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EXPERIMENTAL ANALYSIS OF PROCESS PARAMETERS IN ELECTRO-CHEMICAL SPARK MACHINING & OPTIMIZATION USING NSGA-II

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Abstract

Electro-Chemical Spark Machining (ECSM) has been used due to its advantages, such as less tool wear and complicate pattern shapes that are also developed in hard non conducting material. The purpose of this work is to optimize the process parameter of ECSM using the Non- sorted Genetic Algorithm-II. It will be identified from the literature survey that different technologies are implemented on ECSM as well as on other non-conventional machining processes. After optimizing the process parameter through the Non-Sorted Genetic Algorithm it provides the optimum parameters for this ECSM setup that will be helpful for future research work.

Keywords: Electrochemical Spark Machining (ECSM), Tungsten tool electrode, Soda-lime, NSGA-II

1. INTRODUCTION

In fabrication, the technique of material removal has a critical role. In a few decades, it is found that the machining of non-conducting is very difficult through traditional machining. Non-conducting materials were refined for a variety of industries ranging in various engineering[1]. Machining of these materials with traditional tools results in damage to the work-piece and in tool damage. The tool geometry and tool size limit the shape of the final component that can be machined[2]. These tools tend to leave burrs during the machining on the machined surface and this is another problem with the tool which is undesirable. Non-conventional machining processes resolved these problems[3]. The considerable variation between the traditional and modern machining methods is that traditional methods use a tool which is hard in comparison to work-piece by physical means while the modern machining techniques use soften tool as compare to the workpiece[4].

1.1 Objective

The aim of this research is:-

1. Experiment investigation of process parameters for the machining of soda-lime glass.
2. Evaluate MRR and Taper Angle.
3. Optimization of the process parameter using the Non-Sorted Genetic Algorithm-II.

1.2 Methodology

1. Prepare a testing Rig of ECSM & workpiece of soda-lime glass.
2. Selection of process parameters like voltage concentration and IEG.
3. Obtain MRR and Taper angle in the various set of experiment
4. Formulate the problem in the Fit Regression model[5] composites, super alloys, ceramics, hastelloys, nitralloy, nemonic alloys, carbides, heat resistant steels etc. In EDM, the material removal of the electrode is achieved through high frequency sparks between the tool and the work-piece immersed into the dielectric. The Material Removal Rate (MRR Using Minitab Software and obtain the unique equation of MRR and Taper Angle.
5. Creation of M-file in Matlab[6] 2015.
6. Optimize the equation using the optimization tool for NSGA-II.
7. Analyze the results.

2. LITERATURE SURVEY

Recent research for the process parameters in ECSM:-

Parvesh Antil, Sarbjit, Alakesh Manna [1]. Various strengthen materials are developed by researchers in which the improved composites which are remarkably used in aerospace and marine. In this research the prime parameters are voltage, electrolyte concentration and duty factor and responses are MRR and TWR. The genetic algorithm is used for the optimization of parameter and predicts the value of MRR and Taper was found to be 1.154 mg/min and o.o446 mm respectively.

Parvesh Antil, Sarbjit Singh & Parminder Jit Singh.[2] The experimental investigation is done using the L_9 orthogonal array generated by Taguchi design and concluded:-

- ECDM process is effectively used for the fibrous composites.
- Optimal parameters for MRR are found concentration 110gm/L, voltage 70V and IEG 100mm.
- The trends for the parameter for MRR are directly proportional to voltage and electrolyte concentration and inversely proportional to the inter-electrode gap.

The SEM image of micro-hole in a 100x magnified view. It shows clear-cutting and removal of fibber from the surface of composites.

Lijo Paul, Somashekhar S Hiremath[4]**.** In this review study, it was found that the electrochemical spark machining is an emerging non-conventional machining process to machine various non conducting materials. The machining setup was developed in various stage and the experiments were carried out with different tool geometries to study MRR, HAZ, and TWR. FEM/ANN analysis ware used for the model and simulation aspects.

Yong Liu, Chao Zhang, Songsong Li, Chunsheng Guo and Zhiyuan Wei[7] This research concluded about the optimized mathematical model for machining of microstructures on ultra-clear glass, shows that the side gap increased with an increase in voltage and duty factor and reduced with feed rate and frequency using a rotary helical tool.

Ankit D.Oza, Abhishek Kumar, Vishvesh Badheka, Amit Arora[8]**.** This research is done with traveling wire Electrochemical Discharge Machining of quartz using zinc-coated brass wire for the investigation of MRR and Kerf Width. The optimization of the MRR and Kerf width is done with ANOVA and SEM images are obtained. ANOVA analysis shows that contribution of voltage, concentration, and wire-speed in MRR are 65.79%, 31.48 and 1.04% respectively. Both MRR and Kerf Width the performance is governed by the effects of voltage and electrolyte concentration. Craters are obtained due to no flushing during the machining. This experiment also concluded that micromachining of quartz material is possible with the proper selection of input parameters.

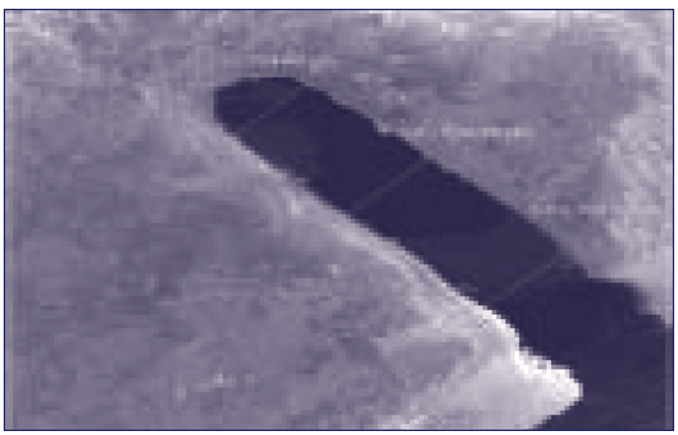


Fig. 1. SEM image [6]

Dilpreet Singh, Mudiamallana Gaud[9]. The MRR of quartz, soda-lime glass and alumina is obtained through the simulation model using Ansys. The effect of convection is considered in this modal which results in lower MRR due to higher heat loss. It confirms that MRR increases with an increase in voltage.

This FEA model is based on the following assumptions:-

- Homogeneous and isotropic properties of materials are considered.
- Thermal conductivity and specific heat are considered as temperature-independent,
- The high-temperature area is very small so heat transfer by radiation is neglected.
- Electrochemical action is not considered in material removal
- The recast layers and resettlement of material is neglected.

Anjali Kulkarni, VK Jain.[10] This paper concluded that the productions of micro-channels are obtained by the ECSM process. In 5 minutes of machining a micro-channel of 1100 micro mm with a depth of 120 micro mm. The machined surface is produced by melting and vaporization it can be analyzed by SEM images of the work-piece. Material removal involves various processes such as electrochemical reactions, nucleate pool boiling breakdown of hydrogen bubbles, generation of electrons electron drifting.

Mohit Vishnoi, A.N Veerndra Kumar and S.Senthil Murugan[11]**.** Their research is related to the optimization of the parameter in the Micro ECDM process of borosilicate glass. The results of the experiments are carried out by Taguchi L9 array and the best fit for drilling is obtained from MINITAB software. The optimal results for MRR and TWR are voltage 55V, electrolyte concentration 40 gm and IEG 6 mm. From the analysis, it was found that IEG has the highest impact on MRR and TWR.

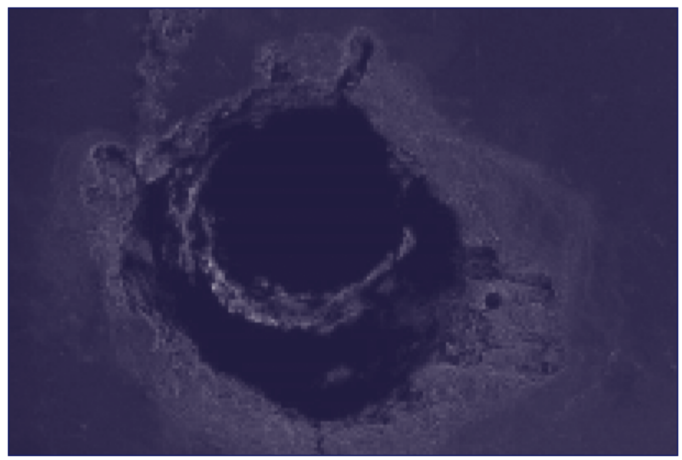


Fig.2. SEM of Machined Holes [11]

B Mallick, B.R Sarkar, B Doloi, Bhattacharya[12]. From this investigation, it was concluded that ECSM can be utilized for micro-channels cutting, micro slot cutting and micro-hole application in non conducting material such as glass:-

- MRR increases with an increase in voltage, electrolyte concentration, duty factors was an increase.
- Overcut increase with an increase in applied voltage, electrolyte concentration, duty factor.
- HAZ area increase with applied voltage, electrolyte concentration and duty factor.

Jiangwen Liu, Zhibio Lin, Zhongning Guo, Shuzhen Jiang, Taiman Yue, and Xiaoler Chen[13] Studied the materials removal mechanism of Grinding Aided Electrochemical Discharge Machining of Metal Matrix Composites. This research found that during the process ECDM effect dissolves & melts metal matrix composites.

- Melting effects obtain a crater on workpiece surface & grinding removes the convex edge of the crater formed by ECDM.

- High-speed condition the material is thrown out volume but also convex material removal volume increases. So high MRR is expected.

Weidong Tang, Xiaoming Kang and Wansheng Zhao. [14] Enhancement of electrochemical discharge machining accuracy and surface integrity using an insulated tool electrode with diamond coating. The insulation layer on the side insulated electrode prevents the electrolyte from contacting the electrode sidewall. So the film formation and discharge formation happened in front of the electrode.

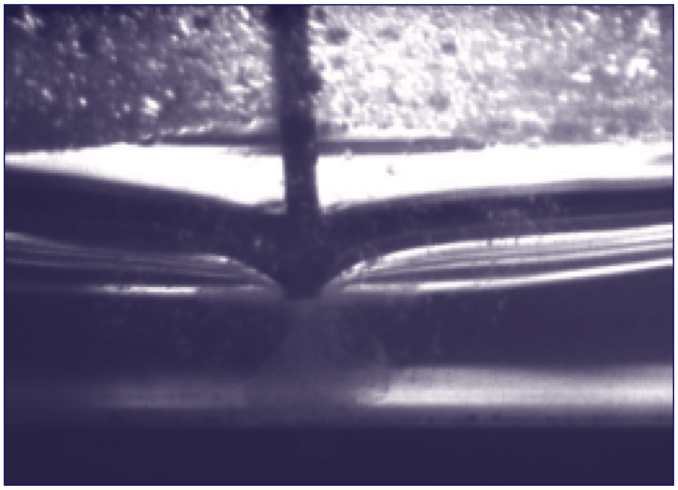


Fig.3. Gas film image when pulses produced [12]

Aninda Das, Pushpendu Chandra & Sabyasachi.[15] The impact of input factor voltage, concentration on the response (MRR, TWR, WOC, and MD) in machining process was analyzed in This research paper and comparison is done on the basis of two different electrolytes and concluded that:-

- MRR and width increase with an increase in applied voltage for a fixed concentration.
- ECDM reveals a tremendous prospective for micro-channel cutting on non-conductive materials.

Debanjan Maity, Bappa Acherjee, Arunanshu S.Kuar [16] Quality improvement of the ECDM process using the firefly algorithm. This paper concluded that:-

- Single and multi-objective optimization in ECSM can obtain by using FA.
- FA converges faster and superior results then ABC.

The optimized results were obtained out of 110 non dominated solutions of the 7 Pareto optimal solutions of the 500th generation.

Balwinder Singh, RO Vaishya and Vikas Sheel [17] Machining of borosilicate glass with ECDM using Different abrasives.

- In the case of KOH and NaOH surface roughness is better than $NaNO_3$.
- Sooth cutting and average MRR with NaOH.
- Electrolyte concentration and abrasive concentration increase MRR.
- Alumina abrasive gives the maximum MRR and minimum SR.

3. SELECTION OF ELECTRODES AND WORKPIECE

3.1 Electrode: Tungsten is used as a tool electrode for the machining of soda-lime glass. Tungsten tool is a rare metallic non-consumable tool electrode used in arc welding and has the highest melting point of any metal 3410 degree Celsius. One of the three preparations can be choosing balled truncated or pointed.

Properties of tungsten are given below (@ 20degree):

Density 19.3 gm/cc, melting point 3410 degree Celsius, boiling 5530 degree Celsius, linear expansion coefficient 4.3X10^{-6} thermal conductivity 0.40 cal/gm/c, specific heat 0.0332 degree Celsius.

3.2 Workpiece

The most common type glass is soda-lime which is produced by melting of soda, lime, silica[18], alumina[19]high values of these properties make it more difficult to shape these materials by machining using conventional methods, thereby limiting their widespread applications. Electrochemical machining (ECM, and small quantities of fining glass at 1675°C in a furnace. Glass sheets of soda-lime obtained by pouring a layer of molten Sheets of a glass of soda-lime obtained by pouring a layer of molten glass on the surface of the molten tin.[2]

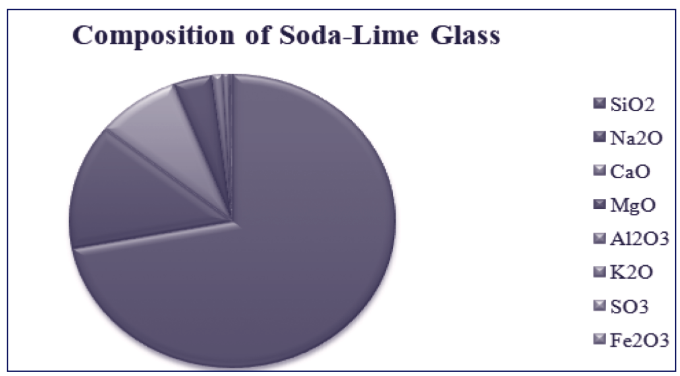


Fig.4. Composition of Soda Lime Glass[20]

4. EXPERIMENTAL ARRANGEMENT

The experiments have been performed on a multi-axis Numerical Controlled (NC) Electro-Chemical Spark Machine[21]. All axis of the machine can be programmed and controlled with NC code through the GRBL control panel. The machining operation takes place by feeding the tool into the workpiece by maintaining the gap.

According to function, ECSM is divided into the following parts:-

1. Structure (3 Axis)

2. DC Power supply Unit (0-300V)[2]

3. GBRL Controller Unit[22]

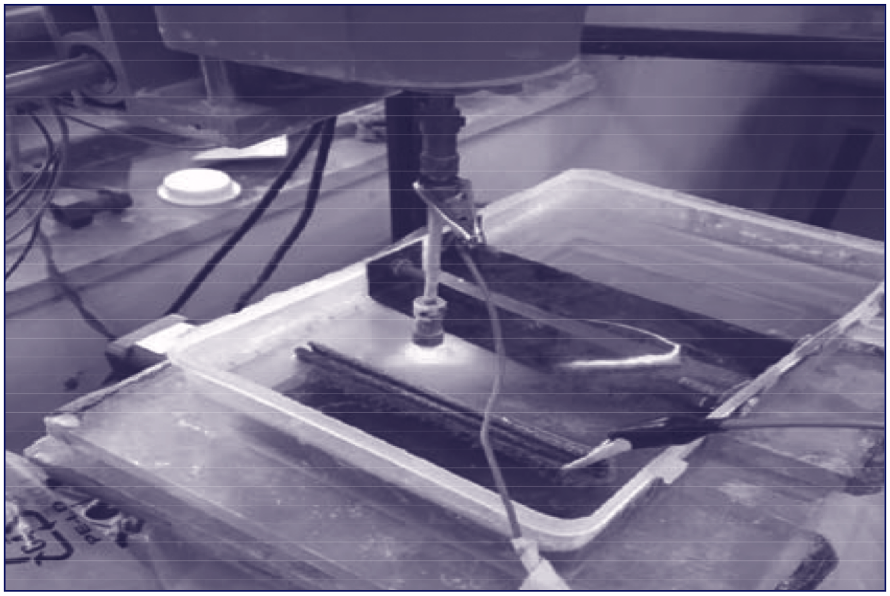


Fig.5. Machining Set-Up

5. MODEL FORMULATION FOR TUNGSTEN TOOL ELECTRODE AND SODA-LIME WORK-PIECE

For better results, analysis, and conclusions the statistical design of the experiment is an efficient procedure for planning[23]. The input parameters are the process parameter and while the output parameter is the response from the statistical design[24]. Each Process parameter can take several values during the experiment and each value is called a level[25].

Table 1 Experimental outcome for various set of process parameter

set no.	voltage	concentration (gm/l)	Ieg (cm)	MRR (micro gm/min)	Taper angle (degree)
1	65	60	3	1060	48.34
2	65	70	4	1207	18.47
3	65	80	5	2791	19.09
4	65	90	6	1662	30.19
5	75	60	4	1361	27.31
6	75	70	3	1554	16.49
7	75	80	6	3030	29.30
8	75	90	5	1911	43.13
9	85	60	5	1432	35.23
10	85	70	6	1354	43.11
11	85	80	3	1967	32.85
12	85	90	4	2256	43.03
13	95	60	6	1449	37.48
14	95	70	5	1709	39.69
15	95	80	4	2027	43.23
16	95	90	3	2182	47.33

Now it is required to know the behaviour of the system. The Fit Regression Model[5]composites, super alloys, ceramics, hastelloys, nitralloy, nemonic alloys, carbides, heat resistant steels etc. In EDM, the material removal of the electrode is achieved through high frequency sparks between the tool and the work-piece immersed into the dielectric. The Material Removal Rate (MRR is used to know the system behaviour was obtained in the form of equations for MRR[26] and Taper Angle[27].

The regression equation[28] for response in the terms of various parameters

$Y=\beta_o+\beta_1X_1+\beta_2X_2+\ldots\beta_nX_n+e$

This equation can also fit with customized interaction terms[29]

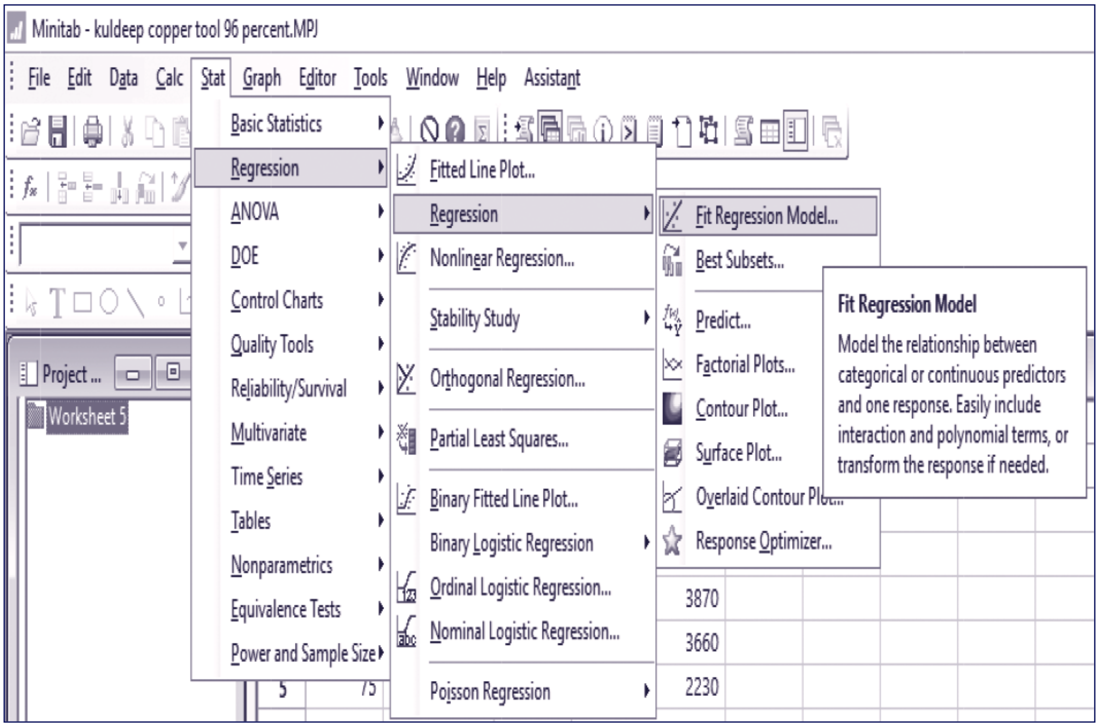


Fig.6 Fit Regression Model in Minitab

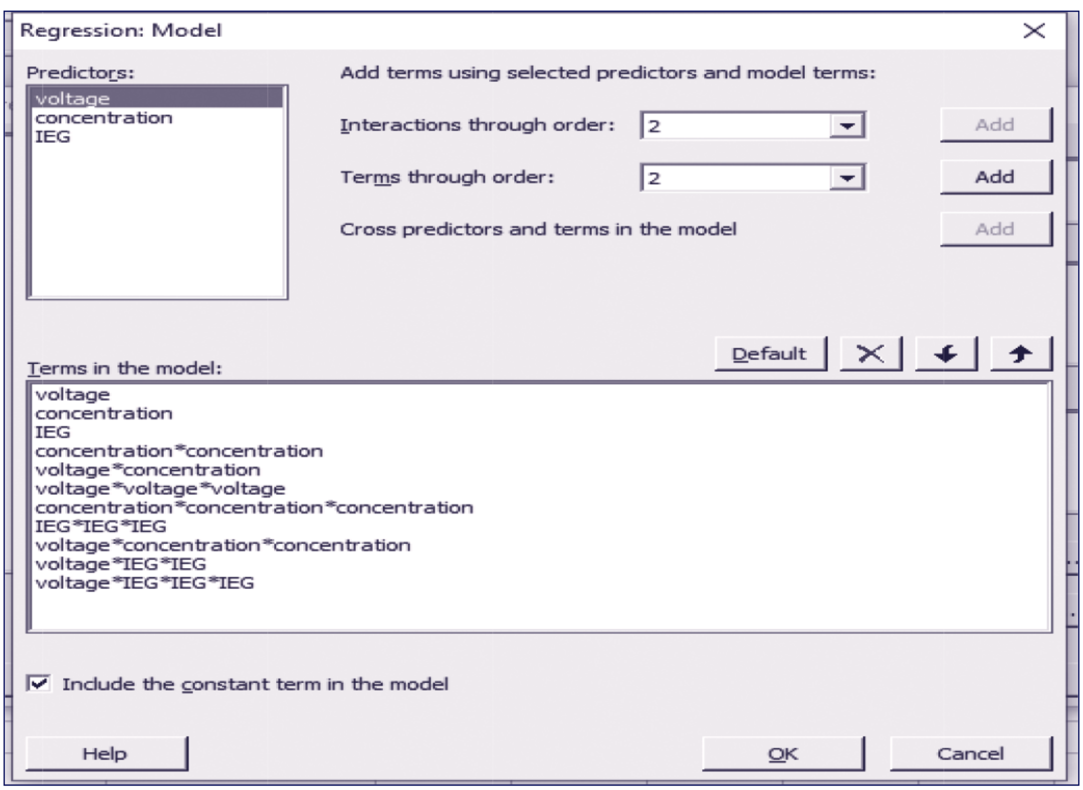


Fig.7. Obtaining the Regression Model

5.1 ANOVA for MRR

Table 2 Analysis of Variance &Equation of MRR for tungsten tool (cathode) by Regression

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	12	4036503	336375	512.62	0.000
A	1	114523	114523	174.53	0.001
B	1	657294	657294	1001.68	0.000
C	1	147474	147474	224.74	0.001
B*B	1	531140	531140	809.43	0.000
C*C	1	191698	191698	292.14	0.000
A*B	1	104520	104520	159.28	0.001
B*C	1	5335	5335	8.13	0.065
B*B*B	1	303365	303365	462.31	0.000
A*B*B	1	106002	106002	161.54	0.001
A*B*C*C	1	360999	360999	550.14	0.000
A*C*C*C	1	228008	228008	347.47	0.000
A*B*B*B*C*C	1	413178	413178	629.66	0.000
ERROR	3	1969	656		
TOTAL	15	4038472			
	S	**R-sq**	**(R-sq(Adj**	**(R-sq(Pred**	
	25.6163	99.95%	99.76%	97.79%	

Taguchi's L16 design of the model is created for sets of tungsten tool electrode. Experiments are conducted and the following equation obtained for

$$\text{MRR } (\mu gm/min) = -228385 + 1019.5\,V + 7280\,C + 6294\,I_{EG} - 74.85\,C2 - 575.0\,I_{EG^2} - 25.91\,V\,C - 19.56\,C\,I_{EG} + 0.2278\,C^3 + 0.1735\,V\,C^2 - 0.20311\,V\,C\,I_{EG^2} + 1.1931\,V\,I_{EG^3} + 0.000017\,V\,C3\,I_{EG^2}$$

5.2 ANOVAs for Taper Angle

Table 3 Analysis of Variance &Equation of Taper Angle by Regression

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	12	1409.04	117.42	403.97	0.000
A	1	126.15	126.153	434.02	0.000
B	1	105.43	105.428	362.72	0.000
C	1	47.25	47.25	162.56	0.001
B*B	1	115.44	115.437	397.15	0.000
B*C	1	12.14	12.139	41.76	0.008
B*B*B	1	117.41	117.41	403.94	0.000
C*C*C	1	70.84	70.835	243.7	0.001
A*C*C	1	202.04	202.04	695.11	0.000
B*B*C	1	17.9	17.904	61.6	0.004
A*A*C*C*C	1	55.9	55.904	192.33	0.001
A*B*C*C*C	1	66.38	66.383	228.39	0.001
A*B*B*C*C*C	1	52.29	52.291	179.9	0.001
Error	3	0.87	0.291		
Total	15	1409.91			
	S	**R-sq**	**(R-sq(Adj**	**(R-sq(Pred**	
	0.5391	99.94%	99.69%	97.65%	

Experiments are conducted and the following results are obtained-

Taper Angle (Degree) $= 2285 - 3.775\,V - 76.51\,C - 267.8\,I_{EG} + 1.0803\,C^2 + 2.827\,C\,I_{EG} - 0.004774\,C^2 + 1.813\,I_{EG}^2 + 0.5873\,V\,I_{EG}^2 - 0.02554\,C^2\,I_{EG} - 0.000178\,V^2\,I_{EG}^3 - 0.001523\,V\,C\,I_{EG}^3 + 0.000011\,V^2\,C\,I_{EG}^3$

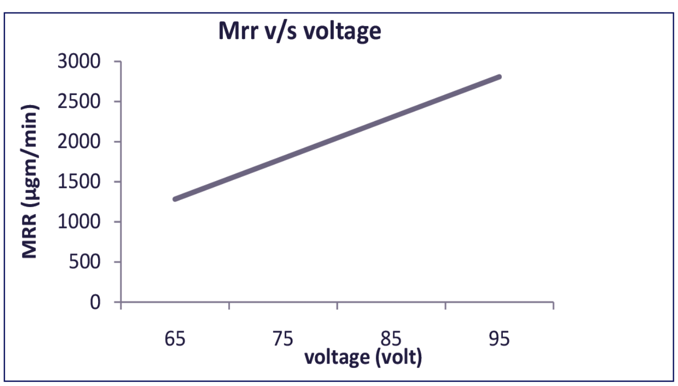
Table 4 Comparative results

set no.	Exp.MRR (µgm/min)	PRED MRR (µgm/min)	Taper angle (°)	Pred. angle (°)
1	1207	1282	18.47	17.89
2	2791	2967	19.09	19.11
3	1662	2096	30.19	32.01
4	1361	2231	27.31	32.39
5	1554	1654	16.49	16.84
6	3030	3136	29.30	28.60
7	1911	2576	43.13	47.85
8	1432	2056	35.23	37.88
9	1354	1546	43.11	44.52
10	1967	2452	32.85	37.28
11	2256	2404	43.03	43.13
12	1449	1947	37.48	38.93
13	1709	2070	39.69	43.13
14	2027	2425	43.23	46.11
15	2182	2569	47.33	47.98
16	1604	1897	35.01	34.60

6. RESULTS AND DISCUSSION

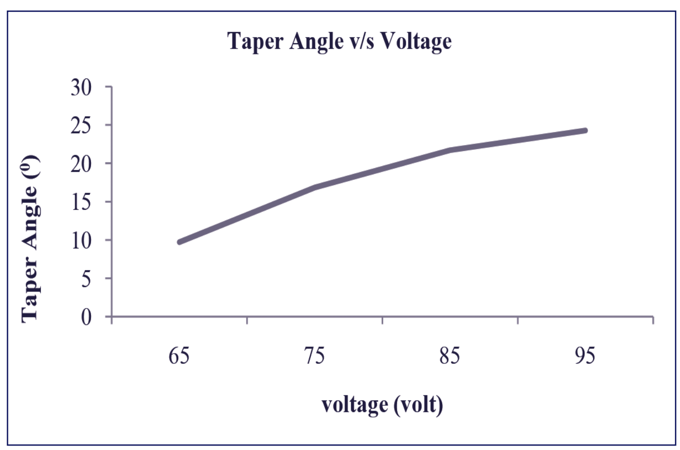
6.1 Effect of voltage:-The effect on material removal rate while increasing voltage is showing in figure it shows that Mrr increase with an increase in voltage. (Concentration=60 gm/l & IEG=3 cm)

Fig.8. Mrr V/s Voltage



The change in the taper angle shown in the figure. It shows that the increase in voltage increase the taper angle. Low voltage results in a lower intensity of electric field that further reduced by stray current so that a low voltage taper angle decreases. Further increase in voltage at a higher value increases the current; hence the taper angle increases with an increase in voltage.

Fig.9 Taper Angle v/s Voltage



6.2 Effect of concentration: - Material removal rate increases with an increase in concentration as shown in the graph while using tungsten electrode and soda-lime glass at constant voltage=95V and IEG=5cm).

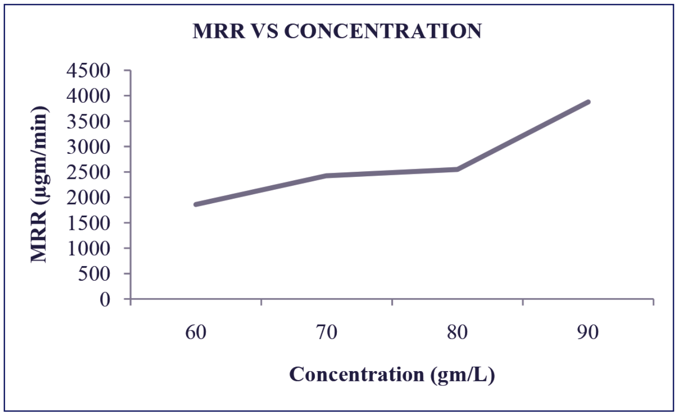


Fig.10 Mrr vs. Concentration

The influence of concentration on the taper angle is shown in the below figure shows that an increase in concentration increase the taper angle. The reaction rate is higher at the top surface as compared to the bottom of the hole which leads to an increase in the taper of the hole.

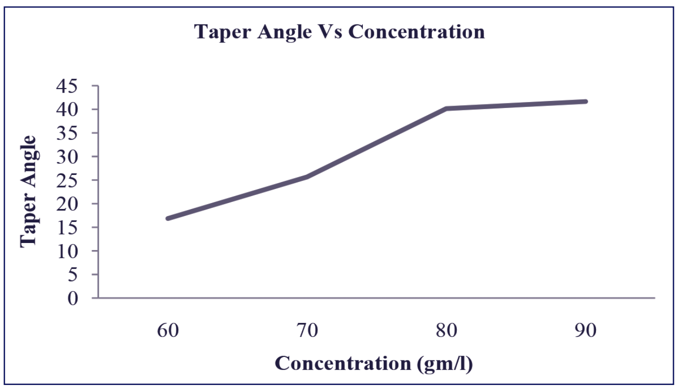


Fig.11 Taper Angle vs. Concentration

6.3 Effect of IEG: - The effect of IEG on material removal rate while using the tungsten electrode as a tool on soda-lime glass showed in figure. It shows that Mrr is decreased with an increase in the inter-electrode gap at constant voltage (95V) & concentration=60gm/l).

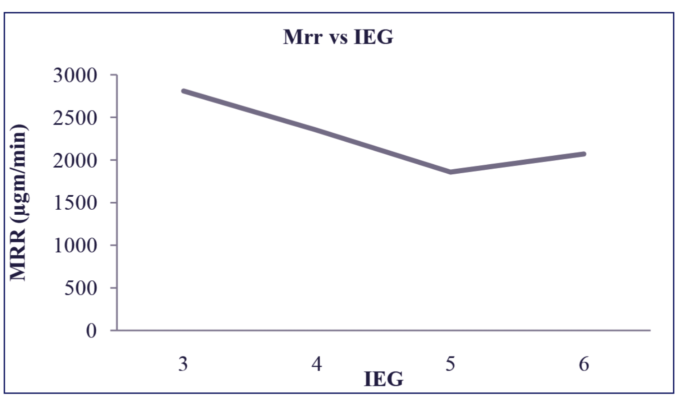


Fig.12 Mrr vs. IEG

The plot of the Taper angle vs. interelectrode gap shown in the figure. The taper angle decreases with an increase in IEG because IEG permits the dissolution of the area at top of the hole.

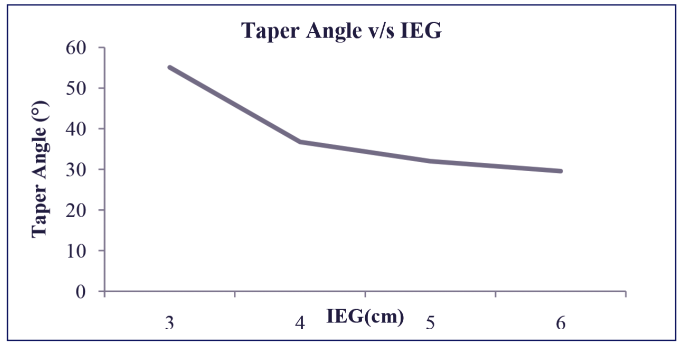


Fig.13 taper angle vs. IEG

6.4 Optimization of MRR and Taper angle tungsten tool used for material removal:

These empirical equations are obtained from Regression Fit Model using MINITAB 7. The R-square value is 0.98 are both MRR and Taper Angle.

Using the multi-objective Matlab 2015 environment for the optimization of response and decision variables. The Pareto fronts obtained for response are shown below:-

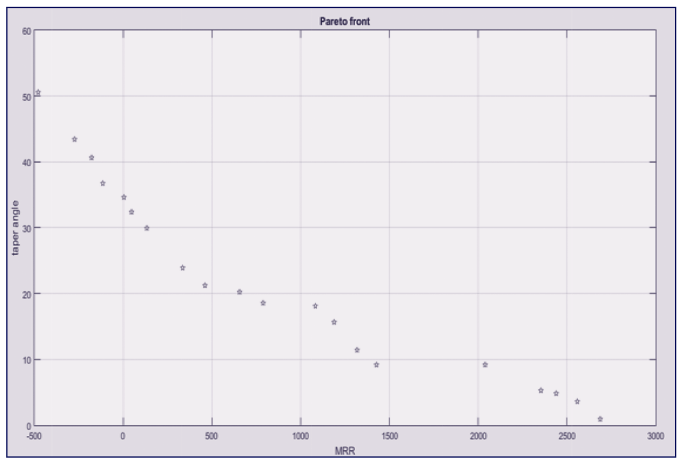


Fig.14 Pareto Front of Response (MRR & Taper Angle)

7. CONCLUSION

From the literature survey, it is found the copper tool electrode was used as cathode generally. In this experiment, a non-consumable tool electrode tungsten is used to obtain the optimized (NSGA-II) process parameter for the ECSM for nonconducting materials.

This experimental research concluded using tungsten tool electrode that:-

a. The characteristic curve is drawn between MRR/taper increases with an increase in voltage and electrolyte.

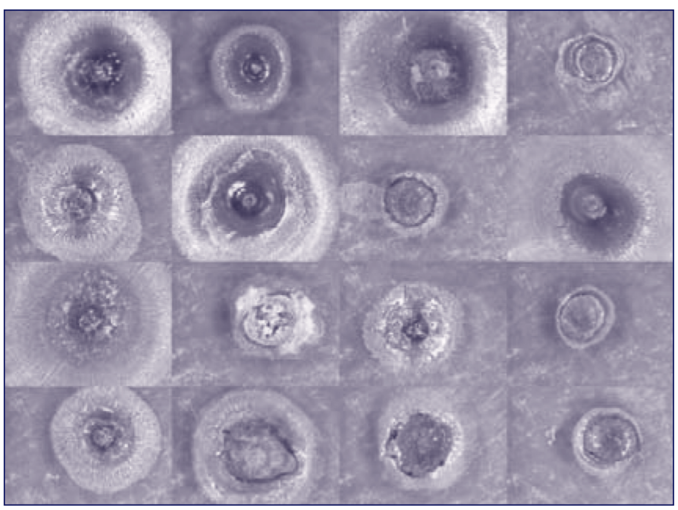
b. The characteristic curve is drawn between the MRR/taper decreases with an increase in the inter-electrode gap.

c. Using Non-Sorted Genetic Algorithm-II Optimum solutions from the Pareto front for response and decision variable are obtained in (between voltage=65-95volt, concentration = 60-90 gm/l and IEG =3-6 cm) as follows:-

Table 5 Optimized Set for Optimum Response

S.No	MRR	Taper angle	Voltage	Concentration	IEG
1	2039.54	9.20	79.77	60.00	3.07
2	1083.88	18.18	65.03	60.18	4.76
3	-478.59	50.54	65.04	89.99	3.01
4	2686.40	0.93	91.79	60.21	3.01
5	1426.11	9.22	65.00	60.22	3.80
6	2686.40	0.93	91.79	60.21	3.01
7	2440.63	4.84	86.59	60.26	3.02
8	-272.70	43.41	65.27	89.96	3.18
9	-114.38	36.73	65.04	89.98	3.37
10	4.12	34.59	65.59	89.95	3.44
11	2558.13	3.65	88.33	60.41	3.02
12	2354.60	5.32	86.00	60.02	3.04
13	459.65	21.25	65.04	89.99	4.07
14	-176.75	40.66	65.52	89.95	3.26
15	132.27	29.99	65.43	89.96	3.61
16	47.44	32.41	65.11	89.89	3.52
17	787.05	18.59	65.03	89.95	4.52
18	335.85	23.96	65.15	89.97	3.89
19	1317.65	11.38	65.72	60.10	4.16
20	1189.68	15.69	65.06	60.30	4.60
21	655.67	20.23	65.02	89.70	4.29

Fig.15 Soda Lime Workpiece after Machining



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