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An Experimental Investigation Of Effect Of Electrolyte Solution On Material Removal Rate In ECDM

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ABSTRACT

Electrochemical Discharge Machining (ECDM) has been demonstrated to be an alternative spark-based micromachining method for fabricating micro-holes and micro-channels in non-conductive brittle materials. In this paper attempts experiments on ECDM have been carried out according to designed experimental plan based on standard orthogonal array (L_9) to identify the effect of electrolyte solution on material removal rate. In controlling the machining performance, such as material removal rate the signal-to-noise (S/N) ratio is performed to find the relative contributions of the main machining parameters, such as applied voltage, electrolyte concentration and inter-electrode gap. The non-conducting and highly brittle Soda lime Glass is used as a work-piece material and aqueous KOH and NaCl is used as electrolyte solution.

1. INTRODUCTION

Electrochemical discharge machining (ECDM) is a hybrid non-conventional manufacturing process which combines the features of electrochemical machining (ECM) and electro discharge machining (EDM). It can be successfully used for machining electrically non-conductive advanced engineering materials such as glass and ceramics has shown the possibility of drilling micro- holes by smaller electrodes efficiently and economically. It has been found that the advanced materials are difficult to machine by the conventional machining processes. It is no longer possible to produce parts with better surface finish, close tolerances and complex shapes in advanced materials by conventional machining methods. So far, it is still necessary to provide more study for machining of non-conductive brittle materials since they have become key materials in the MEMS field. For example, the glass or quartz is usually bonded with the semi-conductive material due to their transparency, chemical-resistant properties and so on. Likewise, the engineering ceramic is also used often in the high-tech apparatus [9].

The performance of ECDM, in terms of Material removal rate and rate of machining, is affected by many factors. Relationships between these factors and machining performance are highly non-linear and complex in nature Therefore, it is very difficult to develop a relationship between those factors and the machining performance with conventional mathematical modelling. In this study the performance characteristic such as MRR has been studied using KOH and NaOH as an electrolyte solution [2].

2. PRINCIPLE OF ECDM

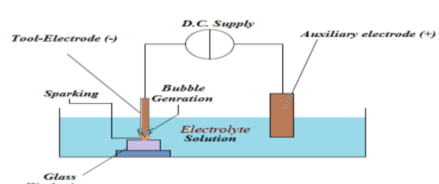

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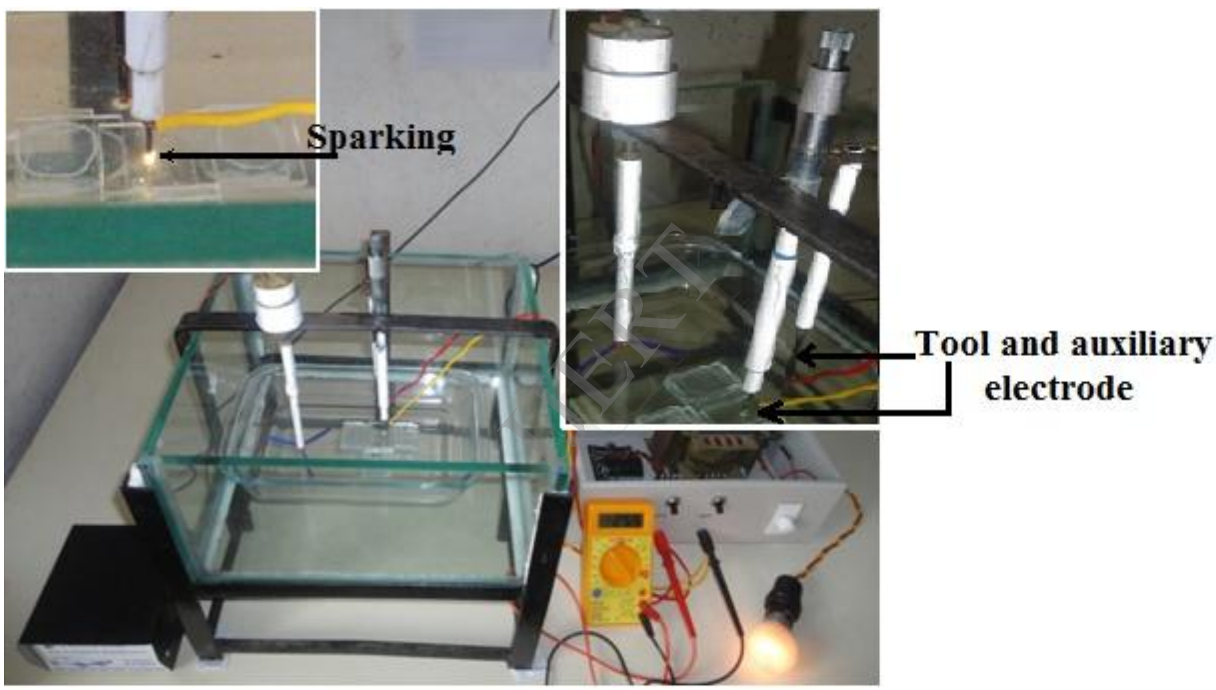
Fig 2.1: Principle of ECDM process

The electrochemical discharge phenomenon is clearly demonstrated by the following simple experience. Two electrodes are dipped inside an aqueous electrolyte. The cathode is chosen with a much smaller surface than the anode. When the D.C. voltage is applied electrolysis happens and Hydrogen gas bubbles are formed at the tool-electrode (cathode) and oxygen bubbles at the counter electrode (anode). When the voltage is increased, the current density increases too and more and more bubbles grow forming a bubble layer around the electrodes. When the voltage is increased above the critical voltage, bubbles coalesce into a gas film around the tool-electrode. Sparking phenomena is observed in the film where electrical discharges happen between the tool-electrode and the surrounding electrolyte. Similar behavior can be obtained by inverting the polarity of the electrodes and by changing the electrolytes. Fig 2.1 explains the ECDM phenomenon [5].

3. EXPERIMENTAL SETUP



3.1 Photograph of the experimental set-up.

A screw gauge micrometer is used as a screw feed mechanism which is employed to dip the tool in the electrolyte with controlled depth. A glass beaker is used as the electrolyte bath. The work-piece is 30mm$\times$ 30mm with 3 mm thickness soda lime glass. Stirrer is used to maintain uniform temperature and circulation of electrolyte solution. Geared D.C. motor used for the rotation of Stirrer. At the cathode, sparking occurs at supply voltage of 40 V and above. Glass samples crack above 70 V supply voltage. Hence the working supply voltage range chosen is 40V to 60V. The concentration window was decided upon by performing many experiments to arrive at a permissible concentration range. It was observed that machining does not take place below 10% concentration of KOH. Hence 10% - 30% concentration ranges for KOH electrolyte. Level of electrolyte is maintained at 1 mm above the work piece surface in the ECDM cell. Experiments are conducted with Voltage, Electrolyte

Concentration and Inter-electrode gap as the control variables. Copper is used for making the cathode of 1mm thick wire and anode of 3mm thick wire. Figure 3.1 shows the photograph of the experimental set-up. The depth of anode inside the electrolyte is also maintained at a fixed position.

3.1. MACHINING CONDITIONS

Following machining parameters are selected on the basis of performance characteristics,

Table 3.1: Machining condition for analysis

Machining condition	Specification
Constant parameter	
Tool-electrode material	Copper
Auxiliary electrode material	Copper
Level of electrolyte	1mm above the w/p
Work-piece material	Soda-lime Glass
Machining time	30 min
Gap between tool-electrode and work-piece	25 µm
Variable parameter	
Applied voltage	40V - 60V
Inter-electrode gap	20mm - 40mm
Electrolyte concentration	20% - 40%

3.2. SELECTION OF MACHINING PROCESS PARAMETERS

Table 3.2 shows machining parameters and selected levels for experimental procedure

Table 3.2: Process parameter and their levels

Symbol	Machining parameter	Level 1	Level 2	Level 3
A	Applied voltage (V)	40	50	60
B	Electrolyte concentration (%)	10	20	30
C	Inter-electrode Gap (mm)	20	30	40

Table 3.3: Composition of Soda lime glass

Element	SiO_2	Na_2O	CaO	Al_2O_3	K_2O	SO_3
Wt.%	74%	13%	10.5%	1.3%	0.3%	0.2%

3.3. Larger is best characteristics

Data sequence for material removal rate, which is higher-the-better performance characteristics, is pre processed as per equation (3.1).

$$\frac{S}{N} = -10\left(\frac{1}{n}\right)\left(\sum\left(\frac{1}{y^2}\right)\right) \text{ ------ (eq. 3.1)}$$

Where, '*y*' is value of response variables and '*n*' is the number of observations in the experiments. Table shows the experimental results for MRR and the corresponding S/N ratio using eq. (3.1). Since the experimental design is orthogonal, it is possible to sort out the effect of each machining parameter at different levels.

3.4. Measurement of Machining Performance

Experiments were conducted as per designed experimental plan and the performance or responses were measured for each experimental run. The amount of metal removed (MR) was measured by taking difference in weight of the specimen before machining weight (W_1) and after machining weight (W_2) The MRR can be evaluated as;

$$\frac{\textbf{MRR}}{\textbf{T}} \textbf{ or } \frac{(\textbf{W}_1 - \textbf{W}_2)}{\textbf{T}}$$

Where, T-Machining time
W_1 -Before machining weight
W_2 - After machining weight

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3.4. EXPERIMENTAL PROCEDURE

The design resulted in total of eighteen experiments, which are performed at 40V-60V supply voltage, 10%-30% electrolyte concentration and 20mm-40mm inter-electrode gap as the values for the control variables. The responses measured are:

- Material removal rate (MRR)

Scheme of the experiments is as shown in Table 3.3

Table 3.3: Experimental L9 orthogonal Array

Expt. no	Applied voltage (V)	Electrolyte Concentration (%)	Inter-electrode Gap (mm)	For KOH		For NaCl	
	A	B	C	MRR (mg/min)	S/N Ratio	MRR (mg/min)	S/N Ratio
1	40	10	20	0.9400	-0.53744	0.9312	-0.61914
2	40	20	30	1.0295	0.25253	1.0007	0.00608
3	40	30	40	1.3082	2.33348	1.1694	1.35926
4	50	10	30	1.1132	0.93146	1.1044	0.86253
5	50	20	40	1.0122	0.10533	1.0034	0.02948
6	50	30	20	2.1202	6.52754	2.0914	6.40874
7	60	10	40	1.4965	3.50153	1.4877	3.45031
8	60	20	20	2.3265	7.33406	2.1177	6.51729
9	60	30	30	2.0953	6.42492	2.0165	6.09196

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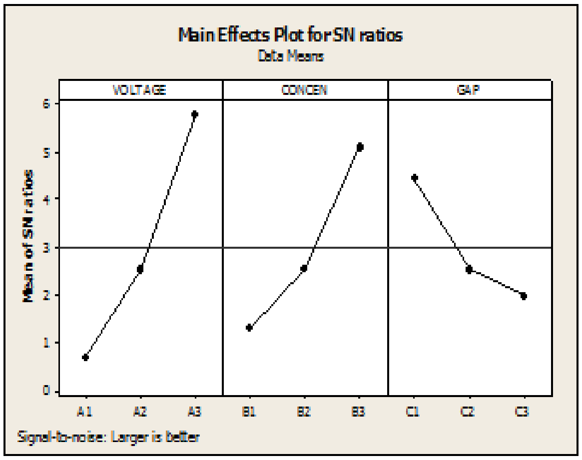
4. RESULTS AND DISCUSSION

4.1. Case I (Electrolyte solution - KOH, Work-piece – Soda lime glass)

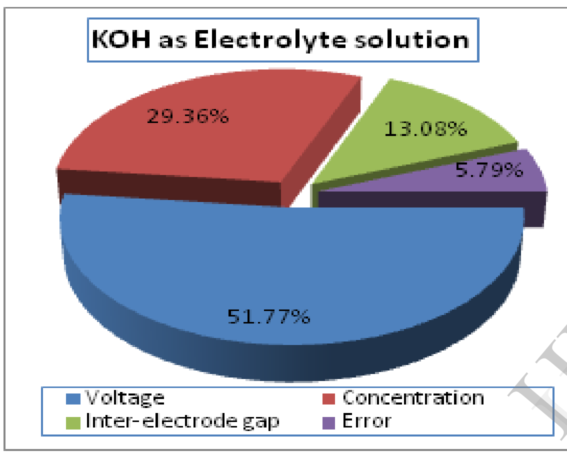
Table 4.1: ANOVA for Material Removal Rate (KOH as electrolyte)

Source	DF	Sum of squares	Mean of squares	F ratio	P value	Contribution
Voltage(A)	2	39.538	19.769	8.96	0.100	51.77%
Electrolyte concentration (B)	2	22.425	11.212	5.08	0.164	29.36%
Inter-electrode gap (C)	2	9.997	4.998	2.27	0.306	13.08
Error	2	4.412	2.206			5.79%
Total	8	76.372				100%
S = 1.485 R-Sq = 94.2% R-Sq(adj) = 76.9%						

From the main effect plot refer Figure 4.1 it can be seen that, as the value of voltage increases (from 50 v to 60 v), the material removal rate increases for the KOH electrolyte solution. This is due to at higher voltage stronger spark is generated so melting starts at earlier, Hence, as the voltage increases the material removal rate is increases due to increasing spark energy. Secondarily, concentration gives high MRR. This is due to higher ionization and deionization which causes high erosion and thermal discharging. Whereas, this range concentration helps to continue the bubble generation and spark produced during the machining process.



Graph4.1:Main Effects Plot for SN ratios (KOH)



Graph4.2:Contribution of process parameters

The regression analysis for MRR of Electrolyte solution using Minitab 15 software is shown in equation (4.1)

$$MRR = -0.580 + 0.0440\,A + 0.0329\,B - 0.0262\,C \quad \text{------- (4.1)}$$

The equation (4.1) shows that voltage is dominant factor affecting MRR.

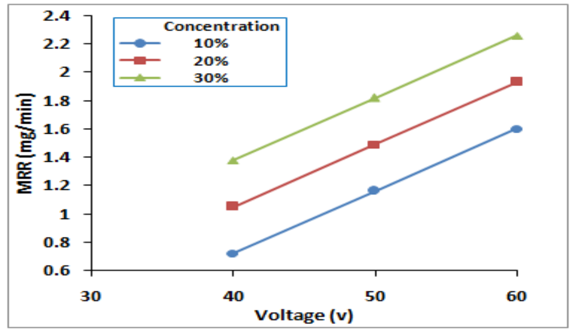


Fig (a)

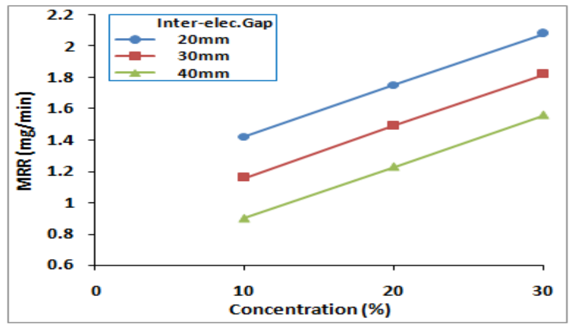
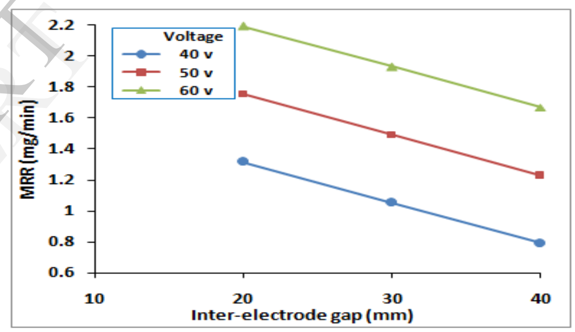


Fig (b)



Fig(c)

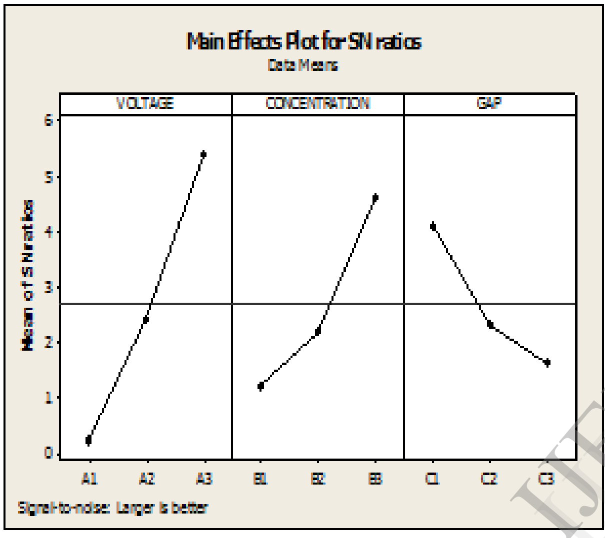
Graph 4.3. Effects of process variables on material removal rate (MRR). (a) Effects of Voltage on material removal for different Concentration, Inter-electrode Gap= 30mm. (b) Effects of Concentration on material removal for different inter-electrode gap, Voltage= 50v. (c) Effects of Inter-electrode gap on material removal for different Voltages, Concentration= 20%

As KOH is strong base the ion mobility of this electrolyte much higher than the other electrolyte solution. Our work-piece is a soda lime glass containing the 74 % Silicate which is higher than the other constituent such as Na_2O (13%) and K_2O (0.3%) so these three constituent are more chemically reactive with the electrolyte solution Causing the higher material removal rate.

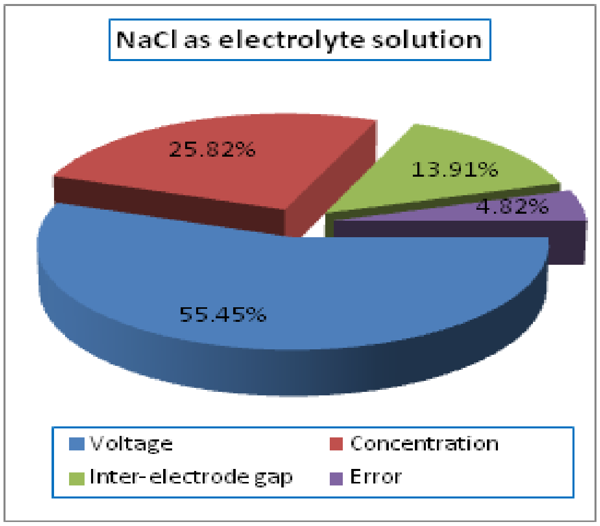
4.2: Case: II (Electrolyte solution-NaCl, Work-piece – Soda lime glass)

Table 4.2: ANOVA for Material Removal Rate (NaCl as electrolyte)

Source	DF	Sum of squares	Mean of squares	F ratio	P value	Contribution
Voltage (A)	2	39.353	19.677	11.51	0.080	55.45%
Electrolyte concentration (B)	2	18.325	9.162	5.36	0.157	25.82%
Inter-electrode gap (C)	2	9.873	4.936	2.89	0.257	13.91%
Error	2	3.420	1.710			4.82%
Total	8	70.970				100%
S =1.308 R-Sq =95.2% R-Sq(adj) = 80.7%						



Graph 4.4:Main Effects Plot for SN ratios



Graph 4.5:Contribution of process parameters

Fig.4.4 Shows the MRR increases with increasing in voltage and electrolyte concentration also improved MRR is obtained with decreased inter-electrode gap. The increase in machining voltage causes a greater machining current in the electrode gap, thereby causing the enhancement of the MRR.

From the table (4.2) and fig. 4.5 as shown above following results are drawn for NaCl, are salt of strong acid and strong base hence slightly reaction takes place with soda lime glass .when NaOH and HCl are mixed together a reverse chemical reaction takes place which result in formation of NaCl and water separates out. When NaCl is mixed with water Na^+ and Cl^- ions are formed.

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The regression analysis for MRR of Electrolyte solution using Minitab 15 software is shown in equation (4.2)

MRR = - 0.509 + 0.0420 A + 0.0292 B - 0.0247 C ----- (4.2)

The equation (4.2) shows that voltage is dominant factor affecting MRR.

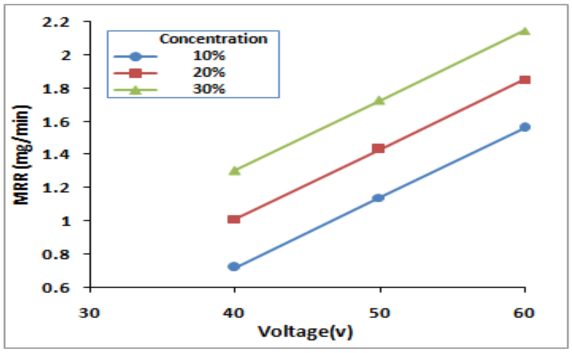


Fig (a)

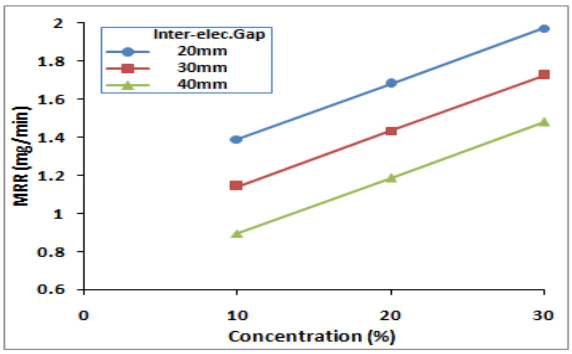
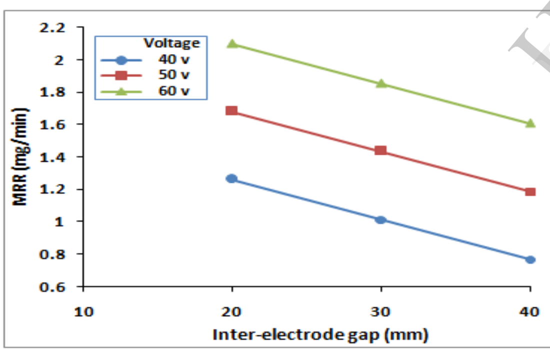


Fig (b)



Fig(c)

Graph 4.6: Effects of process variables on material removal rate (MRR). (a) Effects of Voltage on material removal for different Concentration, Inter-electrode Gap= 30mm. (b) Effects of Concentration on material removal for different inter-electrode gap, Voltage= 50v. (c) Effects of Inter-electrode gap on material removal for different Voltages, Concentration= 20%

Above graph show interrelation of trends like MRR, voltage, concentration, gap. There is an increased trend in MRR observe at a voltage of 60v and concentration 30% while decrease in MRR is observed at an inter-electrode gap of 40mm. As compared to KOH material removal rate for NaCl is less.

5. CONCLUSION

Present work is performed for material removal in drilled holes by ECDM process. The experiments were performed by using Taguchi method of design of experiments. Analysis was carried out using Minitab15 software. The preliminary experiments were performed on Soda lime glass as work material using KOH, for only one response variables such as MRR. Three process parameters were selected such as applied voltage, Electrolyte concentration, and Inter electrode gap from the Final experiments, it is concluded that:

- A new test rig is designed developed for ECDM for non conducting ceramic material.
- Applied voltage is found to be most influential parameter for MRR.
- Electrolyte concentration is a secondary fact of concern affecting the material removal rate.
- From the design, development and analysis we conclude that for non conducting ceramic materials in this case soda lime glass KOH is the best electrolyte solution having much better removal rate than the other proposed electrolyte solutions.

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