

## Optimization of electrochemical spark machining process by using taguchi method

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### Abstract

Electrochemical Spark Machining (ECSM) process is an emerging potential technology used for machining conducting as well as non-conducting materials. In this paper an attempt has made to optimize the process parameter using Taguchi method. Experiments are conducted according to Taguchi orthogonal array L<sub>27</sub> to groove on Borosilicate glass material. The effect of process factors like Concentration of Electrolyte, Voltage and Standoff distance on Material Removal Rate (MRR) is discussed. The significance factor which will impact on MRR is determined by using Analysis of Variance (ANOVA).

**Keywords:** Electrochemical Spark Machining (ECSM), Taguchi Method, MRR, ANOVA

### 1. INTRODUCTION:

The machining of non-conductive and conductive advanced materials such as ceramics, glass, quartz and composite materials are difficult task to manufacturers to machine by conventional method. These materials are having several application in the field of aerospace, automobile and defense. By using conventional process it is difficult to achieve required dimension and good surface finish. Hence nontraditional machining process like Electro Chemical Machining (ECM) and Electro Discharge Machining (EDM) processes are evolved to solve the problem. These processes are still has drawbacks, to overcome the problems in these two process hybrid machining process like ECSM is evolved. It is capable of machining nonconductive and conductive material in easy and economical way. It works on combined principle of ECM and EDM process. Machining of work specimen chemical etching and high temperature melting.

**B Bhattacharya, et.al, [1]:** have reviewed for development of experimental setup and discussed the phenomenon of Electro Chemical Spark Machining on non-conducting materials like glass, ceramic materials. The main phenomenon of ECSM is bubble generation and the spark generation. Initially at certain voltage the bubble is formed, after further increase in the voltage

causes densification of the bubbles which forms thin insulting layer between the tool and work piece. It will cause the spark generation. They discussed the influence of applied voltage, inter-electrode gap, concentration of electrolyte, electrolyte, the shape, size and material of the electrodes, concentration, and voltage and tool tip geometry on MRR and condition of machined surface.

**V K Jain, et.al, [2]:** have reviewed the mechanism of Electrochemical Spark Machining (ECSM) process and has been successfully applied for cutting of quartz work piece material using a controlled feed and a wedge edged tool. The quartz plates can be machined with different polarity conditions in ECSM process. Electro chemical spark machining with reverse polarity and direct polarity have been used for machining quartz plates. From the results, it concluded that reverse polarity cuts the quartz plate at a faster rate, higher tool wear and higher surface roughness compared to direct polarity.

**M L Harugade, et.al, [3]:** have reviewed the selection of effective electrolytic solution for Electro Chemical Arc Machining process. They considered 3 types of electrolytic solution. From the results, it shows that the acidic solution shows intermittent and disturbed spark, this affects the excessive erosion to electrode and work

piece. The salty electrolyte solution shows remarkable wear of the tool no damage to work piece. The basic electrolytic solution gives negligible wear, constant spark and better surface finish of the work piece.

**Akhil S Prasad, et.al, [4]:** have reviewed experiments conducted on brittle glass specimen in electro chemical discharge machining process by using different tool materials. A thorough study was also conducted to determine the influence of altered machining parameters on electro chemical discharge machining of brittle glass. Mathematical model was developed to determine the output characteristics.

**K L Bhondwe, et.al, [5]:** In this paper FEM based model has been developed for the determination of transient temperature distribution due to single spark. It help to determine the MRR using the temperature plots. From the results it can be concluded that there is a good correlation between the experimental results and predicted results.

**Min-seop, et.al, [6]:** In this fine graphite powder mixed with electrolyte has been applied to the ECDM process. borosilicate glass, which is frequently used as a material for micro structures, was used as an work piece.to investigate effectiveness of the proposed methods experiment was conducted.as a result surface quality was improved compared to the form of conventional machining process. Various experimental results of product quality with respect to powders volume ratios also presented.

**Min-seop han, et.al, [7]** in this, a cylindrical tool with micro textures on the surface is proposed as an cutting electrode. Partial electrical shielding of the tool electrode was also employed to stabilize the discharge characteristics by minimizing the reactive tool area. Two dimensional contour cutting of soda lime glass using this method.

**N Jagannatha, et.al, [8]:** have reviewed the approach and adopted by design of experiments through the Taguchi orthogonal array. It is very popular for solving the optimization problems in manufacturing engineering. ANOVA is successfully utilized for the process optimization. This concept is used to determine the best combination of factors to machine on soda lime glass material using abrasive hot air jet machining.

**Anjesh H Sahasrabudhe, et.al, [9]:** They discussed about optimization of process parameter relation with the machining alumina ceramic material with stainless steel and copper tool in addition to that fresh electrolyte is used. They also studied about the effect of noise factor.

**N Sathisha, et.al, [10]:** have reviewed the Taguchi orthogonal array  $L_9$  concept used to conduct the experiments on the soda lime glass material. They conducted experiments according to Taguchi orthogonal array  $L_9$  to groove on work material. Taguchi method and utility concept is employed to optimize the process factors of the multiple response of material removal rate (MRR) and tool wear rate (TWR). The significant parameter which effect on MRR and TWR are determined by using Analysis of variance (ANOVA). From the results it is observed that the tool work piece gap has greatest impact on TWR and MRR. The confirmation test shown that the good agreement between the estimated results and experimental results.

**N S Mitra, et.al, [11]:** In this paper they discussed about analysis of travelling wire electrochemical discharge machining of Hylam based composites by Taguchi method. Optimal combination of operating parameters were observed. Form the results, predicted optimum parameter level are in good agreement with the results.

**N Sathisha, et.al, [12]:** have reviewed the parametric optimization of Electro chemical arc machining using Taguchi based grey relational analysis and they have done the work on soda lime glass. Taguchi orthogonal array  $L_9$  and grey relation analysis is employed to optimize the process parameter of multi responses. And significant parameter determined by using ANOVA. SOD has more impact on (TWR) tool wear rate and MRR

**Ashutosh Kumar Pandey, et.al, [13]:** In this study they discussed about optimization of process parameters in micro electric discharge machining using response surface methodology and genetic algorithm.

**N Sathisha, et.al, [14]:** have reviewed for the prediction of material removal rate using Artificial Neural Network and Regression Analysis model for ECAM process. Experiments were conducted using Taguchi's orthogonal array to reduce the number of experiments. The statistical tool ANOVA has been used to optimize the process parameter which affects the MRR. The comparison of the developed models with experimental results is also discussed.

In this paper, developed ECSM setup utilized to machine Borosilicate glass. Experiments are conducted according to Taguchi orthogonal array  $L_{27}$ . The regression model is developed to forecast output results. The statistical tool ANOVA has been used to obtain the significant parameter. The effect of process parameters like Concentration of electrolyte, Voltage and Standoff Distance studied.

## 2. Materials

In this work, Borosilicate glass material is used as work material, mixed electrolyte used as work medium. The work specimens are weighted before machining. After the machining, the work specimen is measured in digital balance. The weight loss per unit time is calculated and is

known as Material Removal Rate (MRR). This process involves more than five variables, for investigation purpose major process variables like Concentration of electrolyte, Voltage and Standoff distance are considered. Variable process factors and their levels are shown in table 1.

Table 1 Process factors and their levels

	Parameter	Level 1	Level 2	Level 3
A	Concentration of Electrolyte (%)	10	20	30
B	Voltage (V)	40	50	60
C	Tool –Work piece gap (mm)	0.03	0.05	0.07

## 3. Experimentation

The experimental setup of Electrochemical Spark Machining process is shown in fig 1. It consist of cathode tool (stainless steel), auxiliary anode (steel plate), CNC table, Tool monitoring unit, stepper motor, micro controller and CNC controller. The standoff distance gap is adjusted by using feeler gauge. The Z axis movement of tool is controlled by tool monitoring unit with the help of microcontroller. The work piece movement is

controlled by CNC machine with the help of CNC controller. In these work strong base electrolyte solutions like NaOH and KOH is used for medium. The Standoff distance kept constant during the experiment. When the voltage is applied to cell at certain voltage hydrogen bubbles are formed, after that further increase in the voltage spark will be generated. Experiments conducted for grooving operation on borosilicate work specimens by varying levels and factors.

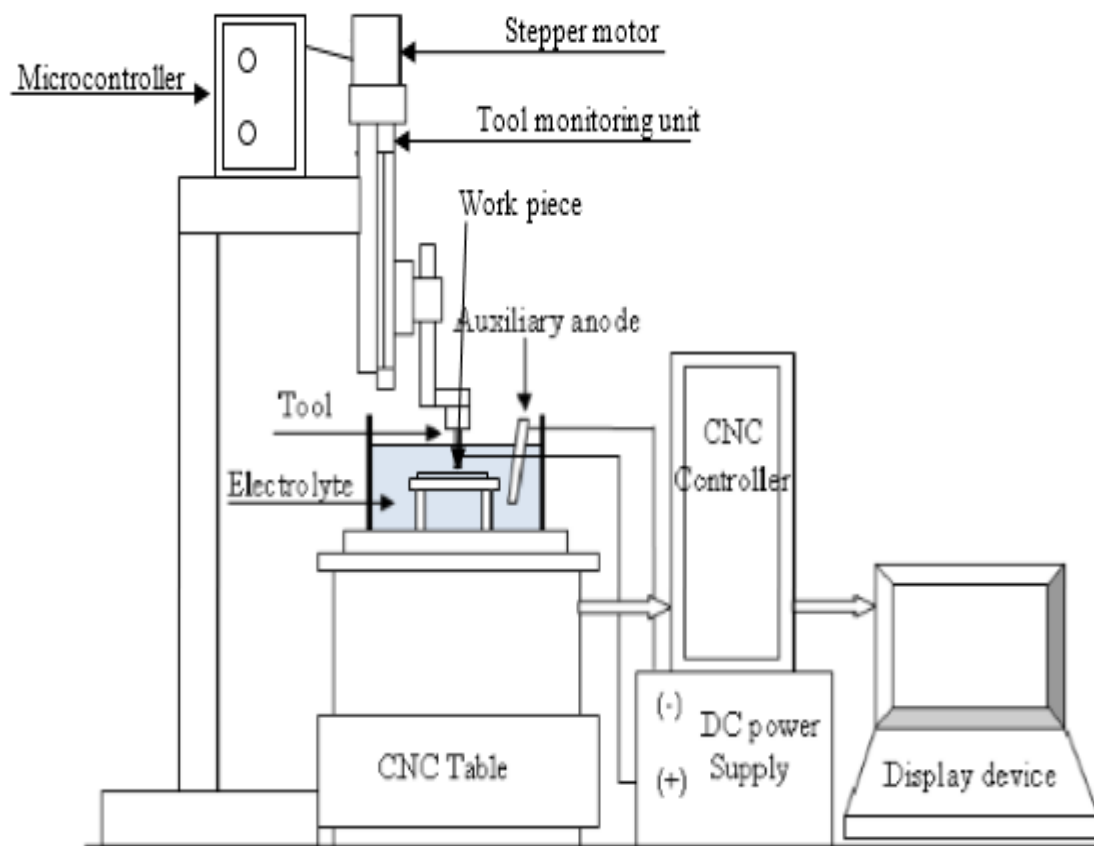


Figure 1: Experimental setup ECSM

## 4. Results and discussion

### 4.1 Regression Analysis

It is a statistical analysis method used for modeling by using the experimental results and it helps in the prediction of the output values. It also estimates the relationship between the variables present in the experiments.

The regression equation is solved to compute regression coefficients and these coefficients are helps to estimate the MRR. Statistical tool Minitab 17 is used to generate regression equation for predicting the MRR values and is given in equation (1)

$$Y = 0.218 + 0.00443 A - 0.000914 B - 1.43 C \quad (1)$$

Where,

Y= MRR in mg/min, A= Concentration of electrolyte (weight %), B= Voltage (in volts), C= SOD (in mm)

The prediction of regression model is verified with experimental results. From the table 2, it shows that the results obtained from regression model are very close to experimental results. The error % for all trials are calculated by the following equation,

$$\text{ERROR \%} = \frac{1}{n} \sum \left[ \frac{\text{MRR}_{\text{Expt}} - \text{MRR}_{\text{pred}}}{\text{MRR}_{\text{Expt}}} \right] \% \quad (2)$$

Table 2 Comparison of Experimental MRR with predicted MRR

Sl.no	MRR <sub>Expt</sub> in mg/min	MRR <sub>pred</sub> in mg/min	ERROR $\left[ \frac{\text{MRR}_{\text{Expt}} - \text{MRR}_{\text{pred}}}{\text{MRR}_{\text{Expt}}} \right] \%$	Sl.no	MRR <sub>Expt</sub> in mg/min	MRR <sub>pred</sub> in mg/min	ERROR $\left[ \frac{\text{MRR}_{\text{Expt}} - \text{MRR}_{\text{pred}}}{\text{MRR}_{\text{Expt}}} \right] \%$
1	0.181	0.182	-0.55	14	0.157	0.160	-1.910
2	0.184	0.182	1.086	15	0.161	0.160	0.621
3	0.179	0.182	-1.67	16	0.197	0.208	-5.583
4	0.142	0.145	-2.112	17	0.205	0.208	-1.463
5	0.147	0.145	1.360	18	0.203	0.208	-2.463
6	0.143	0.145	-1.398	19	0.208	0.214	-2.884
7	0.115	0.107	6.956	20	0.212	0.214	-0.943
8	0.102	0.107	-4.901	21	0.215	0.214	0.465
9	0.109	0.107	1.834	22	0.276	0.262	5.072
10	0.196	0.198	-1.020	23	0.260	0.262	-0.769
11	0.189	0.198	-4.761	24	0.267	0.262	1.872
12	0.198	0.198	0.00	25	0.215	0.224	-4.186
13	0.159	0.160	-0.628	26	0.221	0.224	-1.357
14	0.157	0.160	-1.910	27	0.225	0.224	0.444

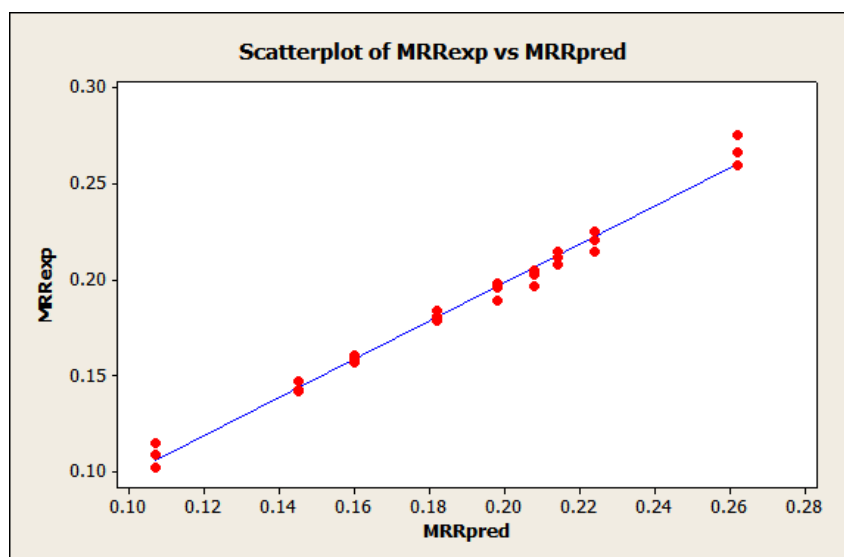


Figure 2: Comparison of Experimental MRR vs predicted MRR

The MRR forecasted values are obtained by using the regression equation in statistical tool Minitab. The obtained MRR values are written in the table 2. The forecasted values compared and verified are illustrated in the fig 2. The obtained results are near to the results achieved. From the results it concludes that there is less deviation between the MRR Exp vs. MRR pred.

#### 4.2 Optimal combination of ANOVA

Statistical tool Minitab is used to perform the ANOVA and is shown in the table 3. From the table ANOVA results, it shows that high MRR is obtained at 30% concentration of electrolyte, voltage at 50V and SOD at 0.03mm.

Table 3: ANOVA results

Source	DF	Seq SS	Adj SS	Adj MS	F	C
A	2	0.0353827	0.0353827	0.0176914	709.13	68.32%
B	2	0.0016963	0.0016963	0.0008481	34.00	3.27%
C	2	0.0147043	0.0147043	0.0073521	294.70	28.39%
Error	20	0.0004990	0.0004990	0.0000249		
Total	26	0.0522823				

From the above analysis it is clear that the parameter which is more significantly effects on MRR is concentration of electrolyte and less significant parameter on MRR is voltage. Contribution of electrolyte concentration 68.32%, voltage 3.27% and SOD 28.39% impact on MRR. Fig 3 shows the main effects plot for MRR. From the main effective plot it's observed that MRR is high for electrolyte concentration at 30%, it's because of large amount of ions present in the electrolytic solution. More number of ions rapidly

accelerates the rate of electrolysis process and thus resulting higher amount of material removal.

More amount of material will be removed for smaller SOD of 0.03mm. The smaller SOD facilitate the flow of electrolyte to the tool end as well as it enables the rapid formation of gas film. The spark density is high at the gap intensifies the discharge frequency resulting in effective erosion of work piece. The MRR is high at moderate voltage of 50V, also it facilitates good environment to remove material. At high voltage tool is unstable and will be a chance of tool burn out.

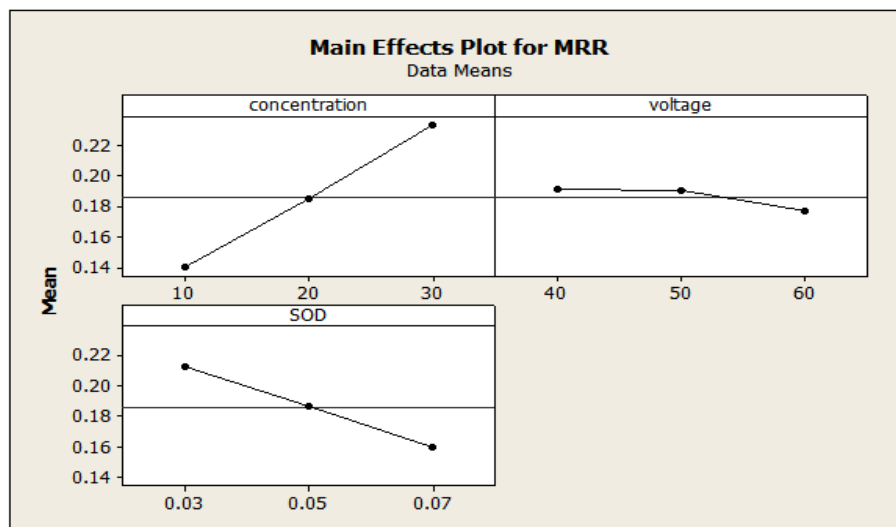


Figure 3: Main effects plot for MRR

#### 5. Confirmation test

After identifying the most influential factors, the final stage verifies the experimental results with predicted result. By comparing the results of ANN model and RA model with experimental results it can be concluded that ANN model gives least deviation with the experimental values. Hence ANN values are used for confirmation test. In order to validate the

experiment three trails are conducted according to the parameters of  $A_3B_2C_1$  (Electrolyte concentration is of 30%, voltage is of 50V and SOD is of 0.03mm). Table 4 shows the confirmation test results.

Table 4 confirmation test results

Sl. No	Concentration of electrolyte %	Voltage in volts	SOD in mm	MRR in mg/min
1	30	50	0.03	0.269
2	30	50	0.03	0.265
3	30	50	0.03	0.268

After the test it is noticed that there is good relation between the experimental values and predicted results. There is least variation between the predicted experimental values also concentration of electrolyte has high impact on MRR because the presence of more number of ions. MRR is high for least standoff distance because in small gap high intensified spark is produced. MRR is high for optimum voltage of 50V.

## 6. Conclusion

In this work, developed ECSM setup is utilized to conduct experiments. Experiments are conducted on borosilicate glass making use of combined electrolyte as a medium. Modeling and Analysis of experimental results are carried out by using Regression Analysis (RA) tool. Optimization of process parameters was done by using ANOVA tool.

- Make use of the Taguchi method in the experiments, it conclude that MRR will be high for the combination of  $A_3B_2C_1$ . Hence the combination of  $A_3B_2C_1$  is used as optimal combination of process factor.
- It has been observed that there is good correlation between the forecasted results and experimental results.
- From ANOVA, it is observed that voltage has least contribution of 3.27%, the electrolyte concentration has more contribution of 68.32% and Stand of distance is 28.39%. Hence the concentration of electrolyte has more impact on MRR.
- From this work, Regression model is recommended to predict the MRR value and ANOVA tool is recommended to optimize the process parameter.

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