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Parametric optimization of Electro Chemical Spark Machining using Taguchi based Grey Relational Analysis

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Abstract: *The non conductive materials like Glass and Ceramics play a major role in automobiles, aeronautics & other industrial applications due to their enhanced mechanical properties. Electro Discharge Machining (EDM) & Electro Chemical Machining (ECM) play a major role in many industrial applications to machine conducting materials but they fail to machine non-conducting material. In this Paper an attempt has been made to combine the principle of EDM & ECM process to machine non-conducting material. In this consideration an experimental set up of Electro Chemical Spark Machining (ECSM) has been developed. Experiments were conducted according to the Taguchi Orthogonal Array* L_9 *to groove on soda lime glass. The effect of process parameters like Tool-work piece gap, Voltage & Concentration of the electrolyte on Material Removal Rate (MRR) and Tool Wear Rate (TWR) is studied. Grey relational analysis is employed to optimize the process parameters of the multiple responses (MRR and TWR). The significant parameter to effect on MRR and TWR are determined using ANOVA. From the experimental results, it has been found that the Tool-Work piece gap has the greatest impact on MRR and Tool wear rate.*

Key words : *ECSM, Grey Relational Grade, MRR, TWR, Optimization,*

1.INTRODUCTION

The non-traditional machining methods are used for machining the brittle materials like Glass, Ceramics, and Granite etc. Electro Discharge Machining (EDM) and Electro Chemical Machining (ECM) play a major role in many industrial applications to machine conducting materials but they fail to machine non-conducting material. ECSM is a hybrid technology that combines the machining process of ECM and EDM. It is an emerging non-traditional processing technique that involves high-temperature melting and accelerated chemical etching under the high electrical energy discharged on the electrode tip during electrolysis.

B. Bhattacharyya et al.,2008, have developed an experimental setup of ECSM process for machining non-conductive materials like glass and ceramic materials and discussed the influence of electrolyte concentration, voltage and tool tip geometry on material removal rate and condition of machined surface. Electro Chemical Spark Machining (ECSM) process has been successfully applied for cutting of quartz using a controlled feed and a wedge edged tool (Jain and Adhikary.,2008). The ECSM with reverse polarity (ECSMWRP) as well as ECSM with direct polarity (ECSWDP) have been used to machine quartz plates and it has been proved that the surface quality was improved and is comparable to that from the conventional process. Micro-Electrochemical Discharge Machining (MECDM) was developed in order to improve the machining of 3D micro-structures of glass and optimization of process parameters for drilling and milling were studied. Raghuram et al.,1995 have studied the relationship between voltage and current in different kinds of electrolyte with varying concentrations. Kulkarni et al.,2002 have carried out the experiments to explain the mechanism of the spark generation and discussed that the synchronised and transient measurements revealed the discrete nature of the ECSM process. Cheng-Kuang Yang et al.,2010, have investigated that the wettability and machining characteristics of different tool electrode materials and their impact on gas film formation and their machining performance. The various alkaline solutions are used as electrolyte in ECDM. It is reported that the KOH electrolyte gives a smaller machining gap than an NaOH solution which results in increase of MRR, Xuan Doan Cao et al**.**,2009. Jana et al.2012., reported that electrochemical discharge machining can be used to machine the surface texture of glass and micro-channels and also showed that the tool-work piece gap influences the depth of the machined micro-channels. Cheng-Kuang et al. have used a spherical end tool electrode and reported that the curved surface of the spherical tool electrode reduces the contact area between the electrode and the workpiece which results in increasing the discharge frequency and reducing the machining time.

Basak and Ghosh et al.,1996, 97, have developed a theoretical model of discharge phenomenon considering process parameters like critical voltage and current required and compared with the experimental observations. Coteață et al.,2008, have developed an empirical mathematical model, showing the influence of process parameters on the electrode tool wear, MRR, and the shape accuracy of the machined hole. Liu et al. have discussed on the modeling of the discharge mechanism with an emphasis on the prediction of the critical breakdown voltage of the hydrogen bubble in ECSM process applied to machine a particulate reinforced metal matrix composite. Finite Element Model (FEM) based model has been developed by Bhondwe et al.,2006 to study the temperature distribution in the work piece and MRR with respect to change in the input parameters like electrolyte concentration, duty factor and energy partition.

The approach adopted by design of experiment through the Taguchi orthogonal array is very popular for solving optimization problems in manufacturing engineering. The ANOVA has been used successfully in process optimization by Chen and Chen,2007, Zhang et al.,2007 etc. The modified Taguchi robust design and utility concept is applied to determine optimal combination of process parameters to machine soda lime glass using Abrasive hot air jet and also ANOVA is used to identify the most significant factor by Jagannatha et al.,2012. Recently grey relational analysis is successfully employed in conjunction with Taguchi design of experiments to optimize the multiple response problems by Sathia and Jaleel, 2010, Chen et al., 2011, etc. Optimization of the process parameters was carried out using grey fuzzy analysis and ANOVA to find the percentage contribution of the drilling parameters to machine CFRP composites (Krishnamoorthy et al.,2012)

From the above literature survey, it is evident that ECDM is one of the best processes for machining non-conductive materials. In this paper, an attempt has been made to optimize the ECSM process parameters using Taguchi based GRA. The experiments were conducted according to the Taguchi Orthogonal Array L_9 to perform grooving operation on soda lime glass. The effect of process parameters like Tool-work piece gap, Voltage and Concentration of the electrolyte on MRR and TWR is studied. ANOVA is used to study the significant parameter to effect on output characteristics.

2. MATERIALS

In this paper, Soda-lime glass was used as the work material and the specimens were weighed before machining. After the test, the samples were cleaned and final weight was measured using a digital electronic balance (BSA224S-CW, SARTORIOUS, GERMANY) with resolution of 0.1mg. Four measurements for each sample were taken. The weight loss per unit time for each specimen is calculated and considered as Material Removal Rate (MRR). Similarly the Tool wear rate was calculated by the weight loss of tool after machining. This process involves more number of variables. For the purpose of present investigation, only major and easy to control variables like Tool-Work piece gap, percentage concentration of electrolyte and voltage were considered. The other experimental parameters are kept constant throughout the machining process.

3. EXPERIMENTATION

The schematic diagram of experimental set up of ECSM as shown in Figure 1. It consists of Tool (Cathode made up of stainless steel of diameter 0.6 mm), Zinc plate (Anode), Tool monitoring unit, Electrolyte container, work piece holder, D-C power supply unit and two axes table with CNC controller. The tool-work piece gap is adjusted using touch sensors. The vertical movement of the tool is controlled by automatic feed mechanism with micro controller. The movement of work piece is controlled by X-Y table with CNC controller. The gap between tool electrode and auxiliary anode is kept constant. In this work, different concentrations of NaOH are used as the electrolyte. When voltage is applied to the cell, reduction of electrolyte with liberation of hydrogen gas takes place at the gap. Discharge occurs at the tip of cathode when the voltage is increased beyond a critical value. Machining takes place on the work surface near the cathode at the location of discharge. Experiments were conducted for grooving operation on the work surface by varying tool- work piece gap for different values of voltage and electrolyte concentration.

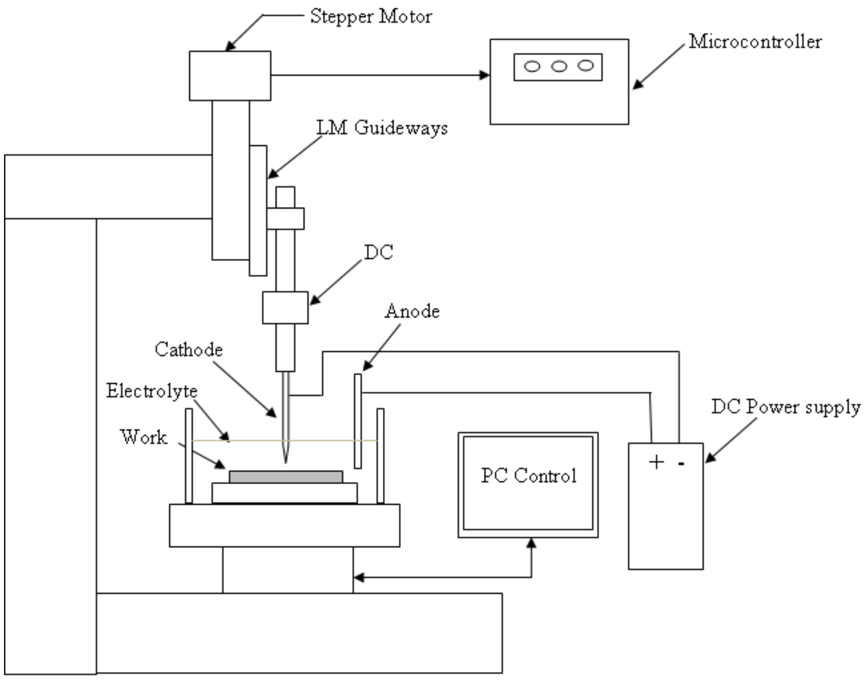

Figure 1- Schematic representation of Experimental set up of ECSM

4. RESULTS AND DISCUSSION

4.1 Grey Relational Analysis (GRA)

In the procedure of GRA, the experimental result of MRR and TWR are normalized at first in the range between zeros to one due to different measurement units. This data pre-processing step is termed as 'grey relational generating'. Based on the normalized experimental data, grey relational coefficient is calculated to correlate the desired and actual experimental data using equation (4). The overall Grey Relational Grade (GRG) is determined by averaging the grey relational coefficient corresponding to selected responses using equation (5). This approach converts a multiple response process optimization problem into a single response optimization by calculating overall grey relational grade. The normalized experimental results can be expressed as follows.

For the larger-the-better characteristic

$$x_i\,(k) = \frac{y_i(k) - min\ y_i(k)}{max\ y_i(k) - min\ y_i(k)} \qquad (1)$$

For the smaller-the-better characteristic

$$x_i\,(k) = \frac{max\ y_i(k) - y_i(k)}{max\ y_i(k) - min\ y_i(k)} \qquad (2)$$

and for the nominal-the-better characteristic

$$x_i\,(k) = 1 - \frac{|\,y_i(k) - y_{ob}\,(k)|}{max\ y_i(k) - min\ y_i(k)} \qquad (3)$$

where max $y_i\,(k)$ and min $y_i\,(k)$ are the largest and smallest values of y_i (k), respectively and y_{ob} (k) is the target of y_i (k). The Grey relational coefficient $\xi_i(k)$ for y_i (k) to y_0 (k) is calculated as

$$\xi_i(k) = \frac{\Delta_{min} + \Psi\,\Delta_{max}}{\Delta_{0i}(k) + \Psi\,\Delta_{max}} \qquad (4)$$

where $\Delta_{0i} = \|X_0(k) - X_i(k)\|$ is the difference of absolute value between x_0(k) and x_i(k), Δ_{min} and Δ_{max} are the minimum and maximum values of the absolute differences (Δ_{0i}) of all comparing sequences. Ψ is a distinguishing coefficient, $0 \le \Psi \le 1$, the value of Ψ is to be set to 0.5 to maintain equal weightage of all parameters. GRG, γ_i is obtained by averaging the grey relational coefficient corresponding to each experiment.

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{0} \xi_i(k) \qquad (5)$$

Experiments were conducted according to Taguchi's orthogonal array L_9 and the results of the responses MRR and TWR are given in Table 1. In this paper, the normalized response of MRR can be calculated by considering larger-the-better characteristics where as for the Tool wear rate, the smaller-the- better characteristics was considered. The normalized data, Grey relational coefficient and Grey relational grade for all nine experimental responses are as shown in Table 2.

Table 1. Orthogonal array and Experimental results

Expt.No.	**Levels**			**Experimental Results**	
	A Gap (mm)	**B Concentration(%)**	**C Voltage (V)**	**MRR (g/min)**	**TWR (%)**
1	1	1	1	0.400	1.425
2	1	2	2	0.425	1.610
3	1	3	3	0.412	1.789
4	2	1	2	0.600	1.546
5	2	2	3	0.678	1.487
6	2	3	1	0.613	1.398
7	3	1	3	1.510	1.104
8	3	2	1	1.235	1.068
9	3	3	2	1.298	1.004

Table 2. Grey Relational Analyses for MRR and TWR

Expt.No.	**Experimental data (Results)**		**Normalized values**		**Grey relational Coefficient**		**GRG**
	MRR (g/min)	**TWR (%)**	**MRR**	**TWR**	**MRR**	**TWR**	
1	0.400	1.425	0.0000	0.4636	0.3333	0.4824	0.4078
2	0.425	1.610	0.0225	0.2280	0.3382	0.3930	0.3656
3	0.412	1.789	0.0108	0.0000	0.3357	0.3333	0.3345
4	0.600	1.546	0.1801	0.3095	0.3788	0.4199	0.3993
5	0.678	1.487	0.2504	0.3847	0.4001	0.4483	0.4242
6	0.613	1.398	0.1918	0.4980	0.3822	0.4990	0.4406
7	1.510	1.104	1.0000	0.8726	1.0000	0.7969	0.8984
8	1.235	1.068	0.7522	0.9184	0.6686	0.8596	0.7641
9	1.298	1.004	0.8090	1.0000	0.7235	1.0000	0.8617

4.2 Optimal parameter Combination

The grey relational grades represent the level of correlation between the reference and the comparability sequences, the larger value of grey relational grade means the comparability sequence exhibiting a stronger correlation with the reference sequence. Based on this study, the combination of A_3, B_1 and C_2 shows the largest value of the grey relational grade for the factors A, B, and C, respectively. The combination of A_3 B_1C_2 is treated as the optimal parameter combination of the ECSM.

4.3 ANOVA based on Grey Relational Grade

After the Grey relational analysis, statistical software Minitab16 with an analytical tool of ANOVA is used to determine the parameter which significantly affects the performance characteristics. The results of ANOVA for the grey relational grades are listed in Table 3. It is observed that the Tool-Work piece gap has highest contribution of about 96.9% and the other parameters have less contributions. From Table 3, it is clear that the Tool-Work piece gap is one of the significant factors that have more impact than any other factors.

Table 3. ANOVA for Grey Relation Grade

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**Contribution (%)**
A	2	0.4020	0.4020	0.2010	1160.33	96.9
B	2	0.0038	0.0038	0.0019	11.09	0.92
C	2	0.0090	0.0090	0.0045	26.03	2.17
Error	2	0.0003	0.0003	0.0001		
Total	8	0.4152				

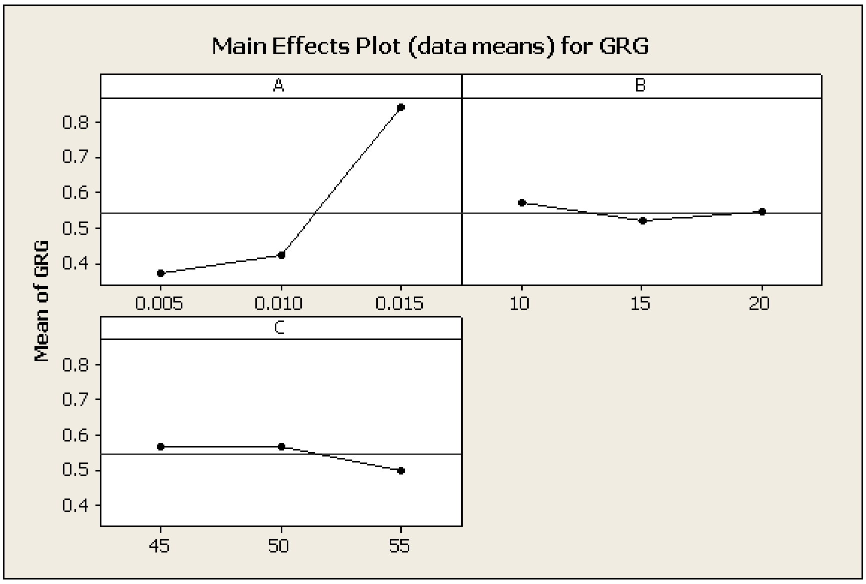

Figure 3 Main effects plot based on Grey Relational Grade

From the Main effects plot (Figure 3), the optimum values of factors like Tool-Work piece gap is available at level 3, percentage of concentration of electrolyte is available at level 1 and voltage is available at level 2 (that is with a Tool-Work piece gap of 0.015 mm, percentage of concentration of electrolyte of 10% and voltage of 50 V). The optimal process parameters combination for maximum MRR and minimum TWR is the one that yields maximum value of Grey relational grade. Thus the optimal process parameter combination is found to be A_3 B_1C_2. It has been proved by main effect plot.

5. CONFIRMATION TEST

After identifying the most influential parameters, the final phase is to verify the predicted results (MRR and TWR) by conducting the confirmation test. The A_3 B_1C_2 is an optimal parameter combination of the ECSM process via the GRA. Therefore, the combination A_3 B_1C_2 was treated as a confirmation test. The estimated Grey relational grade can be calculated using the optimum parameters as

$$\tilde{\gamma} = \gamma_m + \sum_{i=1}^{0}(\overline{\gamma}_i - \gamma_m) \quad (6)$$

where γ_m is the total mean of the Grey relational grade at the optimal level.

Table 4. Results of Confirmation Test

	Optimal parameter combination		
	Initial	**Predicted**	**Experimental**
Setting level	$A_1B_1C_1$	$A_3B_1C_2$	$A_3B_1C_2$
MRR	0.400	-----	1.510
TWR	1.425	----	1.104
Grey relation Grade	0.4078	0.890	0.898

In order to validate the results obtained, three confirmation experiments were conducted for each of the response characteristics at optimal levels of the process variables. The GRG value is calculated and compared with the predicted values. Table 4 shows the comparison of estimated GRG with GRG obtained from the experiment. It may be noted that there is good agreement between the estimated value (0.890) and the experimental value (0.898). Therefore, the condition A_3 B_1C_2 of the parameter combination of the ECSM process was treated as optimal. The optimal combination A_3 B_1C_2 (0.015 mm, 10 %, and 50 V) is also confirmed by ANOVA. It can be found that the Tool-Work piece gap has influencing on the performance of ECSM for glass.

6. CONCLUSION

The optimization of process parameters of ECSM using Taguchi orthogonal array with Grey relational analysis is discussed in this paper. From the experimental investigation and analysis, the following conclusions can be drawn.

- On the basis of GRA, the combination of A_3, B_1 and C_2 (the Tool-Work piece gap of 0.015 mm, percentage concentration of electrolyte of 10 and voltage of 50 V) shows the largest value of the grey relational grade. Hence, the combination A_3 B_1C_2 is treated as the optimal parameter combination of the ECSM.
- From ANOVA, it is observed that the percentage of contribution to the Tool-Work piece gap (96.9%) is more as compared to other parameters. Hence, the Tool-Work piece gap is the most significant factor for the ECSM process. It is confirmed from the main effect plot also.
- It is found that there is good agreement between the estimated value of Grey relational grade (0.890) for optimal combination (A_3 B_1C_2) and that of experimental value (0.898) for the maximization of MRR and minimization of the TWR .

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