A Study of Response Parameters during ECDM on Quartz Material

S G Dileepkumar1, K N Bharath2, B C Naveen3 and Anil kumar4

1,2,4 Department of Mechanical Engineering, GM Institute of Technology, Davanagere, Karnataka - 577006, India.
3 Department of Industrial & Production Engineering, UBDTCE, Davanagere, Karnataka - 577004, India.
*Corresponding email: dileepsmk404@gmail.com

Abstract. Electrochemical discharge machining (ECDM) is a hybrid machining process that combines the possible characteristics of Electro Discharge Machining (EDM) and Electrochemical Machining (ECM) machining. In the present work, Quartz is used as work piece material and potassium hydroxide (KOH) as an electrolytic medium. Experiments were carried out by considering the three factors at three different levels. The input variables are Voltage, Electrolyte Concentration (EC) and Inter-Electrode Gap (IEG). The experimental response variable is Material Removal Rate (MRR). The process variables were analyzed and optimized using ANOVA from the Minitab 14 statistical tool. The response parameters are predicted by using Artificial Neural Network (ANN) and linear regression equation was generated to predict the experimental values. The results reveal that, voltage and electrolyte concentration have approximately equal percentage of contribution in achieving maximum MRR.

1. Introduction
To remove excess material from very hard and delicate materials, non-conventional machining methods are taking advantage of now a few days. Electric Discharge Machining (EDM) and Electro Chemical Machining (ECM) have been introduced to meet the needs of manufacturing industries to machine advanced materials with electrical conductivity properties. This can be used effectively for machining electrically non-conductive advanced engineering materials such as glass and ceramics has shown the possibility of efficiently and cost-effectively drilling micro-holes through smaller electrodes [1]. Hybrid machining means two or more machining processes are combined to maximize the capacities of the machining processes and take advantage of the efficiency of the constituent processes [2]. Hybrid machining method incorporates the features of many traditional as well as non-conventional machining processes that lead to achieving superior machining capabilities, i.e. combining the advantages of different processes. The ECDM is a mechanism which involves a combination of the electrochemical reaction and the electro discharge action. Due to the breakdown of the insulating layer of gas bubbles when the DC power is supplied between the cathode and the anode, the electrical discharge occurs between the tool and the work piece, resulting in material removal owing to melting, vaporization of the work piece material and mechanical erosion [3]. The machining is partly a chemical process and thus the nature of the electrolyte strongly influences the machining behavior. It seems that Sodium hydroxide (NaOH) electrolyte has the most fascinating properties relative to other electrolytes but molten salt electrolytes (eutectic of melting of NaOH and KOH at 170°C) will significantly enhance the smoothness of the machined surface [4]. Due to better flushing action in machining area, the low viscosity of KOH electrolyte yields high MRR. The other electrolytes, such as H2SO4, NaCl, and
NaClO₃ are less flexible due to harmful gas production and poor MRR [5]. Several researchers have studied various parametric optimization of ECDM process. Sathish N et al. discussed the influence of process variables namely electrolyte concentration, voltage and stand-off distance on MRR and tool wear rate. Experiments were done on the soda lime glass and the plan of experiment was according to the Taguchi technique. Taguchi method was utilized to optimize the response parameters. Analysis of variance was employed to determine the significance of input parameters on tool wear rate and MRR [6]. Harugade et al. reported on the effect of various electrolytes on MRR in ECDM processes was discussed. From the results it is noted that the voltage applied is important parameter affecting MRR and that the removal rate of KOH electrolyte is better compared to other solutions proposed [1]. Laio et al. made attempt to improve the quality of drilling by adding the surfactants to the electrolyte in ECDM process. Adding of surfactants to solution improves the current density and more stable bubbles are formed around the cathode electrode [7]. Liu proposed model of ECDM to analyze the influence of discharge mechanism on reinforced metal matrix composites. A set of experiments were carried out to validate the model and experimental outcome shows that the occurrence of arcing action increases with increase in the, duty cycle and current concentration of electrolyte [8]. Bhondwe et al. developed thermal model based on FEM with experimental results, in the range of accuracy. The parametric tests are also carried out for various parameters such as Concentration of the electrolytes, duty factor and partition of the electricity. The increase in MRR is found to increase with electrolyte increase concentration of soda lime glass working component material due to Electro- chemical Spark Machining (ECSM) [9]. The advanced engineering materials with high specific strength, heat-resistant capacity and high corrosion resistance have seen a rapid increase in demand in recent years. The advanced materials include glass (quartz), ceramics, silicon nitride, etc. The machining of quartz glass is very difficult by using conventional method because of its high hardness, brittle and non-conductive properties. Quartz glass is a pure form of silica with more than 99.9 % SiO₂ content. Because of this it has superior working properties such as high hardness, resistance to degradation, stability under atomic bombardment and improved optical transmission than other glass materials. The ECDM has been identified as an effective method for processing of this type of materials [10,11]. In this work an attempt has been made to develop an experimental set up for ECDM and optimize the response variable MRR.

2. Experimentation

2.1 Experimental Setup
Experimental setup of ECDM as shown in ‘Figure 1’, it consists of a container, cathode (tool), anode (auxiliary anode), DC power supply and tool monitoring unit. Work piece is positioned on the table and it is inflexibly secured on the work table. Work table is attached to the container. The container is made up of soda lime glass and it is having the dimension of 8”×8”×6”.

![Figure 1. Schematic Diagram of Electrochemical Discharge Machining](image)

2.1 Experimental Details

| Table 1. The experimental details of ECDM |
|------------------------------------------|
| Electrolyte concentration | Voltage | Stand-off distance | MRR |
|---------------------------|---------|--------------------|-----|
| 1 Molar KOH | 150 V | 5 mm | 0.005 mm/rev |
| 2 Molar KOH | 170 V | 8 mm | 0.008 mm/rev |
| 3 Molar KOH | 190 V | 10 mm | 0.012 mm/rev |
### Non-variable parameters

| Sl. No. | Description                                      |
|---------|--------------------------------------------------|
| 1       | Work piece material: Quartz (25 mm x 25 mm x 10 mm) |
| 2       | Work piece thickness: 1 mm                       |
| 3       | Cathode tool: Stainless steel wire of 1 mm diameter |
| 4       | Auxiliary anode: Stainless steel plate (100 mm x 50 mm x 10 mm) |
| 5       | Electrolyte: Potassium hydroxide (KOH)           |
| 6       | Stand-off distance: 0.03 mm                      |
| 7       | Time: 20 Min.                                    |

### Variable parameters

| Sl. No. | Description                                      |
|---------|--------------------------------------------------|
| 8       | Voltage: 50V, 60V and 70V                       |
| 9       | Electrolyte concentration: 10%, 15% and 20%     |
| 10      | Inter-electrode gap: 20 mm, 30 mm and 40 mm     |

## 2.2 Mechanism of Metal Removal and Spark Generation

The ECDM process consists of a complex bubble are normally formed by hydrogen bubbles. Due to the failure of the non-conductive layer of gas bubbles, the electrical discharge takes place between the tool and work piece. The mechanical erosion and material removal results in the melting and vaporization of the work piece material as the DC power supply voltage is applied between the cathode and the anode. Because of the electrochemical reaction the positively charged ionic gas.

## 3. Results and Discussions

The experimental work on Quartz was carried out with three parameters and three stages of inputs. Experiments were performed using a well-designed series of experiments using Taguchi based DOE technique. Whereas it has been used for three stages and three L9 OA variables consisting of nine trials. The effect of process parameters such as voltage, electrolyte concentration and IEG on material removal rate (MRR) and will be evaluated in order to obtain the finest machining conditions for achieving higher MRR. $W_1 =$ Initial Weight (mg), $W_2 =$ Final Weight (mg).

\[
MRR = \frac{(W_1 - W_2)}{t} \text{ mg/min}
\]

### Table 2. Experimental results of ECDM

| Trial no. | Voltage (volts) | Electrolyte Concentration (%) | IEG (mm) | MRR (mg/min) |
|-----------|-----------------|-------------------------------|----------|--------------|
| 1         | 50              | 10                            | 20       | 0.0591       |
| 2         | 50              | 15                            | 30       | 0.1178       |
| 3         | 50              | 20                            | 40       | 0.1332       |
| 4         | 60              | 10                            | 30       | 0.1243       |
| 5         | 60              | 15                            | 40       | 0.1342       |
| 6         | 60              | 20                            | 20       | 0.1857       |
| 7         | 70              | 10                            | 40       | 0.1296       |
| 8         | 70              | 15                            | 20       | 0.2113       |
| 9         | 70              | 20                            | 30       | 0.2321       |

Analysis of variance is performed to oversee which machining parameter has more essential impact on the quality characteristics of ECDM process furthermore to figure out contribution of machining parameter. From the table 3 it is found that, the probability of the parameter is less than 0.05 and the percentage contribution of voltage is 46.9% which are more than IEG (45.2%) and electrolyte concentration (19.9%). Hence voltage is more significant factor and other parameters such as inter-electrode gap and electrolyte concentration have less implication.
Table 3. Analysis of variance (ANOVA)

| Source     | DF | Seq SS   | Adj SS   | Adj MS   | F      | P   | % of Contribution |
|------------|----|----------|----------|----------|--------|-----|-------------------|
| Voltage    | 2  | 0.010789 | 0.010789 | 0.005394 | 25.24  | 0.038 | 46.9              |
| Electrolyte Conc. | 2  | 0.010417 | 0.010417 | 0.005208 | 24.37  | 0.039 | 45.2              |
| IEG        | 2  | 0.001364 | 0.001364 | 0.000682 | 3.19   | 0.239 | 5.93              |
| Error      | 2  | 0.000427 | 0.000427 | 0.000214 |        |      | 1.97              |
| Total      | 8  | 0.022997 |          |          |        |      |                   |

S=1.615     R-Sq= 94.7 %     R-Sq (Adj)= 80 %

Figure 2. Main Effects Plot for S/N ratios on MRR

Main Effects Plot for S/N ratios on MRR as shown in ‘Figure 2’. Material removal rate increases with increase in the voltage applied and electrolyte temperature [4]. Increase in supply voltage, rate of material removal and machined depth increases. Applied voltage increases the current intensity, hence higher material removal from higher sparks [12]. It is observed that mean value is higher for voltage compared to that of electrolyte concentration and IEG. The MRR is maximum at high frequency and high applied voltage, produces high intensity sparks. Higher level of electrolyte concentration accelerates the rate of production of gas bubbles, which in turn increases the frequency of discharge due to the accelerated forming of films around the electrode; it also facilitates chemical etching [13]. Hence it can be stated that voltage is the primary factor that impacts the MRR followed by electrolyte concentration and IEG. Also it is seen from the graph that 70V, 20% and 30 mm are the optimal combinations of Voltage, Electrolyte Concentration and IEG in achieving higher MRR.

A scientific mathematical statement has been produced by utilizing statistical tool MINITAB 14 to acquire the relationship between the material removal rate and the different input variables such as, Voltage, Electrolyte concentration and IEG. Regression analysis was performed taking into account trial results and estimations of regression coefficients are evolved. The equation for MRR of quartz is
stated as,

\[ MRR = -0.205 + 0.00438(V) + 0.00793(EC) - 0.000985(IEG) \]  

(2)

Experimental MRR value for any given values of input variables like voltage, Concentration and Inter-Electrode Gap can be predicted by using above equation. The equation is used to calculate the error. It is found that the experimental readings and predicted readings have a very lesser amount of deviation. The comparison of experimental MRR and anticipated MRR are outlined in table 4

**Table 4. Comparison of Experimental MRR values with ANN Predicted MRR**

| Trail no. | Experimental MRR (mg/min) | Predicted MRR (mg/min) | Error |
|-----------|--------------------------|------------------------|-------|
| 1         | 0.0591                   | 0.0736                 | -0.2453 |
| 2         | 0.1178                   | 0.1034                 | 0.1222 |
| 3         | 0.1332                   | 0.1332                 | 0     |
| 4         | 0.1243                   | 0.1174                 | 0.0555 |
| 5         | 0.1342                   | 0.1472                 | -0.0968 |
| 6         | 0.1857                   | 0.117                  | 0.3699 |
| 7         | 0.1296                   | 0.1174                 | 0.0941 |
| 8         | 0.2113                   | 0.1472                 | 0.3033 |
| 9         | 0.2321                   | 0.177                  | 0.2373 |

**Figure 3. Plot for Experimental MRR and ANN Predicted MRR**

The evaluation between of experimental MRR and predicted MRR are illustrated in Table 4. It is observed that the values obtained by using regression model are slightly diverged from the experimental values with an average error of 0.093. The correlation between the experimental MRR and the predicted MRR as shown in ‘Figure 3’. It is observed that less variance occurs between the experimental and predicted values.

**4. Conclusion**

Experimental set up of ECDM is developed and experiments were conducted on Quartz using KOH electrolyte. The experiments were carried out using L9 orthogonal array. Finally, the prediction of the response parameters was done using regression analysis. Following conclusions were made

- Combination of 70V, 20% EC and 20mm IEG achieved a higher MRR. The shows the best combination.
From ANOVA, voltage has the highest percentage of contribution to achieving higher MRR.
- The comparison between experimental result and ANN Predicted result are slightly deviated from the experimental result.
- Further work on ECDM is carried out to study the process variables such as tool-wear and surface roughness on quartz material by employing various electrolytes.
- Different materials can be drilled and slots can be produced by using the setup with automated feeding mechanisms

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