

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

Optimization of Material Removal Rate in Electrochemical Discharge Machining (ECDM) of Borosilicate Glass by Taguchi Methodology

Aparna Prakash Yadav¹, V. B. Sabnis², Omkar Prakash Yadav³,

P. G. Student, Department of Mechanical Engineering, K. B. P. College of Engineering, Satara, Maharashtra, India¹

Associate Professor, Department of Production Engineering, K. B. P. College of Engineering, Satara,
Maharashtra, India²

Engineer, B.E, Department of Mechanical, Government College of Engineering, Karad, Maharashtra, India³

ABSTRACT: Electrochemical discharge machining (ECDM) is unconventional hybrid machining process which combines the features of electrochemical machining (ECM) and electro discharge machining (EDM). The spark generation along with electrochemical action results in the material removal. This machining process is able to machine hard, brittle non-conductive and electrically conductive materials. The workpiece material selected in this work is borosilicate glass taking into account its wide usage in micro-electromechanical systems, biotechnology (slides and DNA sequencers), optics (filters, telescope mirrors), electronics (wafers, sensors), photovoltaic, laboratory equipments and devices used in space exploration. In this paper an effort has been done on micro machining of borosilicate glass using ECDM in order to determine the effect of 4 input parameters those are namely voltage (V_g), electrolyte concentration (C wt%), inter-electrode gap (IEG), and machining time (T_m) on material removal rate (MRR) by Taguchi methodology. The tool electrode (cathode) material is tungsten carbide. The auxiliary electrode (anode) material is graphite. To measure hole entrance diameters, profiles of holes are magnified with Rapid I machine. Experiment was conducted in matrix of 9 runs using L9 orthogonal array of Taguchi design of experiment. The relationship between input and output parameters was analyzed with the help of mean effect plots by Minitab software. The signal to noise ratio and ANOVA are employed to find the contributions of input parameters.

KEYWORDS: Electrochemical discharge machining (ECDM), Taguchi technique, ANOVA, Material removal rate (MRR), Signal to noise (S/N) ratio, Rapid I machine, Surface plots.

I. INTRODUCTION

It has been found that the advanced materials like ceramics, composites etc. are difficult to machine by the conventional machining processes. EDM is well suited for cutting intricate contours or delicate cavities in electrically conductive materials but it is not capable to produce sharp corners and MRR achieved is considerably lower. Electrochemical machining (ECM) is a non-traditional manufacturing process to create complex shape for electrically conductive materials. High MRR can be achieved with high surface finish. It is difficult to machine materials such as super alloys, titanium alloys, alloy steel, stainless steel etc. by ECM process. The ECM process is not capable to produce sharp corners. ECDM is unconventional hybrid machining process which combines the features of EDM and ECM processes. This machining process is able to machine hard and brittle non-conductive materials such as glass, ceramics, refractory bricks, quartz, composite materials etc. and electrically conductive materials such as steel, copper, tungsten etc. ECDM find a wide range of applications in advanced industries like nuclear reactor, automobiles, aeronautics, MEMS etc. ECDM can be used in machining complicated shapes with high aspect ratio, groove, channels, micro holes, and micro cavities etc. ECDM is used to manufacture prototypes for sensors, complex shaped micro-contours in insulators, micro fluidic channels, miniature features for turbine blades (micro-tabulated cooling holes),

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

filters for food and textile industries, 3D micro structuring, reusable electrophoresis biochips etc. The existing micromachining technologies for glass like chemical etching, laser machining, ultrasonic micromachining, abrasive machining etc. has undesirable effects and limitations like low machining speed, severe tool wear, and mechanical cracks on surfaces, subsurface micro cracks, chipped edges, thermal damage, residual stresses, safety hazards etc. ECDM has the ability to overcome the micromachining challenges in glass.

ECDM is characterized in its work result by reduced machining time due to high MRR. Machining rate is higher because both ECM and EDM phase occur during the same machining period. The ECDM with reverse polarity (ECDMWRP) as well as ECDM with direct polarity (ECDMWDP) is also possible. By making the tool electrode and the auxiliary electrode small in size, machining can take place on workpieces at both electrodes simultaneously. Some limitations of ECDM are like micro-structures less than 100 μm in size with good surface quality are still a challenge because it is difficult to control the MRR, surface roughness, tool-workpiece gaps, machining resolutions etc. It does not seem possible to obtain patterns smaller than 25 μm with ECDM technology because it is complicated to fabricate high aspect ratio micro tools; there is excessive tool wear and tapered holes due to prolonged machining time resulting in radial overcut. ECDM process has a very low penetration depth which limits its use for drilling purposes and damage to the machined surface (HAZ) due to high temperatures as a result of lack of electrolyte circulation in the machining zone so debris removal becomes increasingly difficult as we machine deeper holes. The researchers who were using gravity feed to the tool electrode could not get more than 2 mm depth of penetration. This has been partially overcome by the use of an orbital rotational tool, and by employing higher voltage across the electrodes and flow of the electrolyte through the tool.

Mohit Sharma et al. [1] used sodium hydroxide (NaOH) and glass as electrolyte and workpiece material respectively. High speed steel (HSS) electrode was used as a tool. By Taguchi and ANOVA method, they have reported that applied voltage and electrolyte concentration has a contribution of 57.74% and 37.07% respectively. Maximum MRR was obtained at parametric conditions, voltage of 60 V, electrolyte concentration of 25% wt and inter-electrode gap of 60 mm. Sumit K. Jui et al. [2] investigated on high aspect ratio micro tools made up of tungsten carbide, used to drill deep micro holes on borosilicate glass using steel as an anode. Surface features less than 100 μm have been machined. They have revealed that lower electrolyte concentration reduces overcut by 22% and increasing the aspect ratio of the micro holes and rotation of the tool electrode improves the circularity of the hole. The surface roughness of machined hole was found to be in the range of 250–350 nm. An aspect ratio of 11 was achieved with 1 M NaOH, voltage setting at 40 V, tungsten carbide tool (Ø 30 μm) feed at 1 $\mu\text{m}/\text{s}$. Cheng Kuang Yang et al. [3] made an attempt to solve problem that machining time and hole entrance diameter were found to increase with increasing machining depth, the increase becomes drastic when machining depth exceeds 250 μm . They have explored that the curved surface of the spherical tool electrode facilitates the flow of electrolyte to the electrode tip resulting in efficient micro hole drilling so spherical electrode has advantages in enhancing machining performance and shape accuracy of the micro hole. Tungsten carbide and graphite electrodes were used as an anode and cathode respectively. The results indicate that using spherical electrode, machining time was reduced by 83% while diameter overcut was decreased by 65%. Xuan Doan Cao et al. [4] investigated on micro-ECDM process to improve the machining of 3D micro-structures of soda lime and Pyrex glass. Various micro-structures less than 100 μm in size such as Ø 60 μm micro-holes, a 10 μm -thin wall and 3D micro-structure were fabricated. Solutions of NaOH and KOH were used as electrolyte. Platinum and tungsten electrodes were used as an auxiliary electrode and tool electrode respectively. The effects of different electrolytes, pulse on/off-time ratio, voltage, tool electrode feed rate, tool electrode rotational speed and the electrolyte concentration in the drilling and milling by ECDM process were studied for glass. The smallest hole size was obtained in potassium hydroxide (KOH 30%) and machining time 17–18 min. High voltage produces poor machining resolution but use of pulse voltage reduces hole size and improves surface quality. Sathisha N. et al. [5] developed the empirical models for grooving (channels) and drilling (holes) process of ECDM using Regression Analysis (RA) and the Artificial Neural Network (ANN) to predict MRR. According to results, the prediction of ANN model of MRR for grooving is better as compared to the regression model. ANOVA showed the results that electrolyte concentration is the significant factor for MRR in ECDM. Results indicated that 30% of electrolyte concentration, 60V of voltage, 0.03 mm of SOD is the optimal parameter combination for the ECDM of soda lime glass. M. L. Harugade et al. [6] conducted experiments on ECDM according to Taguchi method (L9 orthogonal array) to identify the effect of electrolyte solution on MRR. Copper electrodes were used as an anode and cathode. The experiments were performed on soda lime glass

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

workpiece. They have revealed that applied voltage is most influential parameter and electrolyte concentration is a secondary fact of concern affecting MRR in ECDM of holes. For KOH electrolyte solution sparking rate is higher than the sulfuric acid electrolyte solution; resulting in higher MRR. Sanjay K. Chak and P. Venkateswara Rao [7] proposed ECDM of aluminium oxide (Al_2O_3) ceramic by trepanning method and shown the possibility of drilling large size and deeper holes by comparatively smaller electrodes. KOH solution was used as electrolyte and graphite as an anode. At greater machined depth, machining performance gradually deteriorates. To reduce this problem, a spring fed cylindrical abrasive electrode of 1.5 mm diameter has been used under the effect of parameters, namely pulsed DC voltage, duty factor and electrolyte conductivity to assess MRR, machined depth and diametric overcut. The results revealed that pulsed DC reduces the tendency of surface cracking in workpiece, at high voltage compared to smooth DC. V. K. Jain et al. [8] investigated on the mechanism of material removal in electrochemical spark abrasive drilling (ECSAM) of alumina and glass. Solution of NaOH was used as electrolyte. Abrasive cutting tool and conventional cutting tools made of mild steel were used as tool electrode. Response surface equations were obtained for evaluating material removal with conventional cutting tool and abrasive cutting tool by varying supply voltage and electrolyte temperature. The results revealed that machining performance (both in terms of material removal and machined depth) of the ECSAM process using abrasive cutting tools keeps improving with an increase in voltage and temperature of the electrolyte. N. Sathisha et al. [9] conducted experiments to optimize electrochemical spark machining (ECSM) response parameters namely MRR and TWR using Taguchi L9 orthogonal array and grey relational analysis. The electrolyte used was solution of NaOH. Stainless steel and zinc plates were used as cathode and an auxiliary electrode respectively to groove on soda lime glass. From ANOVA, they have reported that the percentage contribution of the tool-workpiece gap is (96.9%) and showed the greatest impact on MRR and TWR. The tool-workpiece gap of 0.015 mm, 10 %wt concentration of electrolyte and voltage of 50 V was found the optimal parameter combination. Min Seop Han et al. [10] investigated on a method to improve the surface integrity of ECDM process, used to fabricate micro surfaces on borosilicate glass using tungsten carbide tool electrode. Results presented the product quality with respect to volume ratio of graphite powder mixed with electrolyte. Graphite powder stabilizes discharge current as a result of discharge energy dispersion. The presence of conductive particles within the hydrogen film reduces the critical breakdown strength resulting in the decreased spark energy per single discharge pulse. By use of 1.0 %wt graphite powder concentration in 30%wt NaOH, the number of micro cracks was significantly reduced and the surface roughness was improved from 4.86 μm to 1.44 μm . B. Mallick et al. [11] investigated on the effects of process parameters like applied voltage (35-55 V), electrolyte concentrations (10-30 %wt), pulse frequency (200Hz-1kHz) and duty ratio (45-65%) on machining performance characteristics such as MRR, overcut (OC) and HAZ during micro-channeling on glass. A cylindrical shaped stainless tool of diameter 350 μm and NaOH solution as electrolyte were used. The results depicts that MRR is high for 55 V and 30%wt electrolyte concentration. Overcut and HAZ area decreases with pulse frequency whereas it increases with duty ratio. MRR increases with the increase of applied voltage, electrolyte concentration, duty ratio but decrease with pulse frequency. HAZ area increases with increase in applied voltage and electrolyte concentration up to 25 %wt and decreases with pulse frequency whereas it increases with duty ratio. Lijo Paul and Somashekhar S. Hiremath [12] investigated the effect of ECDM process parameters on MRR by conducting experiments according to Taguchi L9 orthogonal array. Tungsten carbide wire was used as a cathode and graphite as an anode to produce blind holes. Borosilicate glass has been applied as a workpiece. They have reported optimum values as; voltage of 60 V, electrolyte concentration of 30 %wt and duty factor of 70%. MRR was found to be nonlinear. Response surface modeling (RSM) method was used to mathematically model the MRR and TWR. MRR increases with increase in duty factor, concentration of electrolyte, voltage. TWR is found to decrease with increase in electrolyte concentration and increases with rise in voltage as most of heat will be dissipated through tool electrode than through workpiece or electrolyte. Om Prakash Gupta, Vinod Yadava [13] concluded comparison of machining performances of Drilling-ECDM and Sinking-ECDM, during machining of borosilicate glass. They revealed that MRR in drilling configuration is large as compared to sinking-ECDM process. MRR increases with increase in electrolyte concentration in range of 100-150 g/l, and shows decrease trend thereafter. This behavior follows the dependence on conductivity of solution with concentration of electrolyte. The conductivity of water-NaOH solution increases with increase in concentration so rate of electrochemical reaction and circuit current increases. Moreover, increased circuit current shows the heating effect proportional to the current, this results in enhanced rate of etching on the workpiece. As the concentration of NaOH increases beyond 150 g/l, movement of the ions is impede by collisions.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

In this way conductivity of electrolyte solution decreases, this is responsible for significantly increase in machining time. M. L. Harugade et al. [14] investigated on selection of concentration and type of electrolyte. The electrolyte also governs the TWR and MRR of the ECDM process. Study indicates the facts that the nature, color of spark and process output are correlated. The acidic electrolyte solution shows intermittent and disturbed spark which result in excessive erosion of electrode and damage to the workpiece. The salty electrolyte solution shows remarkable tool wear however no damage to workpiece is recorded. They revealed that with increase in electrolyte concentration, MRR increases.

II. RELATED WORK

[A] Material and Machine: Borosilicate glass is used as workpiece and tungsten carbide electrode is used as tool electrode. Graphite is used as counter electrode. Machining was carried out by using ETREMA ECDM machine. Specifications of ECDM machine are shown in table 1.

Table 1 Specifications of ECDM machine

Description	Details
Machining chamber	Material –Acrylic, Size -180 mm x 140 mm x 55 mm
Machining table	Size-500 mm x 400 mm x 400 mm
Servo system	Manual setup with DRO
Tool electrode diameter	Tool electrode diameter < 1.5 mm
Tool electrode rotation	0 to 3000 rpm
Frequency	19 to 21 kHz
Amplitude	0 to 30 μ m
Power supply	415 V A/C, 3 Phase, 20 A
Voltage and Current	0 to 250/300 V, DC, 0 to 10 A
Duty cycle	8 to 96%
T-On	5 to 2000 μ s

[B] Electrolyte: Potassium hydroxide (KOH) salt solution is used as electrolyte for machining. It releases maximum hydrogen and oxygen gas bubbles at tool and auxiliary electrodes respectively than sodium hydroxide and helps in lowering the freezing point of water.

[C] Fixture: The fixture is made of sub-components like the inter electrode gap control device, acrylic material chamber and work piece holding device. Vertical screw bolts are provided to lock the workpiece. Workpiece holding device gives rigidity to the workpiece during machining to prevent any unnecessary movements. The inter electrode gap control device is a flat plate having open slots at every 10 mm length from the tool electrode position. It allows the positive electrode dipped properly into the electrolyte solution at desired position. The acrylic chamber acts as container inside of which electrolyte solution has been kept and work piece holding fixture has been attached.

[D] Parameter Selection: In this work, the process parameters are taken as voltage (V_g), electrolyte concentration (C), inter-electrode gap (IEG) and machining time (T_m) with 3 different levels shown in table 2.

Table 2 Parameters and values

Parameters	Values			
	Unit	Level 1	Level 2	Level 3
Voltage(V_g)	V	65	70	75
Electrolyte concentration (C)	%wt	30	35	40
Inter-electrode gap (IEG)	mm	20	30	40
Machining time (T_m)	min	12	19	26
Initial gap: Tool Electrode –Workpiece	0.05 mm			
Tool electrode tip dipped into electrolyte	\approx 1 to 2 mm			
Duty factor	70%			
Pulse On/Off time	2 s			

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

The constant process parameters with their value are shown in table 2. The performance parameter considered in this study is MRR which has to be taken seriously and has to be analyze carefully. It is calculated as the difference of initial weight before machining to the final weight after machining of the workpiece divided by total time taken to remove that amount of material.

$$\text{MRR (mg/min)} = (\text{Initial Weight-Final Weight}) / \text{Machining Time}$$

[E] Experimental Details: For the ECDM of borosilicate glass, experimental design matrix was prepared using L9 orthogonal array based upon Taguchi method. Table 3 shows L9 design matrix, MRR and S/N ratios of MRR. In this work, blind holes were machined on borosilicate glass workpiece.

Table 3 L9 Orthogonal array design matrix and experimental observations

Experiment No.	Voltage (V _g)	Electrolyte Concentration (C)	Inter-Electrode Gap (IEG)	Machining Time (T _m)	Material Removal Rate (MRR)	Signal to Noise Ratio for MRR
	V	% wt	mm	min	mg/min	
1	65	30	20	12	0.3333	-9.5433
2	65	35	30	19	0.3158	-10.0118
3	65	40	40	26	0.3846	-8.2998
4	70	30	30	26	0.2692	-11.3985
5	70	35	40	12	0.4167	-7.6035
6	70	40	20	19	0.4737	-6.4899
7	75	30	40	19	0.5263	-5.5753
8	75	35	20	26	0.4231	-7.4711
9	75	40	30	12	0.6667	-3.5214

III.ANALYSIS OF EXPERIMENTAL DATA

Effect of input factors on material removal rate (MRR):

The response table for signal to noise ratio for MRR is shown in table 4 and corresponding analysis of variance (ANOVA) table is shown in table 6. For MRR, the calculation of S/N ratio follows “Larger the Better” model.

Table 4 Response table for Signal-to-Noise ratios for MRR

Level	Voltage	Electrolyte Concentration	Inter-Electrode Gap	Machining Time
	V _g	C	IEG	T _m
1	-9.2850	-8.8390	-7.8348	-6.8894
2	-8.4973	-8.3621	-8.3105	-7.3590
3	-5.5226	-6.1037	-7.1596	-9.0565
Delta	3.7623	2.7353	1.1510	2.1671
Rank	1	2	4	3

Calculation S/N ratios of voltage (V_g) input factor for MRR from table 3:

$$\text{Level 1 of factor} = (S/N)_1 + (S/N)_2 + (S/N)_3 / 3$$

$$\text{Level 2 of factor} = (S/N)_4 + (S/N)_5 + (S/N)_6 / 3$$

$$\text{Level 3 of factor} = (S/N)_7 + (S/N)_8 + (S/N)_9 / 3$$

Calculation of Delta from table 4: Delta = (Max. of S/N Ratio – Min. of S/N Ratio)

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

Table 5 Optimized combination of parameter levels for MRR

Physical requirement	V _g	C	IEG	T _m
Maximum MRR	75	40	40	12

From table 4, the optimized parameter setting for MRR is A3B3C3D1 shown in table 5.

Table 6 Analysis of Variance (ANOVA) for MRR

Sources	D.O.F.	Sum of Squares	Mean Square	% Contribution
V _g	2	23.6244	11.8122	51.0912
C	2	12.8100	6.4050	27.7035
IEG	2	2.0071	1.0035	4.3406
T _m	2	7.7982	3.8991	16.8647
Total	8	46.2396	23.1198	100.000

Calculation of sum of squares for MRR from table 4: $SS_{V_g} = (V_{g1} - V_{g2})^2 + (V_{g1} - V_{g3})^2 + (V_{g2} - V_{g3})^2$

Calculations of mean squares for MRR from table 6: $MS_{V_g} = SS_{V_g}/D.O.F.$

Similarly, calculating sum of squares and mean squares for MRR of electrolyte concentration (C), inter-electrode gap (IEG) and machining time (T_m)

Calculation of % contribution of input factors for MRR from table 6:

% Contribution of input factor = (Sum of squares of input factor / Total sum of squares) X 100

IV. EXPERIMENTAL RESULTS

Experimental study was conducted to see the effect of voltage (V_g), electrolyte concentration (C), inter-electrode gap (IEG) and machining time (T_m) on performance parameter MRR in ECDM of borosilicate glass workpiece. Figure 1 shows the main effects plot for means of MRR with respect to voltage, electrolyte concentration, inter-electrode gap and machining time. Results are discussed here which are obtained from optimization by ANOVA.

The level of parameter with higher means gives the optimal level, so the optimized process parameter setting for MRR was voltage at level 3, electrolyte concentration at level 3, inter-electrode gap at level 3 and machining time at level 1. Thus the best combination values for MRR were voltage 75V, electrolyte concentration 40 %wt, inter-electrode gap 40 mm, and machining time 12 min.

From figure 1, it is observed that in case of voltage, MRR is minimum for 65 V and it goes on increasing as voltage increase up to 75 V, this may happened because more hydrogen bubbles get formed at tool electrode and more spark generation lead to increasing MRR. Due to increase in voltage there is rise in discharge temperature due to the bombardment of the electrons generated during the discharge process lead to increasing material removal. In case of electrolyte concentration, MRR is minimum for 30 %wt electrolyte concentration and it goes on increasing as electrolyte concentration increase up to 40 %wt, this may happened because increase in electrolyte concentration and conductivity, enhanced the rate of electrolysis and efficiency of chemical etching producing a smoother machined surface. As the concentration increase, the critical voltage and critical current increases, increased circuit current shows the heating effect proportional to the current, this results in enhanced rate of etching on the workpiece. This behaviour follows the dependence on conductivity of solution with concentration of electrolyte. The conductivity of water-KOH solution increases with increase in concentration of KOH. In case of inter-electrode gap, MRR increases with increase in inter-electrode gap from 20-40 mm. The gap between tool electrode (cathode) and auxiliary electrode (anode) increased beyond a certain value, the MRR starts increasing because bubbles at both electrodes can't interfere gas film at tool and auxiliary electrode. At 20 mm, the evolved gases tend to destabilize the sparking process but at higher gap it will stabilize the sparking process and hence MRR increases. In case of machining time, maximum MRR is at 12 min. MRR goes on decreasing as machining time increases up to 26 min. As time increases depth of machining increases, so

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

less electrolyte circulation is major problem which decreases the material removal, hence MRR decreases with increase in machining time.

Figure 2 represents percentage contributions of input parameters i.e. electrolyte concentration, voltage, machining time and inter-electrode gap to material removal rate (MRR) in electro-chemical discharge machining (ECDM) of borosilicate glass.

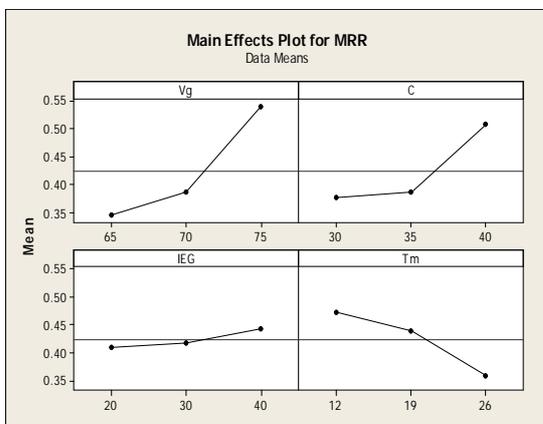


Fig. 1 Main effects plot for means of MRR with respect to voltage, electrolyte concentration, inter-electrode gap and machining time.

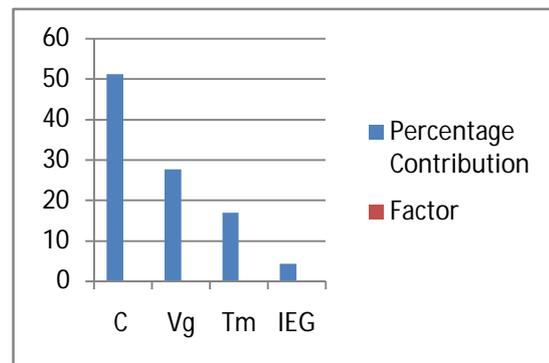
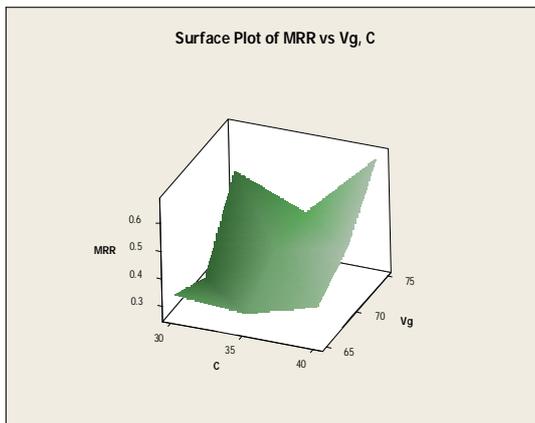
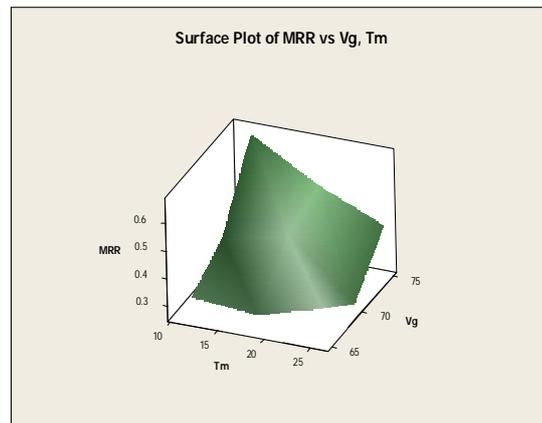


Fig. 2 Percentage contributions of electrolyte concentration, voltage, machining time, inter-electrode gap to MRR in ECDM



(a)



(b)

Fig. 3 Surface plot (a) Surface plot of MRR vs. V_g, C (b) Surface plot of MRR vs. V_g, T_m

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

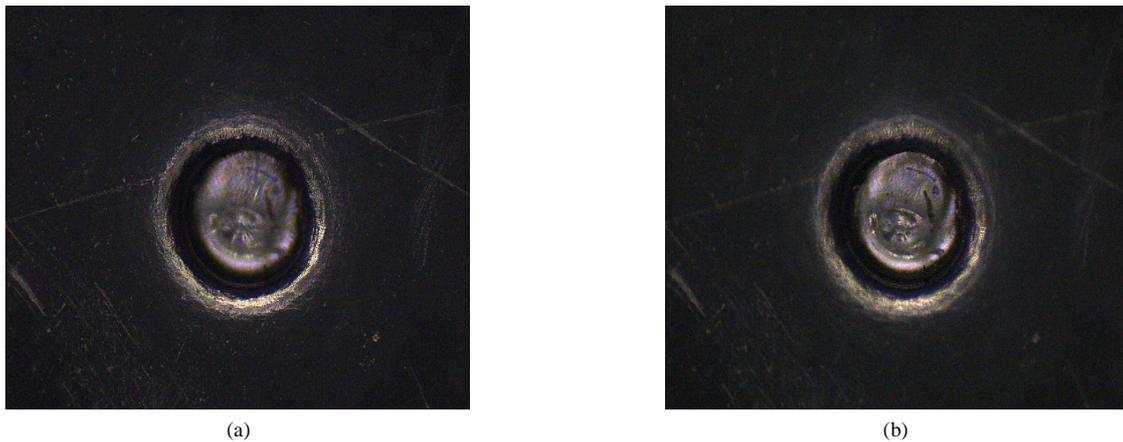


Fig. 4 Rapid I image of hole machined in using ECDM at 70 V voltage, 30% wt electrolyte concentration, 30 mm inter-electrode gap, 26 min. machining time (a) Entrance of hole (b) Bottom of hole

Figure 3 (a) presented surface plot of MRR showing the influence of voltage, electrolyte concentration on MRR, shows that MRR increases with increase in voltage and electrolyte concentration. Figure 3 (b) is presented surface plot of MRR showing the influence of voltage, machining time on MRR, shows that MRR increases with increase in voltage and decreases with increase in machining time.

Figure 4 shows Rapid I image of holes machined using electrochemical discharge machining (ECDM) in borosilicate glass.

V. CONCLUSION

By single optimization method (ANOVA) for electrochemical discharge machining (ECDM) of borosilicate glass, we conclude that factor voltage (V_g) has the largest contribution to material removal rate (MRR) i.e. 51.09%. Factors electrolyte concentration (C) and machining time (T_m) also have considerable contribution in total sum of squares which is 27.70% and 16.86% respectively. The factor inter-electrode gap (IEG) has much less contribution of 4.34%. The larger the contribution of any factor to the total sum of squares, the larger is the ability of that factor to influence MRR. So, voltage (V_g) has maximum effect on MRR. Electrolyte concentration (C) and machining time (T_m) have considerable effect on MRR whereas inter-electrode gap (IEG) has very less effect on MRR. For optimum material removal rate, A3-B3-C3-D1 is optimized parameter set i.e. voltage 70V, electrolyte concentration 40%wt, inter-electrode gap 40 mm and machining time 12 minutes. 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 concentrations can be used for better results. 3. Machining time of hole can be reduced by increasing voltage and concentration of electrolytes.

REFERENCES

- [1] Mohit Sharma, Neeraj Goyal, M. M. Goud (2013) "Fabrication of electrochemical discharge machining Set-up and experimental investigation on Parametric optimization for ECDM on glass using Taguchi Methodology", Proceedings of International Conference on Mechanical and Industrial Engineering, May 2013, ISBN 978-93-82208-95-2, pp. 23-26.
- [2] Sumit K. Jui, Abishek B. Kamaraj, Murali M. Sundaram (2013) "High aspect ratio micromachining of glass by electrochemical discharge machining (ECDM)", Journal of Manufacturing Processes, July 2013, Vol.15, pp. 460-466.
- [3] Cheng-Kuang Yang, Kun-Ling Wu, Jung-Chou Hung, Shin-Min Lee, Jui-Che Lin, Biing-Hwa Yan (2011) "Enhancement of ECDM efficiency and accuracy by spherical tool electrode", International Journal of Machine Tools and Manufacture, March 2011, Vol. 51, pp. 528-535.
- [4] Xuan Doan Cao, Bo Hyun Kim, Chong Nam Chu (2009) "Micro-structuring of glass with features less than 100 μ m by electrochemical discharge machining", Precision Engineering, Jan. 2009, Vol. 33, pp. 459-465.
- [5] N. Sathisha, S. H. Somashekhar, J. Shivakumar (2014) "Prediction Of Material Removal Rate using regression analysis and artificial neural network of ECDM process" International Journal of Recent advances in Mechanical Engineering (IJMECH), May 2014, Vol. 3, Issue 2, pp. 69-81.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

- [6] M. L. Harugade, M. V. Kavade, N. V. Hargude, "Effect of electrolyte solution on material removal rate in Electrochemical Discharge Machining", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), ISSN 2278-1684, pp. 01-08.
- [7] Sanjay K. Chak, P. Venkateswara Rao (2007) "Trepanning of Al₂O₃ by electro-chemical discharge machining (ECDM) process using abrasive electrode with pulsed DC supply", International Journal of Machine Tools and Manufacture, June 2007, Vol. 47, pp. 2061-2070.
- [8] V. K. Jain, S. K. Choudhury, K. M. Ramesh (2002) "On the machining of alumina and glass", International Journal of Machine Tools and Manufacture, Mar. 2002, Vol. 42, pp. 1269-1276.
- [9] N. Sathisha, S. H. Somashekhar, J. Shivakumar, R. I. Badiger, "Parametric optimization of Electro Chemical Spark Machining using Taguchi based Grey Relational Analysis", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN 2278-1684, pp. 46-52.
- [10] Min-Seop Han, Byung-Kwon Min, Sang Jo Lee (2007) "Improvement of surface integrity of electro-chemical discharge machining process using powder-mixed electrolyte", Journal of Materials Processing Technology, 2007, 191, pp. 224-227.
- [11] B. Mallick, M. N. Ali, R. Sarkar, Doloi, B. Bhattacharyya (2014) "Parametric Analysis of Electrochemical Discharge Micro-Machining Process during Profile Generation on Glass" 5th International Design and Research Conference (AIMTDR 2014), Dec 2014, IIT Guwahati, pp. 541-546.
- [12] Lijo Paul, Somashekhar S. Hiremath (2013) "Response Surface Modeling of Micro Holes in Electrochemical Discharge Machining", Procedia Engineering, 2013, 64, pp. 1395-1404.
- [13] Om Prakash Gupta, Vinod Yadava, "Machining of borosilicate glass by ecdm process: comparison of machining performance during drilling and sinking holes", ELK Asia Pacific Journals, ISBN: 978-81-930411-8-5.
- [14] M. L. Harugade, N. V. Hargude, A. P. Shrotri, S. P. Shinde (2015) "A comparative study for selection of Effective electrolyte solution for Electrochemical discharge machining", International Journal of Mechanical Engineering and Technology (IJMET), Jan 2015, ISSN 0976-6359, Vol 6, Issue 1, pp. 98-103.