Optimization of Process Parameters on MRR and Overcut in Electrochemical Micro Machining on Metal Matrix Composites Using Grey Relational Analysis

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ABSTRACT

This paper investigates the influence of the process parameters like machining voltage, electrolyte concentration, frequency on the over cut and Material Removal Rate (MRR) through taguchi methodology and grey relational analysis. This paper discusses a methodology for the optimization of the machining parameters on drilling of Al - 6% Gr Metal Matrix composites using Electrochemical Micro Machining (EMM). Based on the analysis, optimum levels of parameters were determined and the same to validate through the confirmation test. Experimental results are in close agreement with the developed model. The confirmation results reveal that, there is considerable improvement in Material Removal Rate, Overcut, Grey relational grade are improved by 08.33 %, 41.17 % and 81.77 % respectively. It is observed that the machining performance can be effectively improved with respect to initial parametric setting.

Keywords Metal Matrix Composite (MMC), Material removal rate, Overcut, Electrochemical micromachining (EMM), Taguchi, ANOVA, Grey relational analysis.

1. INTRODUCTION

Electrochemical Micro Machining (EMM) is a nontraditional non contact [tool and work piece] machining process in which material is removed by the mechanism of anodic dissolution during an electrolysis process. MMCs having outstanding properties like high modules, low ductility, high thermal conductivity and low thermal expansion, high strength-to-weight ratio, high toughness, high-impact strength, high wear resistance, low sensitivity to surface flaws, and high surface durability. As a result, many of the current applications for MMCs are in many industrial applications including electronics, bio medicine, optics, bio technology, home appliances, Fuel injection system components, ordnance components mechanical machine parts like turbine blades, engine castings, bearing cages, gears, dies and molds and all other major parts in automobile and aerospace industries. Electrochemical machining is widely recognized that has great potential and many applications in micromachining. The micro hole is the most demanding important basic element while fabricating the micro parts and micro devices which are best made in micro ECM. Good surface finish no tool wear, no thermal damage to the work piece and that complex shapes can be machined in extremely hard materials are the major advantage of Electro chemical machining.

2. LITERATURE REVIEW

Stir casting method is very popular due to its unique advantages [1].Al-fly ash composites fabricated by stir casting process, it could be considered as an excellent material in sectors where light weight, enhanced mechanical properties and wear resistance are prime consideration especially in automobile applications [2]. ECM technology and summarized that have been successfully adapted to produce macro, micro components with complex features and high aspect ratios for biomedical and other applications with the help of extensive research work needed in the area of machining parameter and tool design [3]. A very serious problem in machining MMCs because of the hard particles in the matrix present [4]. However, because of the poor machining properties of MMCs, drilling MMCs is a challenging task for manufacturing engineers. Most of the current literature presents experimental results in terms of tool life, quality of drilled hole, and induced force when drilling MMCs. Shorter pulse period machining voltage produces lower side gap and it also increases the unit removal [5]. Analysis of variance (ANOVA) was used for identifying the significant parameters affecting the responses [6-8].In Taguchi’s analysis method, the design parameters and noise parameters which influence the product quality are considered [9-10]. The application of ANOVA and Grey relational analysis for optimization of machining parameters were studied [11-23] .Electrochemical micromachining (ECMM) is an emerging nonconventional technology for producing micro/meso scale components [24].Investigates the effect and parametric optimization process parameters of electro chemical micro machining of 304 stainless steel [25].Experiments conducted with the developed setup by varying the machining voltage, electrolyte concentration, pulse-on time, and frequency on copper plate. In the study, they reported that a considerable amount of MRR at a moderate accuracy can be achieved with a machining voltage of 6–10 V, pulse-on time of 10–15 ms, and electrolyte concentration of 15–20 g/l [26]. The micro ECM process is complex, and it is not easy to decide the optimal machining parameters for improving the output quality. The optimization of process parameters is essential for the realization of a higher productivity, which is the preliminary basis for survival in today’s dynamic market conditions. Optimal quality of the work piece in ECM can be generated through combinational control of various process parameters [27]. An attempt made to machine the A356/SiCp composite work material using the ECM process to study the effects of various parameters such as applied voltage, electrolyte concentration, feed rate, and percentage reinforcement on maximizing the MRR [28]. This process produces no tool wear, having shorter machining time and cost effective The ECMM is still in its initial stages of development and a lot of research needs to optimize the various process parameters [29-31]. Aluminum matrix composites are generally regarded as extremely difficult to machine, because of the abrasive characteristics of the reinforced particulates [32].

In the view of the above, an attempt has been made in this present investigation the influence of voltage, electrolyte concentration, frequency on MRR and overcut of the Aluminum matrix composites using Electro chemical micro machining through Taguchi method and Analysis of variance (ANOVA). Optimization of cutting parameters is important for achievement of high quality. Taguchi’s method of experimental design is one of the widely accepted techniques for offline quality assurance of products and processes. Taguchi’s robust design method is a unique statistical tool and it has potential for savings in experimental time and cost on product or process development and quality improvement

3. EXPERIMENTAL DETAILS

3.1 PREPARATIONS OF THE HYBRID COMPOSITES

The material used in this investigation consists of 6061 aluminum alloy as matrix and its chemical composition is shown in below table 1.

TABLE 1. CHEMICAL COMPOSITION OF AL 6061

Component	**Cr**	**Fe**	**Cu**	**Mn**	**Mg**	**Si**	**Ti**	**Zn**	**Al**	**others**
Wt %	**0.2**	**max 0.7**	**0.25**	**0.1**	**1.0**	**0.6**	**max 0.1**	**max 0.15**	**98.1**	**remaining**

It is well suitable for high temperature application due their high thermal conductivity. The aluminum matrix was reinforced with 6 % wt of Gr. The average particle size Gr was 70 microns. The composites were prepared through stir casting route as shown in fig 1. The aluminum alloy was preheated in a resistance furnace at 450º C for 2 to 3 hour before melting. Gr were also preheated in a resistance furnace at 1100º C for 2 hour. The preheated aluminum were first heated above the liquidus temperature to melt them completely, and then slightly cooled below the liquidus to maintain the slurry in the semisolid state. This procedure has been adopted while stir casting aluminum composites [33-34]. The preheated reinforcements were added and mixed manually. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semisolid state. The composite slurry was then reheated to a fully liquid state, and mechanical mixing was carried out for about 20 min at an average mixing speed of 200–300 rpm. The final temperature was controlled to be within 750°C±20°C, and pouring temperature was controlled to be around 700°C. After thorough stirring, the melt was poured into steel molds of size 100x100x10 mm and allowed to cool to obtain cast sheet [35-36]. .Then the thickness was reduced to 0.5 mm through rolling and the same was cut in to 50x50x0.5 mm to accommodate into the EMM.

Fig 1. Stir Casting Set up

Fig 2. EMM Set up

3.2 ELECTROCHEMICAL MICRO MACHINING (EMM)

Electrochemical micro machining (Fig.2) is one of the nonconventional machining processes. It offers the unique advantage of better accuracy with high surface integrity of hard-machined components; also it has wider application because it produces good quality surfaces without affecting the metallurgical properties of the work material. During EMM, there will be reactions occurring at the electrodes i.e. at the anode or work-piece and at the cathode or the tool along with within the electrolyte. Ion and electrons crossing phase boundaries (the interface between two or more separate phases, such as liquid-solid) would result in electron transfer reaction carried out at both anode and cathode. It does not induce any deformation because no heat is generated while machining. Tool electrode feeding system, electrolyte supply system, mechanical machining system, inter electrode gap control system, pulse rectifier system are the major components of the EMM. The tool electrode feed mechanism, with resolution of 2 µm along Z – axis designed with stepper motor and 8051 micro controller. The electrolyte supply system consists of filter and pump arrangement. A pulsed power supply of 20 v and 30 A with capability for varying voltage, current, and pulse width stainless steel electrode of 430 µm diameter was used [36]. The electrolyte of varying concentrations used in this study was sodium nitrate ($NANO_3$) and Al-Gr of thickness of 0.5 mm as work piece. Based on the literature review and preliminary experiments conducted, the initial process parameters and their corresponding levels are chosen. The work piece thickness 0.4 mm, machining current 0.6 A as fixed for entire experiment. Table 2 shows the machining parameters and their level indentified for this investigation.

TABLE 2 : MACHINING PROCESS PARAMETERS AND THEIR LEVELS

	Factors	Level 1	Level 2	Level 3
A	Electrolyte Concentration (g/l)	20	25	30
B	Voltage (V)	5	7	9
C	Frequency (Hz)	25	40	55

Electrochemical micro machining (EMM) characteristics (MRR and Overcut) as output responses for through micro – hole machining. MRR was derived as work piece removal weight over machining time. Overcut of the micro hole has been related with the machining accuracy, hence it is the difference between the diameters of the tool electrode and machined micro hole. With the support of optical microscope the diameter of the machined micro – hole was measured.

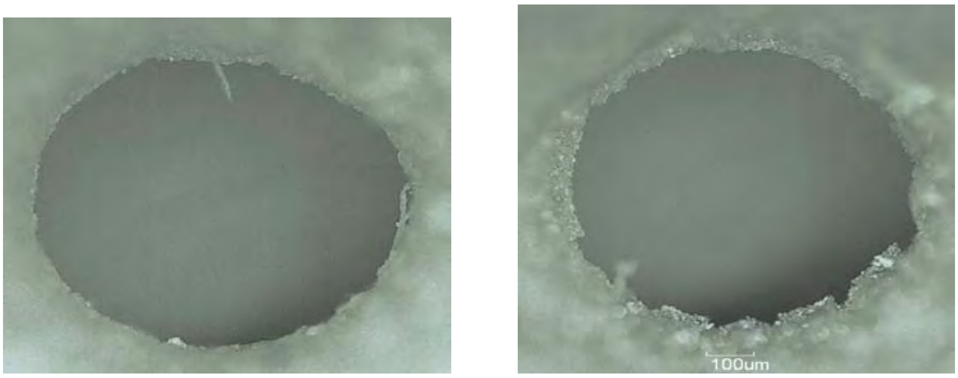


Fig 3.optical image for Micro hole 20 g/l/ 7V / 40 Hz   optical image for Micro hole 25 g/l /9V / 55 Hz

3.3 METHODOLOGY

Twenty seven experimental runs (L_{27}) based on the Orthogonal Array (OA) of Taguchi methods have been carried out. The multi-response optimization of the process parameters viz. MRR, Over cut has been performed for making a micro hole in the process of micro-ECM of Al- Gr metal matrix composites, each experiment was replicated twice. Machining time, over cut, MRR noted for every trial. In this study higher MRR and Lower over cut are desired. Therefore MRR is Larger is better and Overcut is Smaller is better chosen for this study.

Step 1: Calculate S/N Ratio for the corresponding responses using the following formula.

Larger is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination.

S/N = - 10□ log [sum (□1/Y^2) / n)]
(1)

Smaller is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination.

S/N = - 10 □log [sum(□Y^2) / n)]   (2)

where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

The experimental results were substituted into equation 1 & 2 , to calculate the S/N ratios of metal removal rate and overcut shown in Table 3.

Step 2: y_{ij} is normalized as Z_{ij} ($0 \leq Z_{ij} \leq 1$) by the following formula to avoid the effect of adopting different units and to reduce the variability. It is necessary to normalize the original data before analyzing them with the grey relation theory or any other methodologies. An appropriate value is deducted from the values in the same array to make the value of this array approximate to 1. Since the process of normalization affects the rank, we also analyzed the sensitivity of the normalization process on the sequencing results. Thus, we recommend that the S/N ratio value be adopted when normalizing data in grey relation analysis.

$$Zij = \frac{\max\left(y_{ij}, i = 1, 2, ...n\right) - y_{ij}}{\max\left(y_{ij}, i = 1, 2, ...n\right) - \min\left(y_{ij}, i = 1, 2, ...n\right)} \quad (3)$$

(To be used for S/N ratio with smaller the better manner)

Step 3: Calculate Grey relational Co-efficient for the normalized S/N ratio values.

$$\gamma(y_o(k), y_i(k)) = \frac{\Delta \min + \xi \Delta \max}{\Delta_{oj}(k) + \xi \Delta \max} \quad (4)$$

Step 4: Generation of Grey relational grade

$$\overline{\gamma_j} = \frac{1}{k} \sum_{i=1}^{m} \gamma_{ij} \quad (5)$$

Where $\overline{\gamma}_{\mathbf{j}}$ is the grey relational grade for the **jth** experiment and *k* is the number of performance characteristics.

Finally the grades are considered for optimizing the multi response parameter design. The results are given in the table 4.

Table 3 : S/N ratio of MRR and Overcut

Trial No	A	B	C	MRR mg/min	Overcut μm	S/N Ratio for MRR	S/N Ratio for Overcut
1	20	5	25	0.36	245.46	-8.87395	-47.799615
2	20	5	40	0.315	222.32	-10.03379	-46.939571
3	20	5	55	0.435	196.67	-7.230215	-45.874762
4	20	7	25	0.54	211.2	-5.352125	-46.493878
5	20	7	40	0.51	180.62	-5.848596	-45.135317
6	20	7	55	0.435	198.44	-7.230215	-45.952584
7	20	9	25	0.525	200.65	-5.596814	-46.048783
8	20	9	40	0.465	228	-6.650941	-47.158697
9	20	9	55	0.495	224.86	-6.107896	-47.038244
10	25	5	25	0.405	184.4	-7.8509	-45.315218
11	25	5	40	0.3	226.1	-10.45757	-47.086011
12	25	5	55	0.42	193.92	-7.535014	-45.752452
13	25	7	25	0.285	171	-10.9031	-44.659922
14	25	7	40	0.585	193.14	-4.656883	-45.717445
15	25	7	55	0.33	210.86	-9.629721	-46.479884
16	25	9	25	0.39	144.4	-8.178708	-43.191344
17	25	9	40	0.42	207	-7.535014	-46.319407
18	25	9	55	0.405	151.6	-7.8509	-43.613984
19	30	5	25	0.255	217.72	-11.8692	-46.757967
20	30	5	40	0.345	242	-9.243618	-47.676307
21	30	5	55	0.375	216.16	-8.519375	-46.695507
22	30	7	25	0.465	204	-6.650941	-46.192603
23	30	7	40	0.285	267.46	-10.9031	-48.545177
24	30	7	55	0.315	222.32	-10.03379	-46.939571
25	30	9	25	0.435	196.67	-7.230215	-45.874762
26	30	9	40	0.54	211.2	-5.352125	-46.493878
27	30	9	55	0.525	180.62	-5.596814	-45.135317

The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value. It has been observed that trial no. 14 has the best multiple response characteristics among the 27 trials, because it has the highest grey relational grade shown in Table 4.

Step 5: Determine the optimal factor and its level combination. The higher grey relational grade implies the better product quality; therefore, on the basis of grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined. For example, to estimate the effect of factor *i*, we calculate the average of grade values (AGV) for each level *j*, denoted as AGV_{ij}, then the effect, E_i, is defined as:

$$E_i = \mathbf{max\ (AGV_{ij}) - min\ (AGV_{ij})} \qquad (6)$$

The response table of Taguchi method is employed here to calculate the average grey relational grade for each machining parameter level. It is done by sorting the grey relational grades corresponding to levels of the machining parameter in each column of the orthogonal array, and taking an average on those with the same level. Using the same method, calculations are performed for each machining parameter level and the response table is constructed as shown in Table 5. Fig.4 shows the effect of EMM parameters on multi response characterstics

TABLE 4 :	**Normalized S/N ratio**		**Grey relational co-efficient**		**Grey grade**	**Order**
Trial No	MRR	Overcut	MRR	Overcut		
1	0.5847	0.8607	0.4610	0.3674	0.4142	21
2	0.7455	0.7001	0.4014	0.4166	0.4090	22
3	0.3568	0.5012	0.5836	0.4994	0.5415	12
4	0.0964	0.6169	0.8384	0.4477	0.6430	6
5	0.1652	0.3631	0.7516	0.5793	0.6655	5
6	0.3568	0.5158	0.5836	0.4922	0.5379	14
7	0.1303	0.5337	0.7932	0.4837	0.6385	8
8	0.2765	0.7410	0.6439	0.4029	0.5234	16
9	0.2012	0.7185	0.7131	0.4103	0.5617	9
10	0.4429	0.3967	0.5303	0.5576	0.5440	11
11	0.8043	0.7275	0.3834	0.4073	0.3954	25
12	0.3991	0.4784	0.5561	0.5111	0.5336	15
13	0.8660	0.2743	0.3660	0.6457	0.5059	18
14	0.0000	0.4718	1.0000	0.5145	0.7572	**1***
15	0.6895	0.6142	0.4203	0.4487	0.4345	20
16	0.4883	0.0000	0.5059	1.0000	0.7529	2
17	0.3991	0.5843	0.5561	0.4611	0.5086	17
18	0.4429	0.0789	0.5303	0.8636	0.6970	3
19	1.0000	0.6662	0.3333	0.4287	0.3810	26
20	0.6360	0.8377	0.4402	0.3738	0.4070	24
21	0.5355	0.6545	0.4828	0.4331	0.4580	19
22	0.2765	0.5606	0.6439	0.4714	0.5577	10
23	0.8660	1.0000	0.3660	0.3333	0.3497	27
24	0.7455	0.7001	0.4014	0.4166	0.4090	23
25	0.3568	0.5012	0.5836	0.4994	0.5415	13
26	0.0964	0.6169	0.8384	0.4477	0.6430	7
27	0.1303	0.3631	0.7932	0.5793	0.6863	4

TABLE : 5 RESPONSE TABLE FOR THE GREY RELATIONAL GRADE

	Process parameters	Level 1	Level 2	Level 3
A	Voltage	0.5483	**0.5699***	0.4926
B	Elec. concentration	0.4537	0.5401	**0.6170***
C	Frequency	**0.5532***	0.5176	0.5399

*****Optimum Levels

Mean grey grade = **0.53693**

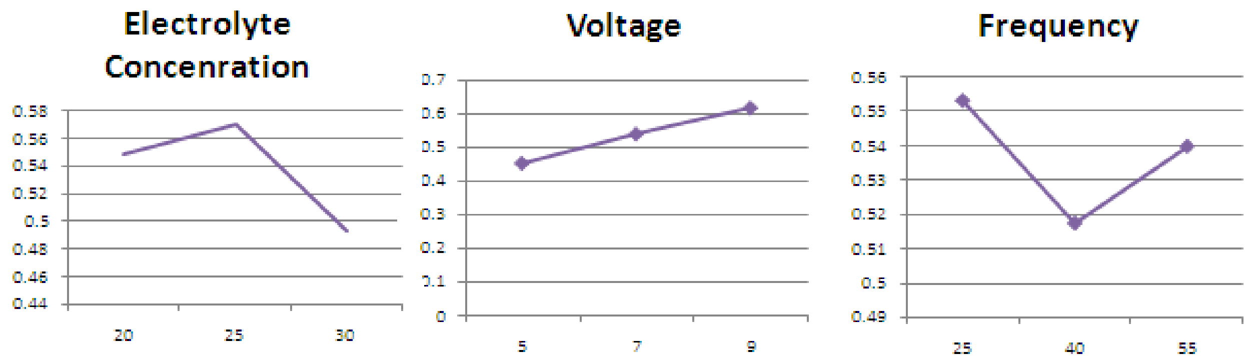


Fig. 4 – Effect of EMM Process parameter level on Grey grade.

Step 6: Considering maximization of grade values (Table 5 / Fig. 4) the optimal parameter conditions obtained are $\mathbf{A_2B_3C_1}$. (Electrolyte concentration, 25 g/l, Voltage, 9 V, Frequency, 25 Hz).

4. MAJOR RESULTS AND INFERENCES:

4.1 ANALYSIS OF VARIANCE (ANOVA)

After the Grey relational analysis, statistical software Minitab16 with an analytical tool of ANOVA is performed to identify the process parameters that influence the MRR and Over cut of this investigation. This analysis is carried out for significance level of α = 0.05, i.e., for a confidence level of 95%. The results of ANOVA for the grey relational grades are listed in Table 6. The results of ANOVA, the Voltage and Electrolyte concentration are the significant machining parameters for affecting the MRR and Overcut. Based on the F value (312.29), Electrolyte concentration is the most significant factor that influences the MRR and overcut with 88.92 % contribution. The second ranking factor is Voltage, which contributes 6.58 %.

TABLE 6. ANOVA FOR GREY RELATION GRADE

Factors	**DOF**	**Sumof squares**	**Mean square**	**F value**	**F $_{0.05}$**	**%of contribution**	
Voltage	2	0.316873	0.158437	312.29	0.000	**88.92**	significant
Elec. Concentration	2	0.023457	0.011728	23.12	0.000	**06.58**	significant
Frequency	2	0.005880	0.002940	5.79	0.010	**01.65**	significant
Error	20	0.010147	0.000507			02.85	
Total	26	0.457639				100 %	

S = 0.0225240   R-Sq = 97.15%   R-Sq(adj) = 96.30%

As machining voltage is increased, the machining rate is increased. The machining rate reaches its maximum value at a particular voltage and decreased because electrode surface is gradually covered by bubbles generated at increased voltage. It is observed that a power supply which maintains a constant voltage and current throughout the machining process is the most effective for electrochemical machining. With the increase in electrolyte concentration, ions associated with the machining operation in the machining zone also increase. A higher concentration of ions reduces the localization effect of electrochemical material removal reactions. This leads to the higher overcut and thus reduces the machining accuracy [36].

Fig. 5 & Fig. 6 shows the interaction between the Voltages, Electrolyte concentration, Frequency to MRR & Overcut and respectively. Fig.7 & Fig. 8 shows the residual plots for Grey grade and the percentage of contribution of factors on the grey relational grade respectively.

Fig 5 **Interaction Plot for SN ratios [MRR]**

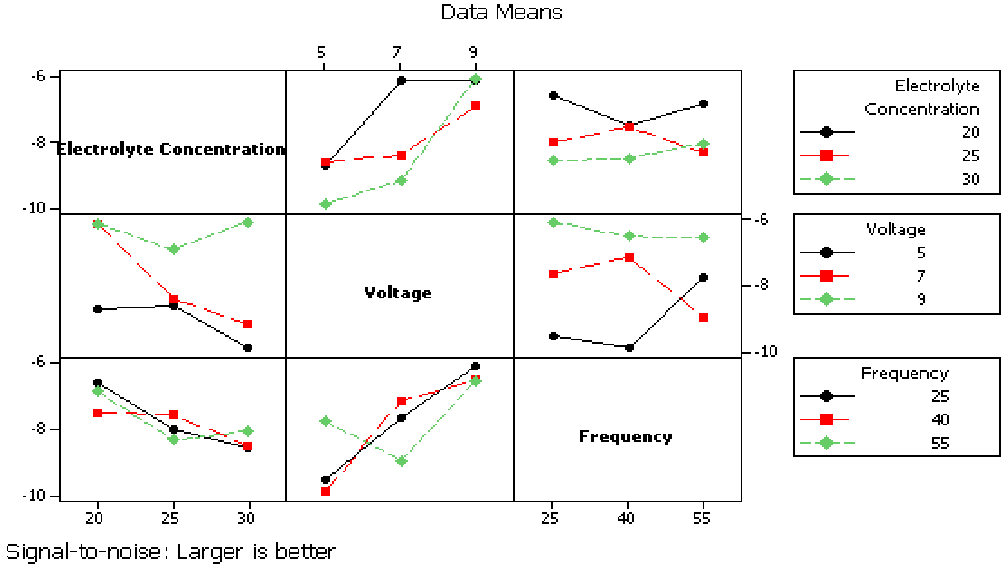


Fig. 6 **Interaction Plot for SN ratios [OVERCUT]**

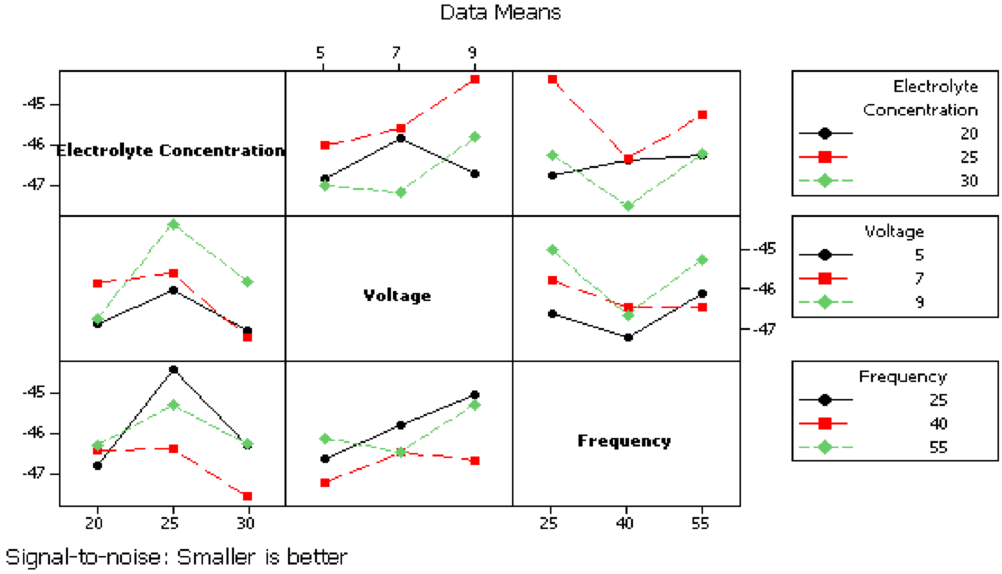


Fig. 7 **Residual Plots for Grade grade**

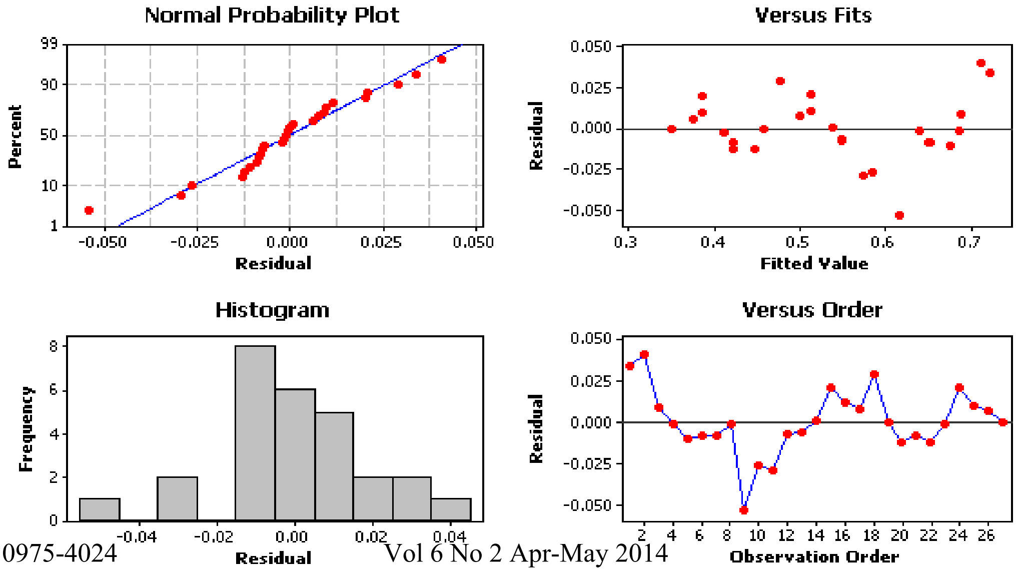
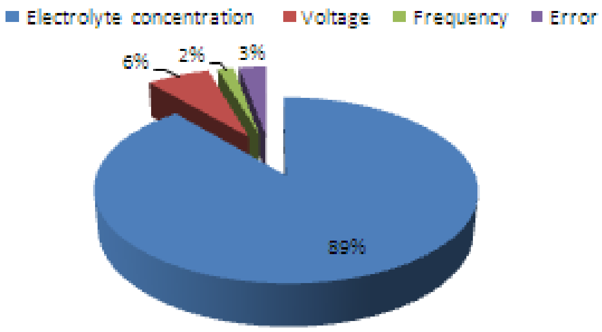


Fig.8 % Contributions of factors on Grey relational grade



4.2 CONFIRMATION TEST

After identifying the most influential parameters, the final phase is to verify the predicted results (MRR and Overcut) by conducting the confirmation test. The $A_2B_3C_1$ is an optimal parameter combination of the EMM process via the GRA. Therefore, the combination $A_2B_3C_1$ was treated as a confirmation test. The predicted Grey relational grade can be calculated using the optimum parameters as

$$\alpha_{predicted} = \alpha_m + \sum_{i=1}^{3} (\alpha_o - \alpha_m)$$

Where , $\alpha_{predicted}$ is = grey relational grade for predicting the optimal EMM Parameter,

α_o = average grey relational grade of the optimal level of a certain significant factor,

α_m = over all mean grey relational grade .

$$\alpha_{predicted} = 0.5369 +(0.5699 - 0.5369)+(0.6170 - 0.5369)+(0.5532 - 0.5369)$$

=0.6663

TABLE 7 CONFORMATION TEST TABLE FOR MRR & OVERCUT

	Initial levels of machining parameters	**Optimal combination levels of machining parameters**	
		Prediction	**Experiment**
Level	$A_1B_1C_1$	$A_2B_3C_1$	$A_2B_3C_1$
MRR	0.36		0.39
Overcut	245.46		144.4
Grey relational grade	**0.4142**	**0.6663**	**0.7529**

The table 7 shows ,the Material Removal Rate an increased value of 0.36mg/min to 0.39 mg/min, the Overcut - reduced value of 245.46 µm to 144.4 µm , Grey relational grade improved 0.4142 to 0.7529 respectively.

5. CONCLUSIONS

The Present investigation is focused on optimization and analysis electrochemical micro machining of Al-6061 - 6 % wt of Gr metal matrix composites machining parameters. From the study of result in EMM was using Taguchi methodology and Grey relational analysis. The following can be concluded from the present study.

1. Based on the confirmation test, improvement in Material Removal Rate, Overcut are 08.33 % and 41.17 % respectively..
2. Grey relational grade is improved by 81.77 %.
3. The parameter combination suggested for the higher MRR and lesser overcut are Electrolyte concentration, 25 g/l, Voltage, 9 V, Frequency, 25 Hz .

4. The results of ANOVA, the Electrolyte concentration and Voltage are the most significant machining parameters for affecting the MRR and Overcut.

5. Confirmation test results proved that the determined optimum combination of machining parameters satisfy the real requirements of EMM operation of metal matrix composites.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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