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Analysis of Electro Chemical Machining (ECM) on Copper Work Piece by Non-Dominated Sorting Genetic Algorithm (NSGA)

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ABSTRACT-

In this research paper, the effect of various input parameters such as applied voltage, electrolyte concentration, flow rate and inter-electrode gap on machining rate was done using Taguchi method. Experiments are conducted on ECM with the aim to check the performance of process parameter on the surface of copper by using Non Dominated Sorting Genetic Algorithm. Set of experiments were designed by using Taguchi L9orthogonal array using Minitab17. Regression equation and analysis of variance (ANOVA) were also done by Taguchi technique. Increase in machining voltage, flow rate and electrolyte concentration, material removal rate is also increasing. Experimental result shows that inter-electrode gap is the most affecting parameters on MRR and taper angle. As the inter-electrode gap increase the MRR and taper angle is decreases.

Keywords– MRR, Taper angle, ANOVA, Copper, Taguchi, Non-dominated sorting genetic algorithm

INTRODUCTION

Electro chemical machining is a non-traditional machining process which is used for machining materials which are difficult to machine by traditional machining process. It is a precise material removal machining process with no tool wear and good surface finish. ECM has several advantages which makes this technique more effective than other unconventional machining process. It is also used for producing complex or intricate shapes**.** H. Hocheng et al.[1]shows that as the value of process parameter (voltage, inter electrode gap, concentration of electrolyte and time of electrolysis) is increasing, MRR increases for SKD61 SS. Time of electrolytes influencing the diameter of hole .

Z. Pandilov et al.[2] they said that it is a contactless procedure with no heat input, the process is not subject to any of the dis advantage experienced with traditional machining method. S. K. Soni et al.[3]conducted experiment for drilling of LM6 AL/B4C composites using Taguchi L27 orthogonal array and the result shows electrolyte concentration and voltage are the most significant machining parameter for affecting the MRR and overcut and the surface roughness. Abhishek Tiwari et al.[4]optimization by the Non-Dominated sorting Genetic Algorithm (NSGA-II) to optimize the metal removal rate and surface roughness by varying different process parameter such as electrolyte concentration, voltage, feed rate and inter electrode gap for electrochemical machining on EN 19 tool. Set of experiment designed by using Taguchi L27 orthogonal array and regression was performed to establish the relationship between dependent and independent variable and process parameter analyzed by ANOVA.

1 Objective

The aim of this research is:-

1. Experiment investigation of process parameters for the machining of copper plate.
2. Evaluate MRR and Taper Angle.
3. Optimization of the process parameter using the Non-dominated Sorted Genetic Algorithm.

2 Methodology

1. Prepare a testing Rig of ECM & workpiece of copper plate.
2. Selection of process parameters like voltage, concentration, IEG and flow rate.
3. Obtain MRR and Taper angle in the various set of experiment.

4. Formulate the problem in the Fit Regression model. In ECM the high current is passed between an electrode and the part, through an electrolytic material removal process negatively charged (cathode), a conductive fluid (electrolyte), and a conductive workpiece (anode). The material removal rate (MRR) using Minitab software and obtain the unique equation of MRR and Taper Angle.

5. Creation of M-file in Matlab2015.

6. Optimize the equation using the optimization tool for NSGA.

7. Analyze the results.

LITERATURE SURVEY

Recent research for the process parameter in ECM:-

Taha Ali El-Taweel et al.[1]Wire electrochemical machining (WECM) is a cutting process in which wire is the cathode (tool) and the workpiece acts as anode. They discussed the feasibility of using a wire as a tool in electrochemical turning process (WECT). They measured the performance namely voltage, wire feed rate, wire diameter ,workpiece rotational speed and overlap distance on the response parameter which is metal removal rate, surface roughness error. Using the Response Surface Methodology (RSM) the regression model and analysis of variance were studied based on the experimental result. From the results and discussion the conclusion were obtained:

1. Micro size turned parts can be produced using wire as an electrode.

2. The increase of the wire feed rate increases the surface roughness while improving the roundness error.

3. The increase of rotational speed of the work piece improves both the productivity of the process and geometrical error of the produced parts.

4. The optimum combination of parameters value was obtained as: applied voltage 32.5V , wire feed rate 0.4 mm/min, wire diameter 1.3 mm, overlap distance 0.03 mm and rotational speed 750 rpm for maximizing

metal removal rate and minimizing both surface roughness and roundness error.

D. Chakradhar et al.[2]They uses Grey Relation Analysis (GRA) to optimize different output parameters such as material removal rate, overcut, cylindricity error and surface roughness by varying different machining process parameters such as electrolyte concentration, feed rate and applied voltage for electrochemical machining of EN-31 steel. Grey Relation Analysis was used to convert multi response variable to a single response grey relation grade. Copper rod coated with epoxy powder resin as tool electrode and aqueous solution of sodium chloride as electrolyte were used. Analysis of variance was performed to analyze the effect of different process parameter on output. They conclude that:-

☐ Robustness of ECM was significantly influenced by the feed rate.

☐ Voltage of 20V, feed rate of 0.32mm/min and electrolyte concentration of 15% yields the best combination that optimizes different process parameters.

☐ Different output parameters i.e. material removal rate, overcut, cylindricity error and surface roughness were optimized using grey relation analysis.

☐ Material removal rate can be maximized using grey relation analysis.

☐ Overcut cylindricity error and surface roughness can be minimized using Grey Relation Analysis (GRA).

D. Saravanan et al.[3]Designed their experiments using Taguchi L18 orthogonal array and perform them to investigate the optimal machining parameter for machining SDSS using electrochemical micro machining .They used Statistical analysis of variance to determine the percentage contribution of individual process parameters on Material Removal Rate (MRR). Among the various factor investigated, duty cycle is found to be the most significant factor and contributes about 42% to the MRR. As the duty cycle increases, the pulse on time increases which contributes to more MRR. It helps to understand the selection of the machining parameters for ECMM of SDSS.

V. K. Jain et al.[4]They designed and fabricated experimental setup to machine micro-holes and micro channels. Machining of these features is done using a sewing needle with 47um tip diameter as a tool. They studied the effect of process parameter such as feed rate, voltage, pulse duty cycle, and electrolyte concentration, on the machined hole diameter, and a mathematical model is developed. A straight tool having a diameter of 80um is fabricated from a 1000um steel wire using the ECMM process. They studied the material removal rate with time and variations of wire diameter. They analyzed micro feature measurement and photographic with the help of using digital microscope.

D. Bahrea et al.[5]They described the potential of Pulse Electrochemical Machining (PECM) for the machining of lamellar cast iron is investigated with regard to the machining performance during electrolysis with sodium nitrate (NaNO3) as electrolyte and stainless steel as cathode. Therefore, the material removal characteristics of lamellar cast iron with PECM are determined by performing systematic design of experiments technique applying an industrial PECM machine system to fulfill the effective utilization of the process and to minimize the number of generating defined surface qualities are contents of this study.

Malapati Manoj Kumar Reddy et al.[6]They performed their experiment on electrochemical machine to analyze the effect of different process parameter such as machining voltage, pulse period, electrolyte concentration and duty cycle ratio on machining performance criteria e.g. machining accuracy and material removal rate to meet the micro machining requirements. They investigate the most effective zone on copper, which gives high machining accuracy with appreciable amount of optimum machining speed and material removal rate. From the experimental result, it observed that the introduction of short pulse period improves. They study and compare the surface condition of the machined micro holes through SEM micrographs.

S. S. Uttarwar et al.[7]They performed their experiment on electrochemical machine to analyze the effect of different process parameter such as time of electrolysis , current, voltage, concentration of electrolyte, feed rate and pressure on output parameter material removal rate and surface roughness of SS AISI 304. They proposed that MRR was remarkably affected by variation in current and surface roughness decreased with increase in current .Hence, it was apparent that irregular MRR was more likely to occur at high currents. The result showed that electric voltage increase with MRR increase, molar concentration of electrolyte, and time of electrolysis and feed rate. However, the time of electrolysis was the most influential parameter on the produced surface finish.

B. Ghoshal et al.[8]They find the most suitable and quickest method of micro tool fabrication by electrochemical machining (ECM). They used tungsten micro tools for fabricated at different machining condition to know the frequency of tool vibration, influences of voltage, amplitude of vibration of tungsten tool, dipping length of tool inside the electrolyte, and concentration of electrolyte.

ELECTROCHEMICAL MACHINING

From the figure of ECM experimental setup, ECM machine consist of two electrode one is anode which is our work material and other one is cathode that is tool. Water with Sodium nitrate is used as electrolytic solution. During experiment following chemical reaction takes place

$H_2O \rightarrow H^+ + OH^-$

$NaNO_3 \rightarrow Na^+ + NO_3^-$

Negatively charged ions that mean anions (OH^- and NO_3^-) move towards the anode while positively charged ions which means cat ions (H^+ and Na^+) move towards the cathode.

Reaction at anode $Fe \rightarrow Fe^{2+} + 2e^-$ Reaction at cathode

$2H^+ + 2e^- \rightarrow H_2\uparrow$

Ferrous ion combines with hydroxide ion to form ferrous hydroxide $Fe(OH)_2$, ferrous ion was formed during reaction. This ferrous hydroxide is complex and it is insoluble in water and hence appears as a solid precipitate which does not affects the chemical reaction.

$Fe^{2+} + 2NO_3^- \rightarrow Fe(NO_3)_2$

$2Na^+ + 2OH^- \rightarrow 2NaOH$

$2NaOH + Fe(NO_3)_2 \rightarrow 2NaNO_3 + Fe(OH)_2$

EXPERIMENTAL SETUP

In ECM, copper tool is cathode and work piece is anode. Electrolyte is passes from the copper tool to the work piece. There is a small gap between the tool and the work piece. This gap is called inter electrode gap. Electrolyte is pumped by water pump and controlled by a flow regulating valve.

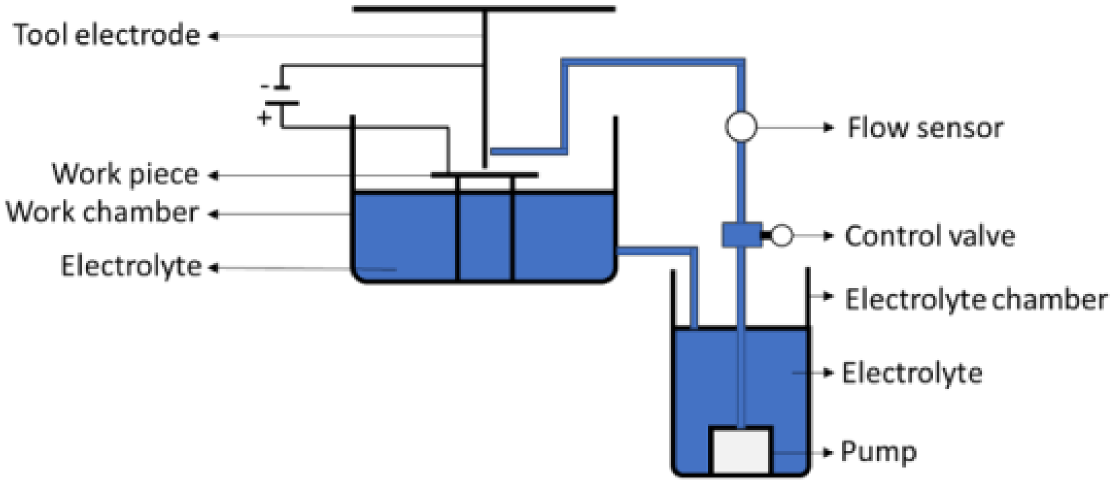


Fig.1 Experimental setup

A flow sensor is connected at the end of flow regulating valve to measure the flow of electrolyte. This flow sensor is connected to an Arduino and this Arduino is connected to computer, discharge of flow is directly seen into the computer. During experiment precipitate occurs on work material is flushed out by the flow of electrolyte.

Complete working condition are given in Table.1 and experimental setup is shown in Fig.1

Table 1 Working condition

S. No.	Parameters	Working Range
1	Voltage	20-30 V
2	Concentration	80-140 g/l
3	Inter electrode gap	0.5-1.5 mm
4	Flow rate	0.54-0.95 L/min

MODEL FORMYLATION FOR COPPER WORK PIECE

For the better results, analysis and conclusion the statistical design of the experiment is an efficient procedure for planning. The input parameters are the process parameter and while the output parameter is the response from the statistical design.

1. Design of experiments

It is extremely important to make a plan with high accuracy to complete the whole process without any loss. This planning helps during experiment without drawbacks or any failure and it also saves time and material and reduces the overall cost of the product. Before the experiment we have numbers of input parameters but we cannot take all these parameters during experiment. So some parameters are taken as constant to complete the experiment. As we have four input parameters with four numbers of levels to design the experiment Taguchi L9 orthogonal array approach was used.

Table 2 Experimental outcome for various set of process parameter

S.no	Voltage (V)	Concentration (gram/lit)	IEG (mm)	Flow Rate (lit/hour)	MRR (gram/min)	Taper Angle (in degree)
1	20	80	0.5	0.54	0.037867	0.3512
2	20	110	1	0.81	0.014602	0.59448
3	20	140	1.5	0.95	0.009692	0.06992
4	25	80	1	0.95	0.025374	0.53863
5	25	110	1.5	0.54	0.024458	1.14318
6	25	140	0.5	0.81	0.018944	1.12982
7	30	80	1.5	0.81	0.027075	1.22634
8	30	110	0.5	0.95	0.037216	0.91732
9	30	140	1	0.54	0.0336	0.9382

2 ANOVA and Regression analysis

After collecting the input data such as voltage, electrolyte, IEG and flow rate to calculating the material removal rate we have to perform the next step. The next step is ANOVA and regression analysis of these collected data with the help of MINITAB 17 software. This process helps to know about the most significant parameters chosen as input parameter.

Table 3 Analysis of variance for MRR

Source	DF	Adj SS	Adj MS	F- value	P- value
Regression	6	0.000769	0.000128	5274.70	0.000
Voltage	1	0.000014	0.000014	591.88	0.002
Concentration	1	0.000001	0.000001	41.27	0.023
IEG	1	0.000120	0.000120	4958.71	0.000
Flow Rate	1	0.000044	0.000044	1810.84	0.001
Voltage*concentration	1	0.000004	0.000004	171.25	0.006
Concentration*IEG	1	0.000103	0.000103	4274.55	0.000
Error	2	0.000000	0.000000		

Total	8	0.000769			

In this table 3, P-value shows that which factor is significant or not. Highest F- value with predictor term has the most remarkable input factor, while lowest F- value with predictor term has the least remarkable input factor. Thus we can conclude that IEG with highest F- value of 4958.71 has the most remarkable input factor and predictor term concentration with the lowest F- value of 41.27 is the least remarkable factor

Table 4 Model summary

S	R- sq.	R-sq. (adj)	R- sq. (pred)
0.0001558	99.99%	99.97%	99.68%

Table 4 shows that the designed model for MRR 99.99% of data points with an average distance of 0.0001558% from the fitted line and can able to predict the response of new observation with the accuracy of 99.68%.

Table 5 Analysis of variance for Taper Angle

Source	DF	Adj SS	Adj MS	F- value	P- value
Regression	7	1.27670	0.182386	2654.20	0.015
Voltage	1	0.07628	0.076282	1110.11	0.019
Concentration	1	0.10224	0.102244	1487.93	0.017
IEG	1	0.15961	0.159614	2322.82	0.013
Flow Rate	1	0.17255	0.172551	2511.09	0.013
Voltage*concentration	1	0.02944	0.029440	428.43	0.031
Voltage*IEG	1	0.07883	0.078831	1147.20	0.019
Concentration*IEG	1	0.29928	0.299276	4355.28	0.010
Error	1	0.00007	0.000069		
Total	8	1.27677			

Similarly in table 5 we can conclude that “concentration*IEG” with the highest F- value of 4355.28 has the most remarkable input factor and predictor term “voltage*concentration” with the lowest F- value of 428.43 is the least remarkable factor. P-value of factor “voltage*concentration” is significant which mean it could not affect response factor higher compare to other factor.

Table 6 Model summary for Taper Angle

S	R- sq.	R- sq. (adj)	R- sq. (pred)
0.0082895	99.99%	99.96%	97.27%

Table 6 shows that the designed model for taper angle fits about 99.99% of data points with an average distance of 0.0082895 from the fitted line and can able to predict the response of new observation with the accuracy of 97.27%.

Regression equation for MRR and Taper Angle is:-

MRR=0.03298+0.003921*voltage-0.000206*concentration-0.068634*IEG-0.025807*flowrate
0.000018*voltage*concentration+0.000500*concentration*IEG (1)

Taper Angle = -8.726+0.32774*Voltage+0.06795*Concentration+7.035*IEG-2.1529*flow

rate- 0.001565*Voltage*concentration-0.13848*voltage*IEG-0.034488*concentration*IEG (2)

The above equation was used to plot the graph between material removal rate and input parameter with the help of

MS EXCEL 2007.

RESULT AND DISCUSSION

1. Effect of applied voltage on MRR and Taper angle

Graph shown in figure 2 indicates that as the machining voltage is increases there is an increase in material removal rate. The reason behind this, the laws of faraday states that material removed from the work piece is directly proportional to the machining current. As the voltage of ECM is increases current density is increases resulting material removal rate is increases.

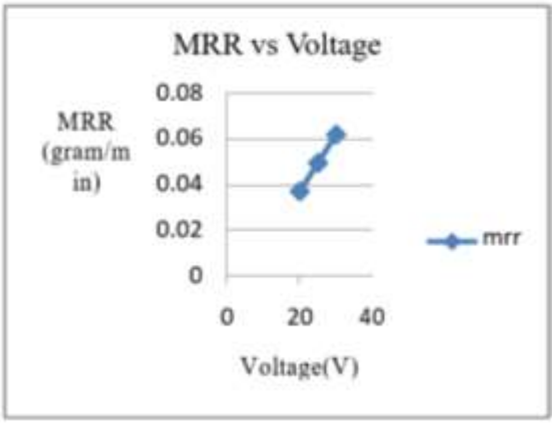


Fig.2 Graph of MRR v/s Voltage

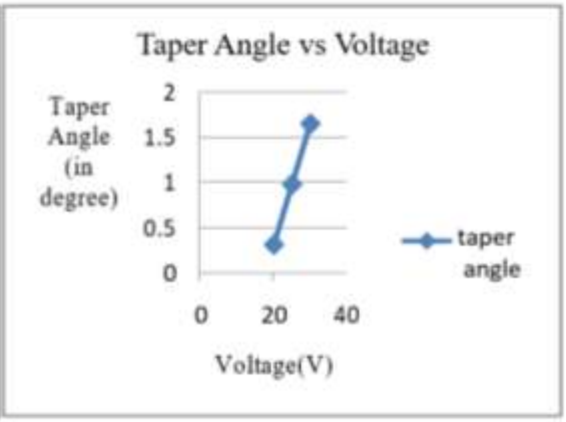


Fig.3 Graph of Taper angle v/s Voltage

The plot of taper v/s voltage is shown in figure 3. The average change in taper is linear in nature with increasing voltage. Taper angle changes from divergent to convergent form, with the increases in voltage. Low voltage result in lower intensity electric field that further reduced the stray current effect, therefore reducing the overcut. If increasing the applied voltage at higher values it results in proportionate increase in current, would result in a higher heating effect a greater depth. This increase the overcut phenomenon, hence taper angle increases.

2. Effect on Concentration in MRR and Taper Angle

The graph shown in figure 4 indicates that as the electrolysis concentration is increases atoms of work piece react quickly to electrolysis and resulting that precipitate is formed on the work piece quickly and this precipitate is flush out but the electrolysis flow. As the concentration of electrolysis is increases, material removal rate is also increases.

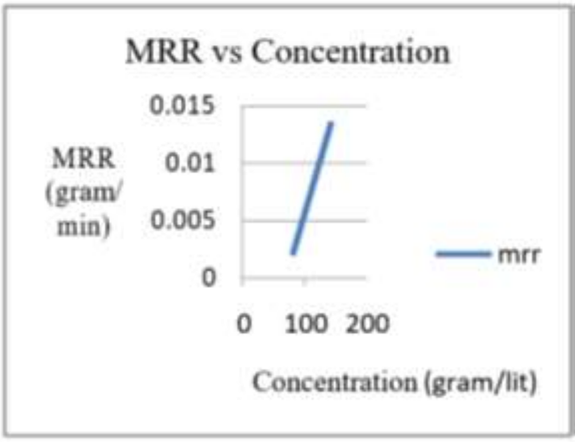


Fig.4 Graph of MRR v/s Concentration

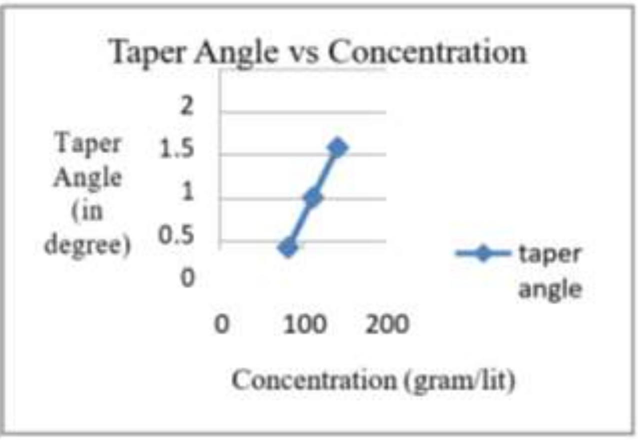
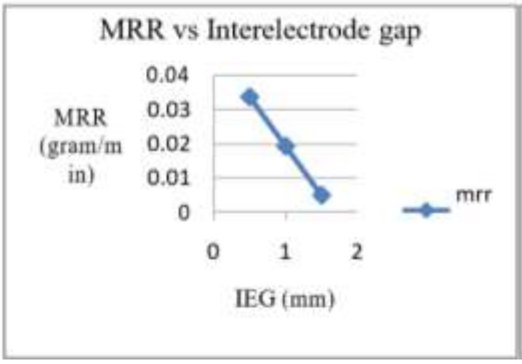


Fig.5 Graph of Taper angle v/s Concentration

The plot of taper v/s electrolyte concentration shown in figure 5. Taper increase with increase in electrolyte concentration moderately. Also the nature of taper change from divergent to convergent. This is because increasing the metal ion concentration has a positive effect on hole taper.

3 Effect of Inter electrode gap (IEG) on MRR and Taper angle

Graph shown in figure 6 indicates that as the gap between tool and work piece is increases, material removal rate is decreases. Reasons is increases is inter electrode gap charge cannot be easily transmitted on the surface of the work piece due to which charge cannot react with the work piece surface and the precipitate can't occurs on work piece. As IEG is decreases more precipitate is formed on the work piece surface and this precipitate is removed by flow of electrolysis.



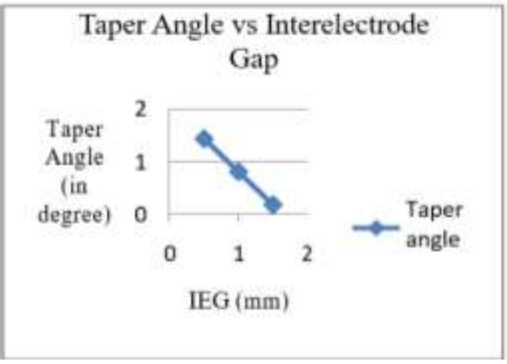


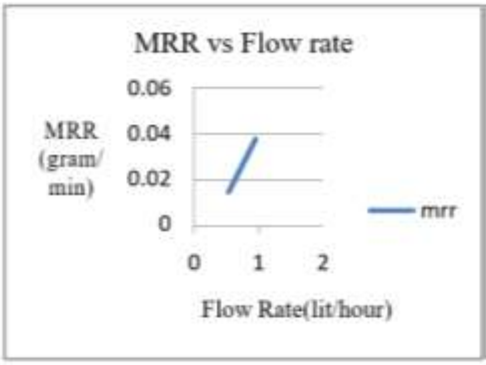
Fig.6 Graph of MRR v/s Inter electrode gap

Fig.7Taper angle v/s Inter electrode gap

The plot of taper v/s inter electrode gap is shown in figure 7. Taper angle decreases with increase in IEG. The reason for this that increase in inter electrode gap permits dissolution of the area at top of the hole is longer, that results overcut in formed at the top part of the hole. Higher IEG results in formation of more hydrogen bubble between the machining gap that increase the local electric resistance, therefore current flows mainly to the bottom of the tool whose resistance is relatively small and then the exit diameter become large.

4. Effect of Flow rate on MRR and Taper angle

The graph MRR v/s flow rate in figure 8 shows that as the flow of electrolyte are increases material is removed from the work piece more quickly. Because it flushes the cavity which was occurs on the work piece surface during machining.



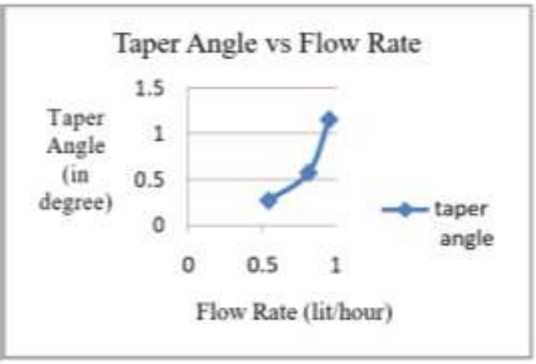


Fig.8 Graph of MRR v/s Flow Rate

Fig.9 Graph of Taper angle v/s Flow Rate

The plot taper angle v/s flow rate shown in figure 9 that the machining hole by ECM process material is dissolved from the side wall and the bottom surface of the hole simultaneously. The machining of side wall leads to taper formation and machining of the bottom surface leads to increase of hole depth. Hence the increase of flow rate leads to the increase in taper angle

OPTIMIZATION OF MRR AND TAPER ANGLE

These empirical equations are obtained from Regression Fit Model using MINITAB 17. The R-square value is 99.99% are both MRR and Taper Angle.

Using the multi-objective Matlab2015 environment for the optimization of response and decision variables. The Pareto fronts obtained for response are shown below:-

Where:-

Objective 1 = MRR Objective 2 = Taper Angle

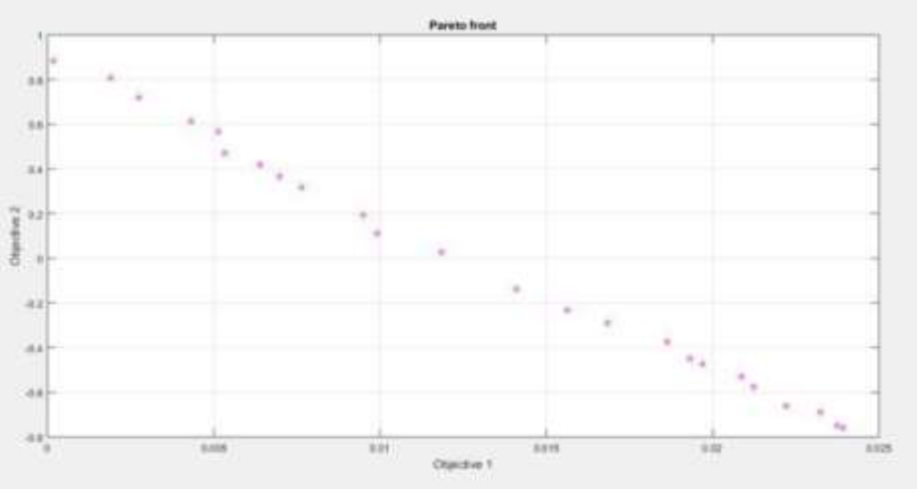


Fig.10 Pareto Front of Response (MRR & Taper Angle)

CONCLUSION

This experiment research concluded using copper tool electrode that:-

a. The characteristic curve is drawn between MRR/taper increases with an increase in voltage, concentration and flow rate.

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 solution from the Pareto front for response and decision variable are obtained in (between voltage = 20-30volt, concentration = 80-140 gram/lit, IEG = 0.5-1.5mm and flow rate = 0.54-0.95) as follows:-

Table 7 Optimized set for optimum response

S. No	MRR	Taper Angle	Voltage	Concentration	IEG	Flow Rate
1	0.024	-0.76	29.917	137.191	1.48	0.937
2	0.003	0.718	20.108	95.343	1.46	0.943
3	0.005	0.569	20.518	104.906	1.459	0.943
4	0.005	0.471	20.128	113.905	1.498	0.943
5	0	0.884	20.006	86.896	1.498	0.943
6	0.008	0.319	20.392	122.85	1.468	0.942
7	0.024	-0.76	29.917	137.191	1.48	0.937
8	0.023	-0.687	29.478	135.506	1.488	0.938
9	0.009	0.194	21.175	126.995	1.484	0.942
10	0.021	-0.576	28.134	136.055	1.483	0.939
11	0.007	0.365	20.399	119.625	1.483	0.943
12	0.014	-0.137	23.281	136.228	1.479	0.939
13	0.021	-0.529	27.87	135.4	1.482	0.937
14	0.022	-0.661	28.775	137.146	1.481	0.939
15	0.017	-0.29	25.123	135.797	1.481	0.937
16	0.01	0.113	20.558	135.31	1.496	0.94
17	0.006	0.419	20.444	116.18	1.494	0.941
18	0.012	0.027	22.045	133.264	1.472	0.941
19	0.016	-0.235	24.36	136.066	1.48	0.941
20	0.004	0.613	20.451	130.105	1.483	0.943
21	0.002	0.809	20.379	91.488	1.498	0.941
22	0.019	-0.374	26.446	134.549	1.471	0.941
23	0.019	-0.449	26.871	135.485	1.482	0.94
24	0.024	-0.749	29.792	137.191	1.48	0.937
25	0.02	-0.475	27.121	135.61	1.482	0.94

Pictures of all machined micro hole on Copper workpiece is given below:

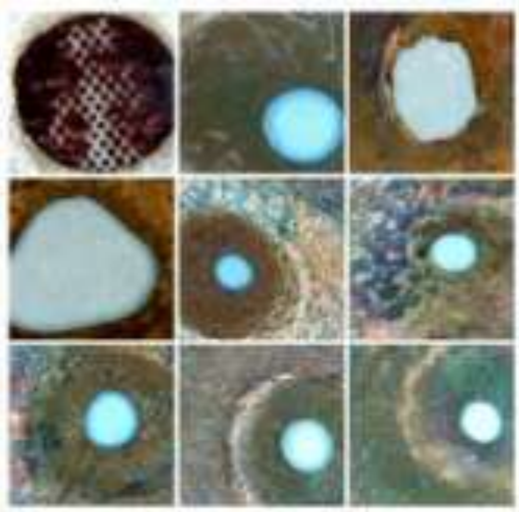


Fig.11 Front Side

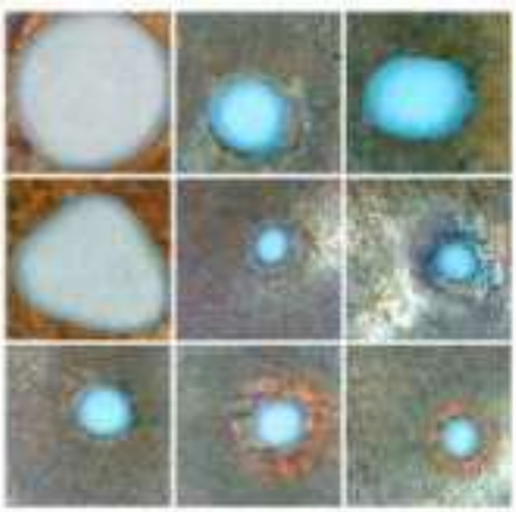


Fig.12 Back Side

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