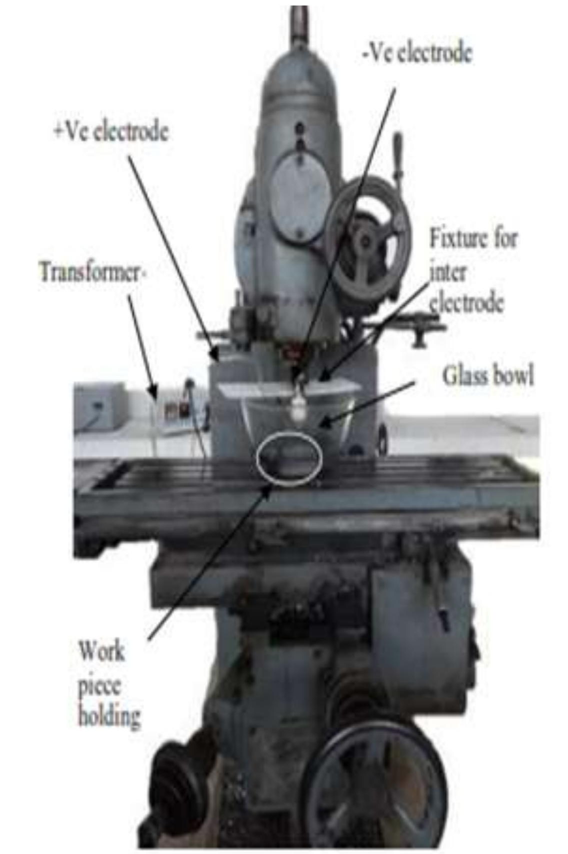

Fig.2: ECDM set-up on vertical milling machine

II. Experimental Setup

In this research, we had studied the effect of various input parameters for making micro-hole in glass using ECDM process. The experimental setup consists of many system and their sub-systems:

A. The machine

Usually it is a table top fabricated machine or a specialized set-up comprising of all the necessary features. It is a vertical milling machine which is fitted with an insulator at the tool-machine interface to prevent the flow of current onto the overall body of machine.

B. The pulsed DC power supply

It is consisting of AC to DC converter and voltage modulator or pulsed modulator. It is a step-down transformer which can module up to 240V. The different parts of the modulator are: The transformer: Comparing with step up transformer, a step down transformer has more number of turns of wire on the primary coil than the secondary coil. This makes the secondary coil to induce smaller voltage. It is known as step down transformer since the output voltage is smaller than the input voltage. If there are half as many turns of wire in the secondary coil, then the output voltage will be half the input voltage.

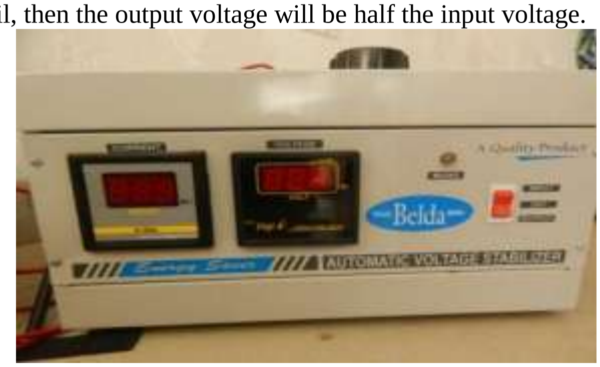

Fig.3.Step-down Transformer

Fig. 4: Ammeter and voltmeter

Decreasing the voltage does not decrease the power. Step down transformers are used to step down high voltages that is from 11000v to 220v or 110v and from 220v or 110v to 10, 12, 20 or 24 volts etc.

C. Dimmer:

The transformer is attached with a dimmer on its top surface. Dimmer plays the primary capability of the transformer. The dimming function on lighting utilizes a transformer to step down the voltage coming in from the mains. For example, if we need to vary a light to 50% of its illumination at 12V, we could rotate the dimmer switch so that 6V are being supplied to the light. This is one of the most common ways that transformers are used in recent days.

D. Voltmeter and ampere-meter

The transformer is having two digital meters. One is ampere meter and the other is voltage meter. The ampere meter shows the reading of current being consumed by the machine and the volt- meter shows the voltage variation of the machining process.

Electrolyte: KOH has been taken as electrolyte for machining. Few properties of the electrolyte are shown below.KOH is also known as Caustic Potassa, Potassa, Potash lye, and Potassium Hydrate.

- It releases maximum HHO than Sodium Hydroxide.
- It helps in lowering the Freezing Point of water.
- It always use for Food grade Quality, not all KOH is the same.

E. Fixture

The fixture is made of many other sub- components like the inter electrode gap control device, borosilicate glass bowl and work piece holding device. The inter electrode gap device is a flat plate having open slots at every 20mm length from the tool position. It allows the positive electrode dipped properly into the electrolyte at desire position. The borosilicate glass bowl act as the container inside of which electrolyte has been kept and work piece holding fixture has been attached inside of it. This gives a strong rigidity to the work piece during machining to prevent from any unnecessary movements. Feed has been given manually to the process at constant rate during machining using feed arrangement attached to the milling machine. Keeping in view the requirements of machining of glass, electric current from DC power supply was applied between the tool and auxiliary electrode.

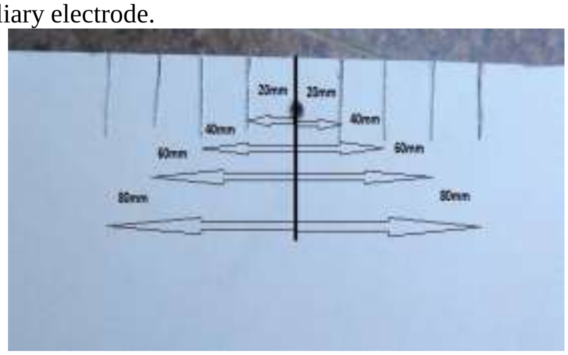

Fig. 5: Fixture for positioning electrode

F. Electrode

There are two electrode used in ECDM. Copper needle is used as cathode or negative electrode and a steel scale is used as anode or positive electrode. ECDM electrodes consists of highly conductive and erosion resistive material such as copper, steel, graphite etc. ECDM electrodes include components made up of brass, copper and copper alloys, graphite, molybdenum, silver, and tungsten. Such material need to have properties that easily allow charge and yet resist the erosion that the ECDM process encourages and stimulates in the non conductor it machines.

The electrodes we have taken here for the experiment are highly conductive in nature and possess less erosion of material during spark generation. Both the electrode has good oxidation at elevated temperature. In the electrode of steel Carbide precipitation can occur in the temperature range 800-1600F.

Fig. 6: Electrodes

If carbide precipitation does occur it must be removed by heating above 1900F. Copper wire is used to connect both the electrode with the power supply, such that no power is lost. The spark generates at the negative electrode after forming bubbles at its tip. The negative electrode is cylindrical shaped, having point cross section at its tip to make ensure easy slotting or drilling on the material surface.

III. Experimental Work

A. Parameter Selection

In this present experimental work the process parameters are taken as voltage with different levels of 25V to 75V, variable concentration of KOH as electrolyte with 30% to

50% by volume inter electrode gap of 40mm to 80mm and ratio of area of electrode with 1:20 to 1:40. The constant process parameters with their value are shown in table I:

Table I- Parameters and their value

Parameters	Value		
Voltage	25V	50V	75V
Concentration of electrolyte	30%	40%	50%
Inter-electrode gap	40mm	60mm	80mm
Ratio of area of electrode	1:20	1:30	1:40
Feed rate	3µm/sec		
work-piece material	Borosil glass		
Auxiliary electrode material	High speed steel		
Electrode-material (tool)	Copper electrode		
Time	5 minute		
Electrolyte temp.	30˚C		

Material removal rate is the main response which has to be taken seriously and has to be analyze carefully. It is defined as the total amount of material removed from the work piece per unit time after undergoing machining process. It is calculated as the difference of initial weight before machining to the final weight after machining of the work piece divided by total time taken to remove that amount of material

$$\textbf{MRR (mg/min)} = \frac{\textit{initial weight} - \textit{final weight}}{\textit{Machining time}}$$

Each Experiment was performed 3 times and the values of MRR were used for study Purpose. Below table are showing the values of Initial and final weight of each glass work piece

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TABLE II- INITIAL AND FINAL WEIGHT

Sr.No.	*Initial weight (mg)*			*Final weight (mg)*		
1	6190	6097	6080	6184.91	6091.99	6074.98
2	6232	6232	6105	6225 15	6225.18	6098.17
3	6105	6266	6144	6097.81	6258.83	6136.86
4	6090	6115	6192	6082.31	6107.25	6184.37
5	6098	6086	6230	6089.25	6077 31	6221.19
6	6234	6107	6107	6222.25	6095.31	6095.32
7	6259	6143	6090	6246.71	6130.68	6077.7
8	6116	6190	6078	6102.02	6176.05	6064.01
9	6082	6233	6105	6067.17	6218.25	6090.19

Experimental Design was prepared using L9 orthogonal array based upon taguchi technique. Total 27 experiments were performed. The experimental results are shown in table 3

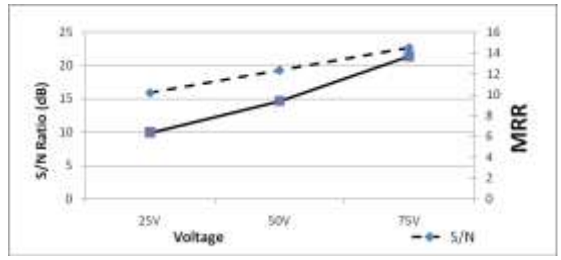
TABLE III- EXPERIMENTAL DESIGN

Voltage	Conc.	Gap	Ratio of area	MRR			S/N Ratio
				R1	R2	R3	
25V	30 %	40mm	1:20	1.018	1.002	1.004	0.068
25V	40 %	60mm	1:30	1.002	1.364	1.366	2.713
25V	50 %	80mm	1:40	1.004	1.434	1.428	3.126
50V	30 %	60mm	1:40	1.37	1.55	1.526	3.738
50V	40 %	80mm	1:20	1.364	1.738	1.762	4.860
50V	50 %	40mm	1:30	1.366	2.338	2.336	7.389
75V	30 %	80mm	1:30	1.438	2.464	2.46	7.821
75V	40 %	60mm	1:40	1.434	2.79	2.798	8.926
75V	50 %	40mm	1:20	1.428	2.95	2.962	9.423

IV. DISCUSSION

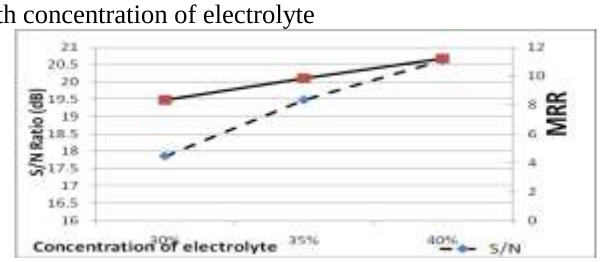
A. Effect of voltage on MRR

When the voltage increased, current starts flowing more rapidly along the circuit. This made the electrons gathered in more number near the tip of electrode in lesser time. As a result spark generated continuously and more rapidly, such that material started removing from the work piece. If we increase more voltage, it will generate more sparks per unit time and material will remove more quickly. It is done due to availability of increased energy that ionizes the gaseous layer at the cathode causing sparking



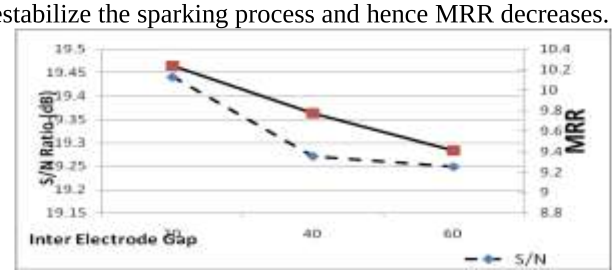
B. Effect of concentration of electrolyte on MRR

On increasing concentration of electrolyte, number of OH ion increased. As a result more hydrogen bubbles formed at the tip of cupper electrode. When this hydrogen bubbles splitted, spark generated. In other words increasing concentration of electrolyte, spark increased and MRR increased. MRR varies with concentration of electrolyte



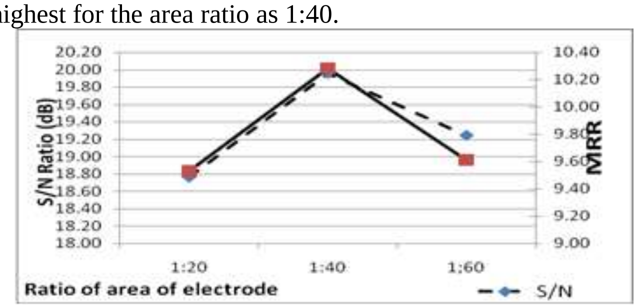
C. Effect of inter-electrode gap on MRR:

Form the graph; it can be notice that as the gap between cathode electrode and anode electrode increased beyond a certain value, the MRR starts decreasing. At 20mm, the evolved gases tend to stabilize the sparking process but at higher gap it will destabilize the sparking process and hence MRR decreases.



D. Effect of ratio of area of electrode on MRR

It can be observed from graph that as ratio of area of electrode increases i.e. area of cathode to area of anode ratio; MRR increases up to a certain value and then decreases. MRR is highest for the area ratio as 1:40.



V. ANALYSIS

To study the significance of the parameters, ANOVA is performed. The experimental design according to larger the better which preferred to maximize the result, and the ideal target value is infinity. To study the significance of the parameters, ANOVA was performed. It was noted that % contribution of Voltage was highest (83.17) followed by concentration of electrolyte (14.13) and inter electrode gap (2.615).

TABLE IV. ANOVA DATA

Parameter	SS	DOF	V	P	F-Ratio
V	9.8066	2	4.9033	84.9130	79945.42
C	1.4929	2	0.7464	12.9271	12170.877
G	0.1256	2	0.0628	1.0875	1023.913
R	0.12	2	0.061	1.06	1000.57
Error	0.00	18	0.000	0.01	
Total	11.5490	26		100.0000	

SS-sum of square, DOF-degree of freedom, V- variance

VI. CONCLUSIONS

From this experimental research few points were noticed:

1. It is easy to obtain micro-hole by proper optimization of process parameters.
2. Different electrolytes and its temperature can be used for better results.
3. Drilling time can be reduced by increasing voltage and concentration of electrolytes.
4. The percentage contribution of voltage is highest, that is concentration of electrolyte, inter-electrode gap and ratio of area of electrode respectively.
5. In this research paper 120mm hole was obtained at V2C2 G1 R2. It was noticed that at higher voltage MRR increases.again.

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