Effect of Different Tool Materials and Process Parameters on Material Removal Rate and Surface Roughness in Electrochemical Machining

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Abstract— Studies on Material removal rate (MRR) and surface roughness (Ra) are of greatest importance in ECM, since it is one of the determining factors in the process decisions. This research deals that to investigate the effect of different electrodes and process variables on the material removal rate and surface roughness of electrochemical machining (ECM) on AISI D2 steel component. In this experimental study, Design of Experiment Method has been employed to find out the effects of different electrodes (brass and alluminium) and process variables (voltage, electrolyte concentration and machining time) on material removal rate and surface roughness. ANOVA and Regression analysis is performed to estimate the characteristics in terms of the values of the machining parameters by the use of Minitab16 software.

Key word: Material removal rate (MRR), electrochemical machining (ECM), ANOVA

I. INTRODUCTION

Electrochemical machining (ECM) was introduced in the late of 1950s and early 1960s in the aerospace and other heavy industries for shaping and finishing operations. Electrochemical machining (ECM) is an anodic dissolution process. The ECM process connects the workpiece (anode) to the tool (cathode) via an electrolytic cell, through which an electrolyte is pumped, as shown in Fig.1. It utilizes an electrolytic cell formed by a cathode tool and an anode workpiece with a suitable electrolyte flowing between them. The anode workpiece is dissolved according to Faraday's law when a sufficient voltage is applied across the gap between the anode and the cathode in which electrolyte is filled. Electrochemical (electrolyses) reactions are responsible for the chip removal mechanism [1]. ECM has seen a resurgence of industrial interest within the last couple of decades due to its many advantages compared to other conventional or even nonconventional processes. Among several non- conventional processes [2, 5] electrochemical machining is interesting because the removal of material is by an atom to an atom resulting in higher finish with stressed crack free surface and independent of the hardness of the work materials; it does not impart any thermal or mechanical stresses/surface effects on the workpiece. such as no tool wear, stress free and smooth surfaces of machined product and ability to machine complex shape in electrically conductive materials, regardless of their of hardness. However, the practical application of ECM is still limited because of its lack of accuracy, the difficulty of proper tool design, and insufficient control of the operating parameters. In the present work experiment, the interrelation between the process parameters and different electrodes are determined to improve ECM accuracy.

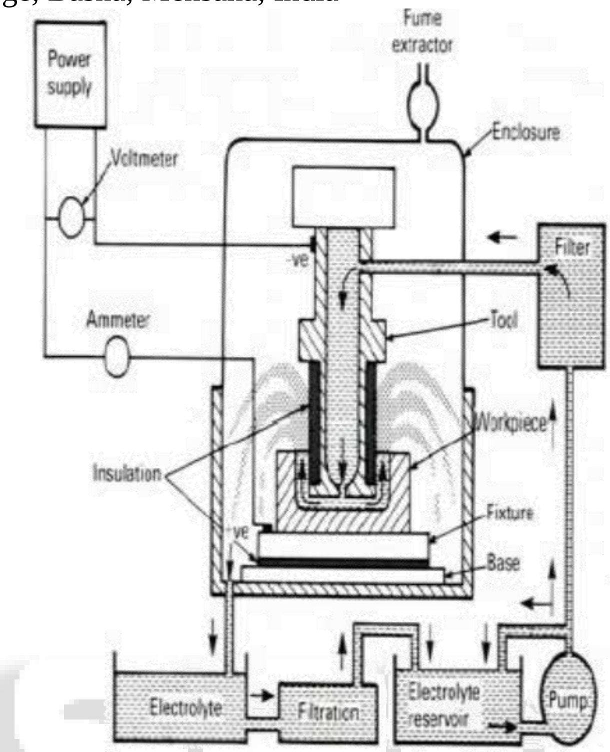

Fig. 1: Schematic diagram of ECM Machine tool

II. LITERATURE REVIEW

S. S. Uttarwar et al. [1] investigated the results obtained from the Electrochemical Machining of AISI 202 stainless steel in which input parameters were taken as voltage, current, electrolytic concentration and time of electrolysis, feed rate and pressure while response variables were MRR and SR. The experiment was designed based on L32 orthogonal array. They explained the effect of variation of each input parameter on material removal rate and surface roughness using theoretical and computation based models. They found that MRR increases with increasing each of the input variables while surface roughness was mainly affected by time of machining.

C. Senthilkumar, et al.[2] investigated that proper selection of manufacturing conditions is one of the most important aspects in the die sinking Electrochemical Machining process, as these conditions determine important characteristics such as Material Removal Rate and Surface Roughness. The material used in the study was LM25Al/10%SiCp composite. Experiments have been carried out to establish an empirical relationship between process parameters and responses in ECM process using Response Surface Methodology. The developed empirical relationships predict the machining conditions within the experimental domain. Analysis of variance (ANOVA) is employed to indicate the level of significance of machining parameters. The contour plots are generated to study the effect of process parameters as well as their interactions.

MRR is influenced by applied voltage and tool feed rather than other parameters. Electrolyte concentration has most significant factor on Ra rather than other parameters. Increase in applied voltage and tool feed rate leads to an increase current density in the Inter-Electrode gap (IEG), and hence MRR increases. Increase in applied voltage and tool feed rate leads to an increase current density in the Inter-Electrode gap (IEG), and hence MRR increases. With increase in electrolyte concentration and electrolyte flow rate mobility of ions is more which increase the speed of the chemical reaction results more MRR.

Bhattacharya et al. [3] developed an electrochemical micro-machining (EMM) experimental set-up to carry out research so that EMM process parameters can be adequately controlled. He found that value of voltage in between 6-10 V provides a significant amount of MRR with reasonable accuracy. He also found that lesser value of electrolytic concentration with moderate pulse on time and high voltage gives good dimensional accuracy lesser overcut and moderate MRR. Micro sparks are undesirable as it results in inaccuracy.

R.Goswami1 et al. [4] optimize the Electrochemical machining process parameters using Taguchi approach. The objective of experimental investigation is to conduct research of machining parameters impact on MRR and SR of work piece of Aluminum and Mild steel. The approach was based on Taguchi's method, analysis of variance and signal to noise ratio (S/N Ratio) to optimize the Electrochemical machining process parameters for effective machining and to predict the optimal choice for each ECM parameter such as voltage, tool feed and current. In this research three level of parameter is considered for experiment. There is L9 orthogonal array used by varying A, B, C respectively and for each combination we have conducted three experiments and with the help of Signal to Noise ratio we find out the optimum results for ECM. It was confirmed that determined optimal combination of ECM process parameters satisfy the real need for machining of Aluminum and Mild steel in actual practice. According to analysis of observed value by Minitab software the most significant factor in case of MRR of Aluminum is voltage(A) and in case SR of Aluminum is tool feed(B).In case of Mild steel the most significant factor of MRR is voltage(A) and in case SR is current(C). And by analyzing the graph of S/N ratio the predicted optimal parameter setting has been found and by this optimal parameter setting experiment were performed and found successful result for ECM optimization.

Bhawna Bisht et al. [5] optimize the Material Removal Rate (MRR) and surface roughness. There are four machining parameters i.e. Voltage, Electrolyte flow rate, Tool feed rate and Current. Taguchi orthogonal array is designed with three levels of machining parameters with the help of software Minitab 15. Nine experiments are performed and material removal rate (MRR) and surface roughness is calculated. Metal removal rate and surface roughness are the most important output parameters, which decide the cutting performance. Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better" and surface roughness was considered with the concept of "the smaller-the-better". The S/N ratio values are calculated by taking into consideration with the help of software Minitab 15. The MRR and surface roughness values measured from the experiments and their optimum value for maximum material removal rate and minimum surface roughness.

Tajdari and Chavoshi et al. [6] developed different models based on artificial neural network (ANN), multiple regression analysis and co-active neuro fuzzy inference system (CANFIS) to envisage overcut in electrochemical drilling. They investigated that voltage and electrolyte concentration had increasing effect on radial overcut while feed rate has a decreasing effect. They further compared the models and found that ANN and CANFIS models are more accurate than regression analysis with an average error of almost 5 % in predicting radial overcut.

S. Rama Rao and G. Padmanabhan [7] investigate the effect of process variables on Metal Removal Rate in electrochemical machining of Al-B4C composites. The important process variables of ECM process are feed rate, electrolyte flow rate, current, voltage, inter electrode gap, electrolyte concentration, type of electrolyte, etc. which affects the process responses like metal removal rate, radial over cut, surface finish, tool life, and production cost. The responses also depend largely on the workpiece material physical and electrical properties. In composites the physical and electrical properties depends on the percentage of reinforcement of particulates in the metal matrix. The salient feature of the present research is that percentage of reinforcement is considered as one of the input parameter along with the voltage, feed rate and electrolyte concentration and varied within the selected range to study the metal removal rate (MRR) of ECM of LM6 Al-B4C metal matrix composites produced through stir casting process. Mathematical model for MRR was developed based on response surface methodology (RSM). Surface plots are generated to study the effect of input parameters on MRR. The developed models are tested for their prediction accuracy using twenty experimental test cases and observed that the predicted values are closely related with the experimental values. MRR decreases with the increase in percentage of reinforcement and increases with increase in voltage, feed rate and electrolyte concentration.

Chakradhar and Gopal [8] Considered the effect of process parameters such as applied voltage, tool feed rate, electrolyte concentration for ECM on EN-31 steel and optimized them using grey relational analysis. Multi objective optimization is applied to consider surface roughness, MRR, overcut, cylindricity error simultaneously and it was observed that the most significant process parameter was feed rate. Grey relation analysis was used to convert the above four responses into single Grey relational grade as the response to simplify the procedure.

Samanta and Chakraborty [9] applied artificial bee colony (ABC) algorithm to find out the optimal combinations of different operating parameters for three nontraditional machining processes, i.e. ECM, EDM, and ECMM. Both the single and multi-objective optimization problems for the considered NTM processes are solved using this algorithm. The results obtained while applying the

ABC algorithm for parametric optimization of these three NTM processes are compared with those derived by the past researchers, which prove the applicability and suitability of the ABC algorithm in enhancing the performance measures of the considered NTM processes.

III. MATERIALS AND METHODOLOGY

The Fabricated Electrochemical Machining (ECM) set up is used for machining of different metals depends on different control parameter available. The responses studied are MRR, and Surface Roughness. The Parameters studied are Voltage, Electrolyte Concentration and Inter-Electrode Gap. The water based NACL are used as an Electrolyte. Every experiment is carried out for constant 30 minutes. The material of work piece is AISI D2 steel. It is a high carbon, high chromium tool steel alloyed with vanadium, molybdenum, cobalt. It has high compressive strength, good thorough hardening properties, highly stable after hardening and shows resistance when tempered back. The work piece is in the shape of semi-circular disk of 30 millimeter diameter and 10 mm thickness.

Fig. 2: Workpiece Material after EDM

	C	SI	S	P	Mn
%	1.800	0.150	0.033	0.018	0.200
	Ni	Cr	Mo	V	
%	0.190	10.580	0.019	0026	

Table.1: Chemical Composition of AISI D2 steel

Process Parameters	Level 1	Level 2	Level 3
Voltage(A)	1	2	3
Electrolyte Concentration(B)	1	2	3
Inter-Electrode Gap(C)	1	2	3

Table 2: Experimental design and optimization process parameters with their values at 3 levels

The experimental layout was developed based on Taguchi's Orthogonal Array Experimentation Technique. An L9 Orthogonal Array Experimental layout was selected to satisfy the minimum number of experimental conditions for the factors and levels presented in Table. 3.

Sr No	Voltage	Electrolyte Concentration	Inter-Electrode Gap
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3: L9 orthogonal array

The optimization of the measured control factors was provided by signal-to-noise (S/N) ratios. The highest value of MRR and lowest values of surface roughness are very important for quality improvement of the product. For this reason, the ''higher-the-better'' equation was used for MRR and ''lower-the-better'' equation was used for the calculation of the S/N ratio for SR. Design of Experiment [DOE] using Taguchi's Analysis & ANOVA for Main effects plot has been done using Minitab 16 application software. The results of the same with their respective graphs & interpretations are mentioned below in the sequential order.

Voltage (V)	Electrolyte Concentration (gm/ litre)	Inter-Electrode Gap (mm)	Weight before (gm)	Weight after (gm)	MRR (mm^3/min)	SR (μm)
10	10	0.2	64.5215	63.0014	6.5801	7.344
10	20	0.4	66.6514	65.1538	6.4830	7.294
10	30	0.6	65.6521	64.1752	6.3935	7.431
14	10	0.4	64.6549	63.1782	6.3926	7.234
14	20	0.6	62.5028	61.0494	6.2917	6.957
14	30	0.2	60.8025	59.1483	7.1610	6.762
18	10	0.6	64.5961	63.1252	6.3675	6.457
18	20	0.2	65.6563	64.0021	7.1614	5.664
18	30	0.4	62.2745	60.6732	6.9320	5.604

Table 4: Observed Values for Performance Characteristics of Alluminium Electrode

Voltage (V)	Electrolyte Concentration (gm/ litre)	Inter-Electrode Gap (mm)	Weight before (gm)	Weight after (gm)	MRR (mm^3/ min)	SR (μm)
10	10	10	64.8971	64.0290	3.7580	3.465
10	20	20	63.0883	62.2803	3.4978	3.273
10	30	30	65.4224	64.6523	3.3337	3.571
14	10	20	64.8481	64.0751	3.3463	3.241
14	20	30	66.7862	66.0532	3.1731	2.925
14	30	10	66.0124	65.1002	3.9489	2.731
18	10	30	68.3032	67.6112	2.9956	3.337
18	20	10	64.3021	63.4225	3.8077	2.578
18	30	0.4	56.8824	56.0055	3.7961	2.518

Table 5: Observed Values for Performance Characteristics of Brass Electrode

A. *Material Removal Rate:*

The material MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material [6].

B. *Surface Roughness:*

Surface roughness values of finished work pieces were measured by Mitutoyo Surface Roughness Tester SJ – 201 by a proper procedure.

IV. RESULT AND DISCUSSIONS

A. *S/N Ratio, Mean plot and ANOVA for MRR of Alluminium Electrode:*

Level	Voltage (v)	Electrolyte Concentration (gm/litre)	Inter-Electrode Gap (mm)
1	16.16	16.02	16.80
2	16.31	16.29	16.27
3	16.47	16.63	15.87
Delta	0.32	0.61	0.94
Rank	3	2	1

Table 6: Response Table for S/N Ratios of MRR (Larger is Better –Alluminium)

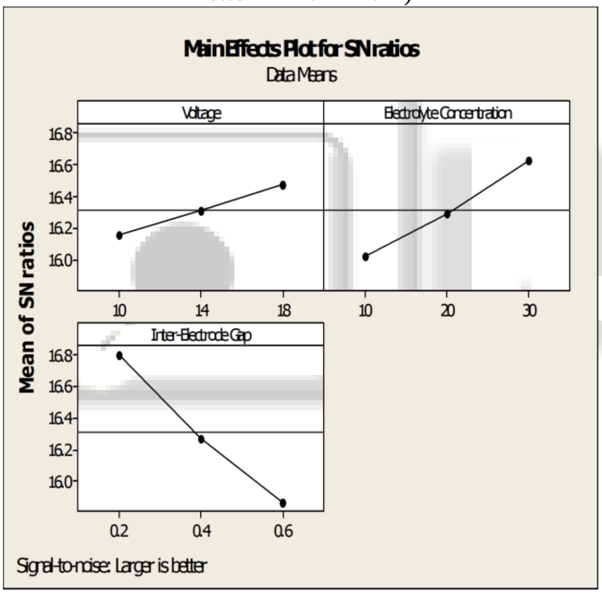

Fig. 3: Main Effect Plot for S/N Ratio of MRR (Larger is Better-Alluminium)

Level	Voltage (v)	Electrolyte Concentration (gm/litre)	Inter-Electrode Gap (mm)
1	6.425	6.328	6.924
2	6.554	6.534	6.517
3	6.676	6.793	6.214
Delta	0.251	0.464	0.710
Rank	3	2	1

Table 7: Response Table for Means for MRR (larger is better-Alluminium)

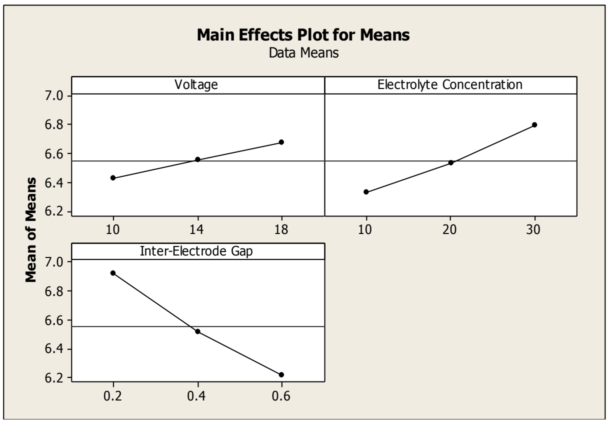

Fig. 4: Main Effect Plot for Means of MRR (Larger is Better-Alluminium)

Source	DOF	Seq SS	Adj SS	Adj ms	F	%
A	2	0.1782	0.0890	0.0853	22.74	18.0
B	2	0.2038	0.1019	0.1094	29.18	20.7
C	2	0.5842	0.2921	0.2883	76.84	59.6
Error	2	0.0130	0.0068	0.0037		01.6
	8	0.9800				

Table.8: Percentage contribution for MRR-Alluminium

- The most significant parameters for MRR are Inter-Electrode Gap.
- The optimum condition for maximum MRR is Voltage (18 V), Electrolyte Concentration (30 gm/litre), and Inter-Electrode Gap (0.2 mm).
- The Analysis of Variance table can also justify the rank order of significant parameter as Inter-Electrode Gap (59.61%), Electrolyte Concentration (20.79%) and Voltage (18%).

B. *S/N Ratio, Mean Plot and ANOVA for MRR of Brass:*

Level	Voltage (v)	Electrolyte Concentration (gm/litre)	Inter-Electrode Gap (mm)
1	10.94	10.31	11.68
2	10.82	10.84	10.98
3	10.91	11.33	10.01
Delta	0.13	0.82	1.67
Rank	3	2	1

Table 9: Response Table for Means for MRR (larger is better-Brass)

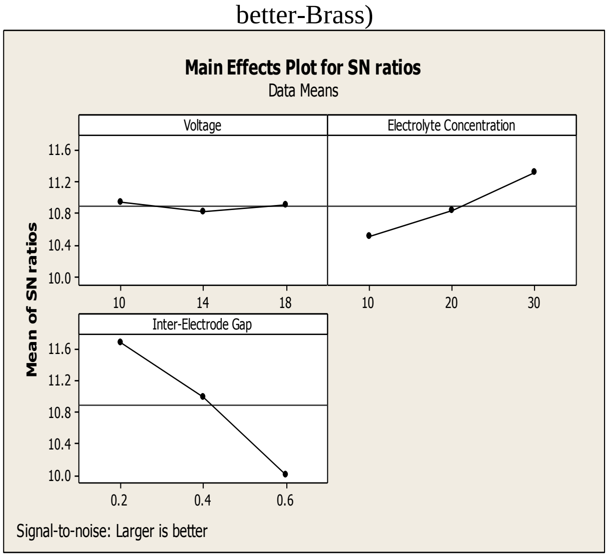

Fig. 5: Main Effect Plot for Means of MRR (Brass)

Source	DOF	Seq SS	Adj SS	Adj ms	F	%
A	2	0.0035	0.0035	0.0017	0.23	6.28
B	2	0.1623	0.1623	08119	10.41	17.3
C	2	0.6986	0.6986	0.3393	43.47	61.4
Error	2	0.1561	0.1561	0.0078		14.8
	8	0.8601				

Table 10: Percentage contribution for MRR-Brass

– The most significant parameters for MRR are Inter-Electrode Gap.
– The optimum condition for maximum MRR is Voltage (18 V), Electrolyte Concentration (30 gm/litre), and Inter-Electrode Gap (0.2 mm).
– The Analysis of Variance table can also justify the rank order of significant parameter as Inter-Electrode Gap (61.44%), Electrolyte Concentration (17.38%) and Voltage (6.28%).

C. S/N Ratio, Mean plot and ANOVA for SR of Alluminium:

Level	Voltage (v)	Electrolyte Concentration (gm/litre)	Inter-Electrode Gap (mm)
1	-17.22	-17.43	-16.95
2	-17.06	-17.16	-17.14
3	-17.15	-16.83	-17.34
Delta	0.17	0.60	0.39
Rank	3	1	2

Table 11: Response Table for S/N Ratios of SR (Smaller is Better-Alluminium)

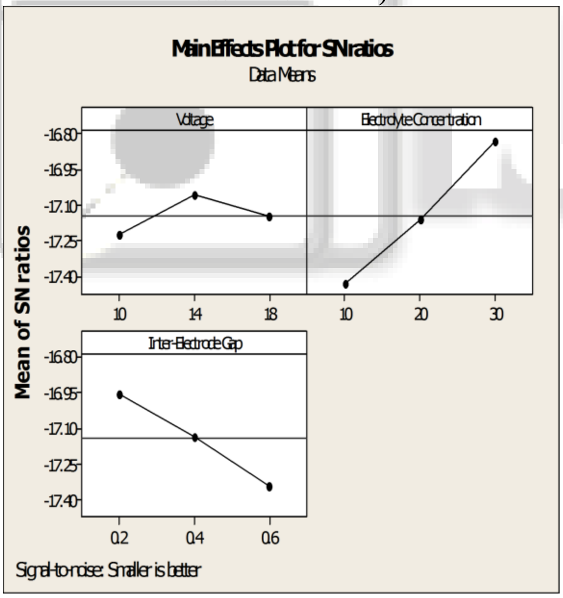

Fig. 6: Main Effect Plot for Means of SR (Al)

Level	Voltage (v)	Electrolyte Concentration (gm/litre)	Inter-Electrode Gap (mm)
1	7.265	7.444	7.046
2	7.130	7.215	7.195
3	7.210	6.946	7.364
Delta	0.135	0.498	0.318
Rank	3	1	2

Table 12: Response Table for Means of SR-Alluminium

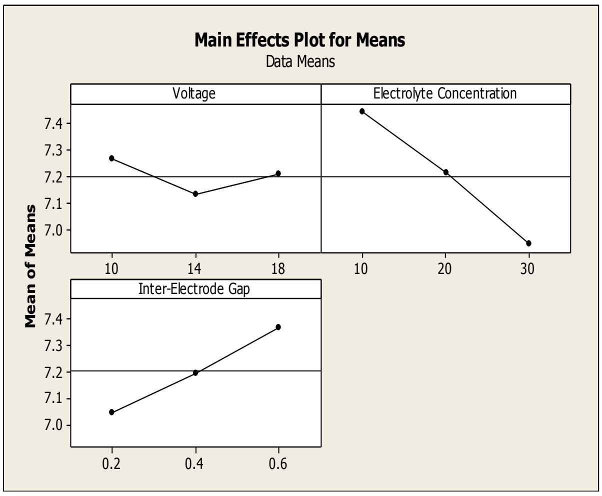

Fig. 7: Main Effect Plot for Means of SR (Smaller is Better-Al)

Source	DOF	Seq SS	Adj SS	Adj ms	F	%
A	2	0.2766	0.2766	0.0138	5.06	4.90
B	2	0.3722	0.3722	0.1861	68.05	66.8
C	2	0.1518	0.1518	0.0759	27.76	27.2
Error	2	0.0054	0.0054	0.0027		1.05
	8	0.5573				

Table 13: Percentage contribution for Surface Roughness of AL Electrode

– The most significant parameters for SR are Inter-Electrolyte Concentration.
– The optimum condition for minimum SR is Voltage (18 V), Electrolyte Concentration (30 gm/litre), and Inter-Electrode Gap (0.2 mm).
– The Analysis of Variance table can also justify the rank order of significant parameter as Electrolyte Concentration (66.80%) Inter- Electrode Gap (27.25%) and Voltage (4.90%).

D. S/N Ratio, Mean Plot and ANOVA for SR of Brass:

Level	Voltage (v)	Electrolyte Concentration (gm/litre)	Inter-Electrode Gap (mm)
1	-10.636	-10.964	-9.745
2	-10.211	-10.292	-10.331
3	10.029	-9.620	10.800
Delta	0.608	1.344	1.054
Rank	3	1	2

Table 14: Response Table for S/N Ratios of SR (Smaller is Better –Brass)

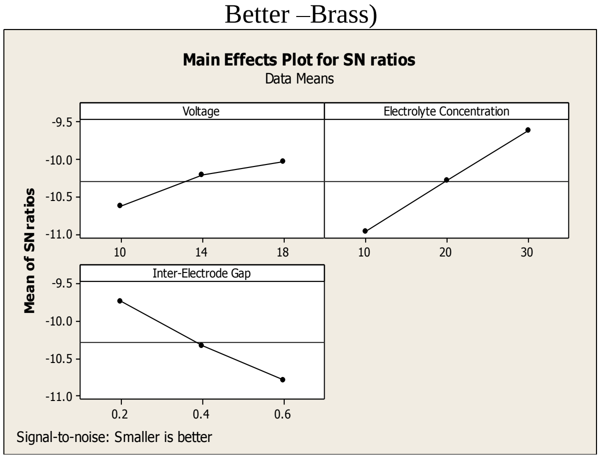

Fig. 8: Main Effect Plot for S/N Ratio of SR (Smaller is Better-Brass)

Level	Voltage (v)	Electrolyte Concentration (gm/litre)	Inter-Electrode Gap (mm)
1	3.403	3.534	3.083
2	3.257	3.277	3.294
3	3.187	3.035	3.469
Delta	0.216	0.499	0.386
Rank	3	1	2

Table 15: Response Table for Means of SR (Smaller is Better –Brass)

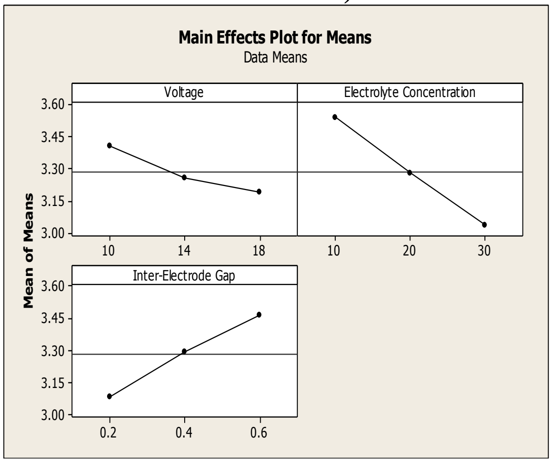

Fig. 9: Main Effect Plot for S/N Ratio of SR (Smaller is Better-Brass)

Source	DOF	Seq SS	Adj SS	Adj ms	F	%
A	2	0.0730	0.0730	0.0365	144.9	10.8
B	2	0.3731	.03731	0.1861	739.9	55.6
C	2	0.2237	0.2237	0.1118	443.7	33.3
Error	2	0.0005	0.0005	0.0002		0.07
	8	0.6704				

Table 16: Percentage contribution for Surface Roughness of Brass Electrode

- The most significant parameters for SR are Electrolyte Concentration.
- The optimum condition for minimum SR is Voltage (18 V), Electrolyte Concentration (30 gm/litre), and Inter-Electrode Gap (0.2 mm).
- The Analysis of Variance table can also justify the rank order of significant parameter as Electrolyte Concentration (55.64%) Inter- Electrode Gap (33.35%) and Voltage (10.88%).

V. CONCLUSION

In this work the effect of various process parameters like Voltage, Electrolyte Concentration, and Inter-Electrode Gap on responses like MRR and SR have studied. The Taguchi methodology is applied for investigation and following conclusion are drawn.

- The most significant parameter for MRR is Inter-Electrode Gap (with 59.61 % contribution) for AL as electrode and (with 52.55 % contribution) for Brass as Electrode.
- The maximum MRR for Alluminium is (7.1614 mm^3/min) and for Brass is (3.9489 mm^3/min). It is clearly understood from the above reading that AL having good Material removal rate than Brass electrode that is due to its good conductivity.
- Both electrodes having the same most significant parameter for SR is Electrolyte Concentration but the percentage contribution is different.
- The most significant parameter for SR is Electrolyte Concentration (with 66.80 % contribution) for AL as a electrode and Electrolyte Concentration (with 55.60 % contribution)is the most significant parameter in case if Brass electrode.
- The minimum SR for AL is (5.604 μm) and for Brass is (2.618 μm). It is clearly understood from the above reading that Bras having Lower Surface Roughness(good surface roughness).
- Alluminium is applicable for higher MRR and Brass is applicable for better Surface Finish.

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