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Optimization of process parameters in Electro Chemical Discharge Machining of silica glass through Analysis of Means

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Abstract. In recent years, the Electro Chemical Discharge Machining (ECDM) process has advanced as a substitute for machining of conductive and non-conductive materials. Optimization of the process parameters plays a crucial role in improving the quality of the processed components. The machining of microchannel in silica glass has been successfully attempted in present work by considering Analysis of Means (ANOM) of ECDM process parameters. The experiments were planned using Taguchi's L₉ orthogonal array with applied voltage, stand-off distance (SOD), electrolyte concentration (EC) and pulse on time (TON) as process parameters. The Material Removal Rate (MRR), Machining Depth (MD) and Overcut (OC) were observed as output characteristics. The ANOM study revealed that the error between experimental and predicted values of MRR, MD and OC are 4.22%, 1.92% and 3.46% respectively. Stand-off distance was found to be the most significant factor followed by pulse on time, applied voltage and electrolyte concentration from ANOVA. Confirmation test was performed by setting the optimum combination of process parameters and the predicted values from regression analysis exhibited a good agreement with experimental results.

Key word: MRR, ECDM, silica glass, overcut, microchannel, Machining depth, SOD,

ANOVA, analysis of mean (ANOM).

1. Introduction

ECDM is a nontraditional machining process which includes a combination of different physical and chemical phenomena such as electrical discharge and chemical etching to remove the materials from the workpiece [1]. During ECDM material removal takes place when the applied voltage increases beyond a critical value, a high current density at the tip of cathode tool causes sparking which is attributed to the difference between the surface areas of electrodes [2]. ECDM has been widely



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employed for processing various nonconductive materials such as quartz, glass and ceramics. However, the process is popularly used for machining of variety of glasses including borosilicate glass, sodalime glass, pyrex glass and silica glass. Glasses have enormous applications in several sectors as micro fluidics, MEMS- microsensors, micropumps, medical micro devices [3] due to its distinctive properties such as transparency, chemical resistance, biocompatibility and low thermal and electrical conductivity [4]. However, it has been reported by many researchers that producing microholes and microchannel in glass material is very difficult owing to its brittle nature through conventional processes [5]. During the micromachining of borosilicate glass Paul and Hiremath [2] experimented with various tool tip geometry and reported that tapered tool tips exhibit better machining characteristics as the conical profile of tool tip facilitates the electrolyte contact in the machining zone and concentrates sparking action at the tool tip.

Crichton et al. [6] investigated the mechanism of spark generation in electrolyte and stated that incident of sparks is mainly due to sudden transient and noisy discharge between two electrolytes. Authors also mentioned that sparks of shorter duration favored maximize sparking which consequently resulted in increased MRR. Yang et al. [7] studied the effect of surface roughness on gas film formation of various tool materials and stated that tungsten carbide in comparison with tungsten and stainless steel exhibits the highest machining stability whereas it experiences the highest wear under gravity-feed processing. Bellubbi et al. [8] produced microholes in borosilicate glass using ECDM process and stated that applied voltage was the most dominant factor which affected the MRR followed by electrolyte concentration and machining time. Doloi et al. [8] used Taguchi method [9-11] for the optimization of different process parameters in ECDM of holes in ZrO₂ ceramic components and mentioned that voltage, electrolyte concentration and gap between the electrodes are the foremost parameters affecting MRR and radial overcut. Most of the researchers adopted Taguchi orthogonal array experimental design to reduce the experimental trials during machining of various engineering materials, which reduce machining cost and time [12-14], also this taguchi method provides simple design approach to optimize the response characteristics [15-17]. Further, Several researchers emphasized on optimizing the process parameters of ECDM for different work materials and profile geometry. The literature review reveals abundant research on both experimental and theoretical analysis of the mechanism involved in ECDM. However, it is found that very limited efforts have been published in the past to investigate the effect of process parameters in ECDM of silica glass.

Silica glass is widely used in production of mercury discharge lamps and optical laser corner reflectors. Since the use of traditional machining process to machine silica glass is very difficult, non-conventional machining of the same is required. In the past several researchers have investigated on machining of different profiles in silica glass. These works emphasize studies on effect of process parameters; MRR, width over-cut, surface roughness, electrode wear rate etc. [18-19]. However, from the literature review it is noticed that the published works lack in studies of optimization of process parameters and therefore there is a need to address the optimization of process parameters in ECDM of silica glass.

In the present work microchannel of 250μ m were machined successfully in silica glass using ECDM process, followed by optimization of process parameters involved. Applied voltage, electrolyte concentration, pulse-on time and stand-off distance were considered as machining parameters. The material removal rate (MRR), machining depth (MD) and overcut (OC) were considered as response characteristics. The optimization of process parameters has been carried out by considering L₉ orthogonal array through analysis of means (ANOM).

2. Experimental Details

In the present work, machining of microchannel in silica glass has been carried out with ECDM and the effect of process parameters on MRR, MD and OC has been investigated. Silica glass $(Na_2SiO_3+SiO_2)$ with dimension $76\times26\times5mm^3$ was considered as work material whereas, tungsten carbide wire with 250µm diameter was used as tool for the study. Figure 1 show the schematic of the experimental set up used in the present work. Experiments were planned according to Taguchi's L₉ orthogonal array by considering applied voltage, stand-off distance, electrolyte concentration and

pulse-on time as process parameters. The control factors and their levels are given in Table 1. Interelectrode gap of 40mm and machining time of 20min were maintained constant for all the experiments. NaOH solution was used as electrolyte prepared by blending 10g, 17g and 24g of NaOH pellets in 100ml of distilled water to get the concentration of 10wt.%, 17wt.% and 24wt.% respectively. Stand-off distance was controlled by inserting slip gauges between the tool-electrode and the workpiece.



Figure 1. Schematic view of ECDM Process **Table 1.** Control factors and their levels

Parameter	Symbol	Factor	Level 1	Level 2	Level 3
Applied Voltage (V)	V	А	45	50	55
Stand-off Distance (mm)	SOD	В	0.5	1.0	1.5
Electrolyte Concentration (wt%)	EC	С	10	17	24
Pulse on time (µs)	T_{on}	D	40	50	60

2.1. Evaluation of output characteristics

Some of the MRR was determined using equation (1) by weighing the specimens before and after the machining of microchannels [19].

$$MRR = \frac{Wt_b - Wt_a}{T} mg/hr \dots (1)$$

Where: Wt_b - Weight of work-piece before machining in mg.

Wt_a - Weight of work-piece after machining in mg.

T - Machining time in hr.

The over cut and machining depth were measured at different magnifications with Leica Microscope. The analysis of mean (ANOM) technique was used to obtain optimal combination of process parameters with an objective of minimum overcut and maximum MRR and MD. The analysis of variance (ANOVA) has been performed to determine the % contribution of process parameters. Table 2 depicts the results obtained after performing the experiments according to L₉ OA. Micrographic observation of machined surfaces was carried out with Scanning Electron Microscopy (Model: JEO JSM–6380LA from JEOL, USA) operated at 30kV.

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3. Results and Discussion

3.1. Analysis of means

The analysis of means (ANOM) on signal to noise ratio (SNR) was achieved for determining the optimal setting parameters [20]. In this study, Taguchi's design is proposed for optimizing the multiple objecting responses i.e. MRR, MD and OC. Here, MRR and MD are to be maximized and OC is to be minimized. Hence larger the better characteristic for MRR and MD, smaller the better characteristic for OC have been selected using equations (2)-(4). The SN ratios associated with the responses are given as follows [21-23].

 $SNR_{MRR} = -10\log \frac{1}{MR^2}$ dB (2) $SNR_{MD} = -10\log \frac{1}{MD^2}$ dB (3) $SNR_{OC} = -10\log OC^2$ dB (4)

The output data and signal to noise ratio for MRR, MD, OC are given in Table 2. Averaging of signal to noise ratio of material removal rate, machining depth and overcut was determined using weight function method as shown in equation (5). The weight functions assumed were 0.4, 0.3 and 0.3 for MRR, MD and OC respectively based upon priority of response characteristics.

 $SNR_{AVG} = SNR_{MRR} \times W_1 + SNR_{MD} \times W_2 + SNR_{OC} \times W_3 \qquad dB \qquad \dots \dots \dots \dots (5)$

Where SNR_{AVG} is the average signal to noise ratio in dB, SNR_{MRR} is the signal to noise ratio for material removal rate in dB, SNR_{MD} is the signal to noise ratio for machining depth in dB and SNR_{OC} is the signal to noise ratio for overcut in dB.

The computed SNR_{AVG} were ranked based on the larger-the-better criteria. Hence, 4th experimental trial is considered as best run out of all 9 trials and ranked first as given in Table 2. Further, ANOM mean SNR values were calculated to identify optimal levels of each parameter presented in Table 3 and A₃-B₁-C₂-D₃ combination was considered as optimal setting parameters while, Table 4 presents ANOVA for ANOM Signal to Noise Ratio. Table 4 shows that factor stand-off distance is the most influential factor followed by factors pulse on time, applied voltage and electrolyte concentration based on ANOVA by considering 95% confidence level. Furthermore, factor SOD exhibits highest contribution of 64.785% whereas, pulse on time shows 26.557% contribution. However, it was observed that factors applied voltage and electrolyte concentration influence to a minimum level of 5.995% and 2.663% respectively.

Run		D	C	n	MRR	MD	OC	SNR _{MRR}	SNR _{MD}	SNRoc	SNR AVG	Ran
No	A	Б	U	υ	(mg/hr)	(µm)	(µm)	dB	dB	dB	dB	k
1	45	0.5	10	40	73.51	270.21	122.73	37.3269	48.6340	-41.7790	16.9873	3
2	45	1	17	50	65.73	263.92	152.39	36.3553	48.4294	-43.6591	15.9732	6
3	45	1.5	24	60	76.83	307.37	241.23	37.7106	49.7532	-47.6486	15.7156	7
4	50	0.5	17	60	98.22	392.88	227.494	39.8439	51.8852	-47.1393	17.3613	1
5	50	1	24	40	87.32	349.23	248.376	38.8223	50.8622	-47.9022	16.4169	5
6	50	1.5	10	50	56.87	220.48	246.797	35.0976	46.8674	-47.8468	13.7452	9
7	55	0.5	24	50	96.223	312.34	232.34	39.6655	49.8926	-47.3225	16.6372	4
8	55	1	10	60	95.432	381.92	236.81	39.5938	51.6394	-47.4880	17.0830	2
9	55	1.5	17	40	82.591	318.25	282.91	38.3386	50.0554	-49.0329	15.6422	8

 Table 2. ANOM data analysis

Table 3. Means of SNR _{AVC}

Symbol	Parameters	Level 1	Level 2	Level 3	Optimal level
Α	Applied Voltage (V)	16.2254	15.8412	16.4541	A ₃
В	Stand-off Distance (mm)	16.9953	16.491	15.0343	B_1
С	Electrolyte Concentration (wt.%)	15.9385	16.3256	16.2566	C_2
D	Pulse on time (µs)	16.3488	15.4519	16.7200	D_3

1065 (2021) 012003

Source	Sum of squares	DOF	Mean squares	%P (Percentage contribution)
Applied Voltage (V)	0.5757	2	0.2879	5.995
Stand-off Distance (mm)	6.2215	2	3.1107	64.785
Electrolyte Concentration (wt%)	0.2557	2	0.1279	2.663
Pulse on time (µs)	2.5503	2	1.2752	26.557

Table 4. ANOVA for ANOM Signal to Noise Ratio

3.2. Regression model

From the experimental data, regression model has been obtained by conducting analysis with MINITAB 17 software. The equations (6)-(8) represent the predicted values of MRR, MD and OC in terms of applied voltage (A), stand-off distance (B), electrolyte concentration (C) and pulse on time (D).

Material Removal Rate = -34.9 + 1.939 A - 17.22 B + 0.823 C+ 0.451 D (6)

Machining Depth =
$$-88 + 5.70$$
 A $- 43.1$ B $+ 2.29$ C $+ 2.41$ D(7)

Over cut =
$$-324 + 7.86 \text{ A} + 62.8 \text{ B} + 2.75 \text{ C} + 0.86 \text{ D}$$
(8)

3.3. Confirmation test

Confirmation test was conducted for the A_3 - B_1 - C_2 - D_3 combination of machining parameters obtained from ANOM and experimental responses are presented in Table 5. Predicted values for optimal combination were calculated by using regression equations (6)-(8). From table 5, showed that the error between experimental and predicted values of MRR, MD and OC are 4.22%, 1.92% and 3.46% respectively.

Table 5. ANOM conf	irmation te	st results
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Technique	Response	Optimal Parameters	Predicted	Experimental	% Error
ANOM	MRR(mg/hr)	$A_3B_1C_2D_3$	104.186	99.79	4.22
	Machining depth (µm)	(55V, 0.5mm,	387.48	380.02	1.92
	Overcut (µm)	17wt.%, 60µs)	238.05	229.81	3.46

Figure 2 shows the machined sample and SEM morphology of machined surface obtained after confirmation test with optimal setting parameters $(A_3-B_1-C_2-D_3)$. It is observed that heat affected zone occurred along the microchannel due to side spark with increase in voltage. Electrochemical discharge machining (ECDM) is a promising operation for micromachining of glass. Though it avoids surface cracking, it repeatedly produces surface damage due to its tendency to form subsurface cracks.



Figure 2. (a) Machined silica glass. (b) Typical SEM micrograph of machined surface from confirmation test.

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4. Conclusions

The machining of microchannel in silica glass attempted successfully in this work by considering ANOM of ECDM process parameters. Following conclusions were drawn out.

1. The recommended optimum setting of machining parameters through ANOM for obtaining maximum MRR, Maximum MD and minimum OC was found to be A_3 - B_1 - C_2 - D_3 (55V, 0.5mm, 17wt%, 60 μ s)

2. The ANOM confirmation test result showed that the error between experimental and predicted values of MRR, MD and OC are 4.22%, 1.92% and 3.46% respectively.

3. The analysis of variance resulted that the stand-off distance has major influence on MRR (mg/hr), MD (μ m) and OC (μ m).

References

- [1] Mehrabi, F., et al. "Application of electrolyte injection to the electro-chemical discharge machining (ECDM) on the optical glass." Journal of Materials Processing Technology 255 (2018): 665-672. Another reference
- [2] Lijo Paul and Somashekhar S Hiremath. Evaluation of process parameter in ECDM using grey relation analysis. Int. Con. On Advance in Manufacturing and Materials Engineering 2014; 2273– 2282.
- [3] Bassyouni, Zahraa, and Jana D Abou Ziki. "The Capabilities of Spark-Assisted Chemical Engraving: A Review." Journal of Manufacturing and Materials Processing 4.4 (2020): 99.
- [4] Madhavi, J. Bindu, and Somashekhar S. Hiremath. "Investigation on machining of holes and channels on borosilicate and sodalime glass using μ-ECDM setup." Procedia Technology 25 (2016): 1257-1264.
- [5] N. Sathisha, Hiremath S., J. Shivakumar, Int. J. Recent Adv. Mech. Eng. 3 (2) (2014) 69-81.
- [6] Crichton IM, McGeough JA, Munro W and White C. Studies of the discharge mechanisms in electrochemical arc machining. J of Appl. Electrochemistry 1985; 15: 113-119.
- [7] Cheng-Kuang Yang, Chih-Ping Cheng, A. Chao-Chuang Mai, Cheng Wang, Jung- Chou Hung, Biing-Hwa Yan, Int. J. Mach. Tools Manuf. 50 (2010) 1088–1096.
- [8] Bellubbi, S., Naik, R., & Sathisha, N. (2020). An experimental study of process parameters on material removal rate in ECDM process. Materials Today: Proceedings.
- [9] Doloi, B., B. Bhattacharyya, and S. K. Sorkhel. "Electrochemical discharge machining of nonconducting ceramics." Defence Science Journal 49.4 (1999): 331.
- [10] Naik, Gajanan M., et al. "An investigation on effects of wire-EDT machining parameters on surface roughness of INCONEL 718." Materials Today: Proceedings (2020).
- [11] S. Bellubbi and N. Sathisha. "Reduction in through put time of drum shell manufacturing by single-V welding configuration." MS&E 376.1 (2018): 012104.
- [12] Badiger, Ravindra I., S. Narendranath, and M. S. Srinath. "Optimization of process parameters by Taguchi grey relational analysis in joining Inconel-625 through microwave hybrid heating." Metallography, Microstructure, and Analysis 8.1 (2019): 92-108.
- [13] Badiger, Ravindra I., S. Narendranath, and M. S. Srinath. "Optimization of parameters influencing tensile strength of Inconel-625 welded joints developed through microwave hybrid heating." Materials Today: Proceedings 5.2 (2018): 7659-7667.
- [14] Gajanan M. Naik, S. Narendranath, A parametric optimization of wire-ED turning process parameters on material removal rate of INCONEL 718, Journal of Mechanical Engineering and Biomechanics, Volume 2, Issue 2, Page 8-14, 2017 ISSN- 2456-219X.
- [15] Shetty, Abhishek S., K. S. Akshar, B. Y. Prashanth, and Gajanan M. Naik. "Optimization of machining parameters on MRR for EN19 & EN31 steel using Taguchi method." Int. J. of Emerg. Res. Mngmt 6 (2017): 2278-9359.
- [16] Vishwas, C. J., L. V. Girish, Gajanan M. Naik, B. Sachin, Abhinaba Roy, B. Y. Prashanth, and RavindraIshwar Badiger. "Effect of Machining Parameters on Surface integrity during Dry Turning of AISI 410 martensitic stainless steel." In IOP Conference Series: Materials Science and

IOP Conf. Series: Materials Science and Engineering 1065 (2021) 012003 doi:10.1088/175

12003 doi:10.1088/1757-899X/1065/1/012003

Engineering, vol. 376, no. 1, p. 012127. IOP Publishing, 2018.

- [17] Sadashiv Bellubbi, Vijeath A, Mithesh Gowda J R, Karthik Prabhu. Experimental Investigation of Process Parameters on Machining Force, MRR and Power in Turning of AISI 316 Steel. International Journal of Computer Aided Manufacturing. 2019; 5(1): 18–25p.
- [18] Mallick, B., Sarkar, B.R., Doloi, B. and Bhattacharyya, B. (2017) 'Analysis on electrochemical discharge machining during micro-channel cutting on glass', Int. J. Precision Technology, Vol. 7, No. 1, pp.32–50.
- [19] Nagaraj, Y., Jagannatha, N., Sathisha, N. et al. Prediction of Material Removal Rate and Surface Roughness in Hot Air Assisted Hybrid Machining on Soda-Lime-Silica Glass using Regression Analysis and Artificial Neural Network. Silicon (2020).
- [20] Manjaiah, M., Narendranath, S., Basavarajappa, S. and Gaitonde, V.N., 2014. Wire electric discharge machining characteristics of titanium nickel shape memory alloy. Transactions of Nonferrous Metals Society of China, 24(10), pp.3201-3209.
- [21] M. Durairaj, D. Sudharsun, N. Swamynathan, Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade, Procedia Engineering 64 (2013) 868 – 877.
- [22] Amitesh Goswami, Jatinder Kumar, Optimization in wire-cut EDM of Nimonic-80A using Taguchi's approach and utility concept, Engineering Science and Technology, an International Journal 17 (2014) 236-246.
- [23] Jagannatha, N., S. S. Hiremath, and K. Sadashivappa. "Analysis and parametric optimization of abrasive hot air jet machining for glass using Taguchi method and utility concept." International Journal of Mechanical and materials engineering 7.1 (2012): 9-15.