International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.7, No.01, pp 203-211, 2014-2015

Investigation on Electrochemical Micro Machining of Al 6061-6% wt Gr based on Taguchi design of experiments

P.Satishkumar[1], S.Dharmalingam[2]*, K.Raja[2], K.Lingadurai[2], G.Padmanaban[3]

[1]Department of Mechanical Engineering , JCT College of Engineering & Technology, Coimbatore ,Tamilnadu, India.
[2]Department of Mechanical Engineering , University College of Engineering, Anna University , Dindigul ,Tamilnadu, India.
[3]Department of Mechanical Engineering , Rathinam Technical Campus, Coimbatore ,Tamilnadu. India.

Abstract: Micro Electro chemical machining manufacturers and users are to achieve a better stability and high economical productivity of the manufacturing process is the main objectives of this investigation. This paper investigates the influence of the process parameters like machining voltage, electrolyte concentration, frequency on the over cut and Material Removal Rate (MRR). This paper discusses a methodology for the optimization of the machining parameters on drilling of Al 6061- 6% Gr Metal Matrix composites using Electrochemical Micro Machining (EMM). The taguchi $\mathbf{L_{27}}$ orthogonal array and analysis of variance are employed to study the influence of machining parameters such as machining voltage, Electrolyte concentration, Frequency on the over cut and Material Removal Rate (MRR). Based on the Taguchi analysis, optimum level of parameters is determined and the same to validate through the confirmation test. Experimental results are in close agreement with the developed model. 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, Design of Experiment.

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 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 [29-30]. Aluminum matrix composites are generally regarded as extremely difficult to machine, because of the abrasive characteristics of the reinforced particulates.

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 Preparation of the hybrid composites

The material used in this investigation consists of 6061 aluminum alloy as matrix and its chemical composition is shown in table 1. 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 40 microns. The composites were prepared through stir casting route as shown in fig 1. The aluminum alloy was preheated in a resistance furnace at 400º C for 2 to 3 hour before melting. Gr was also preheated in a resistance furnace at 1250º C for 2 hour. The preheated aluminum were first heated above the liquidus temperature to melt them completely, then slightly cooled below the liquidus to maintain the slurry in the semisolid state. This procedure has been adopted while stir casting aluminum composites]. 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 15–20 min at an average mixing speed of 150–300 rpm. The final temperature was controlled to be within 750°C±20°C, and pouring temperature was controlled to be around 720°C. After thorough stirring, the melt was poured into steel molds of size 100x100x10 mm and allowed to cool to obtain cast sheet. Then the thickness was reduced to 0.4 mm through rolling and the same was cut in to 50x50x0.4 mm to accommodate into the EMM.

3.2 Electrochemical Micro Machining (EMM)

Electrochemical micro machining (EMM)(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 ECM, 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 was used. The electrolyte of varying concentrations used in this study was sodium nitrate ($NANo_3$) and Al-6 %wt 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 0.6A as maintained.

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	0.6	max 0.1	max 0.15	98.1	remaining

Fig 1. Stir Casting Set up

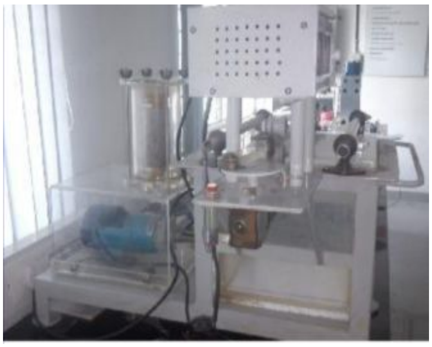

Fig.2 EMM Setup

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.

3.3 Methodology:

The optimization of process parameters is the key step in the Taguchi method. 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 hybrid Al-6% Gr metal matrix composites, each experiment was replicated twice. Machining time, over cut, MRR noted for every trial. There are three categories of quality characteristic in the analysis of the S/N ratio:

1. Larger is better
2. Nominal is best
3. Smaller is best

Larger is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the larger-is-better S/N ratio using base 10 log is:

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

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

Nominal is best (I)

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the nominal-is-best I S/N ratio using base 10 log is:

S/N = -10 log (10 s^2)

where s = standard deviation of the responses for all noise factors for the given factor level combination.

Nominal is best (II)

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the nominal-is-best II S/N ratio using base 10 log is:

S/N = 10 log((Y^2) / s^2)

where Y = mean of responses for the given factor level combination, s = standard deviation of the responses for the given factor level combination, and n = number of responses in the factor level combination.

Smaller is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the smaller-is-better S/N ratio using base 10 log is:

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

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

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.

Table 2 Experimental results for L_{27} OA of Al 6061- Gr MMC

S/N ratio of MRR and Overcut							
Trial No	**E**	**V**	**F**	**MRR mg/min**	**Overcut µ m**	**S/N Ratio for MRR**	**S/N Ratio for Overcut**
1	20	5	25	0.36	245.46	-8.874	-47.7996
2	20	5	40	0.315	222.32	-10.03	-46.9396
3	20	5	55	0.435	196.67	-7.23	-45.8748
4	20	7	25	0.54	211.2	-5.352	-46.4939
5	20	7	40	0.51	180.62	-5.849	-45.1353
6	20	7	55	0.435	198.44	-7.23	-45.9526
7	20	9	25	0.525	200.65	-5.597	-46.0488
8	20	9	40	0.465	228	-6.651	-47.1587
9	**20**	**9**	**55**	**0.495**	224.86	-6.108	-47.0382
10	25	5	25	0.405	184.4	-7.851	-45.3152
11	25	5	40	0.3	226.1	-10.46	-47.086

12	25	5	55	0.42	193.92	-7.535	-45.7525
13	25	7	25	0.285	171	-10.9	-44.6599
14	25	7	40	0.585	193.14	-4.657	-45.7174
15	25	7	55	0.33	210.86	-9.63	-46.4799
16	**25**	**9**	**25**	0.39	**144.4**	-8.179	-43.1913
17	25	9	40	0.42	207	-7.535	-46.3194
18	25	9	55	0.405	151.6	-7.851	-43.614
19	30	5	25	0.255	217.72	-11.87	-46.758
20	30	5	40	0.345	242	-9.244	-47.6763
21	30	5	55	0.375	216.16	-8.519	-46.6955
22	30	7	25	0.465	204	-6.651	-46.1926
23	30	7	40	0.285	267.46	-10.9	-48.5452
24	30	7	55	0.315	222.32	-10.03	-46.9396
25	30	9	25	0.435	196.67	-7.23	-45.8748
26	30	9	40	0.54	211.2	-5.352	-46.4939
27	30	9	55	0.525	180.62	-5.597	-45.1353

4. Major results and inferences:

Minitab 16 statistical software has been used for the analysis of the experimental work. The software studies the experimental data and then provides the calculated results of signal-to-noise ratio. This analysis is carried out for significance level of $\alpha = 0.05$, i.e., for a confidence level of 95%. Fig 3 shows the micro hole image of 20 g/l, 9 V, 55 Hz with the help of optical microscope.

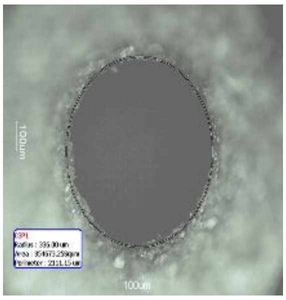

Fig 3 Optical hole image

4.1 Analysis for MRR

Fig 4 shows the main effects at each level, it can be seen that the optimal values for maximum MRR were electrolyte concentration of 20 g/l , machining voltage of 9 V , and frequency of 55 Hz. The MRR increases with an increase in pulse frequency then the dissolution efficiency increases rapidly, causing a rapid increment of MRR in the machining zone. Fig 5 shows the residual plot MRR. Table 3 shows the response table for S/N ratio of MRR.

Table 3 Taguchi Analysis: MRR versus Voltage, Electrolyte concentration, Frequency

Response Table for Signal to Noise Ratios (Larger is better)

Level	Electrolyte concentration (E)	Voltage (V)	Frequency (F)
1	-6.992	-9.068	-8.056
2	-8.289	-7.912	-7.854
3	-8.378	-6.678	-7.748
DELTA	1.386	2.39	0.348
RANK	**2**	**1**	**3**

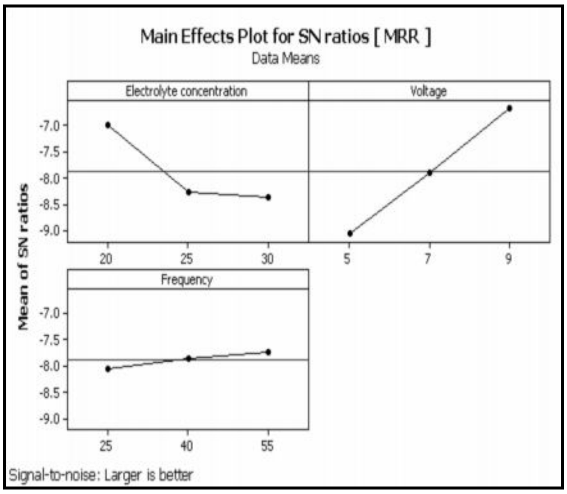

Fig 4. S/N ratio graph for MRR

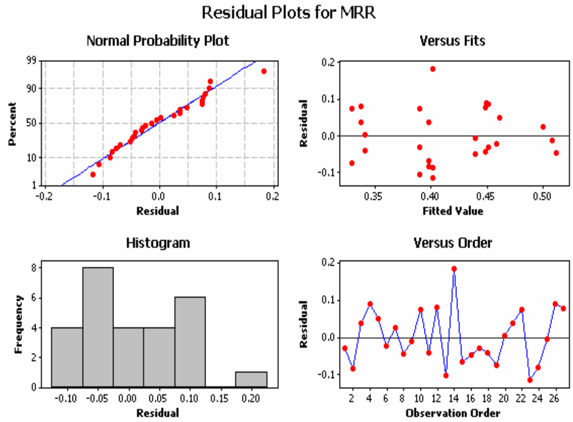

Fig 5 Residual graph for MRR

4.2 Analysis for Over cut

The response table 4 shows the average of selected characteristics for each level of the factor. This table includes the ranks based on the delta statistics, which compare the relative value of the effects. Table 4 shows the response table for S/N ration of Overcut and its ranking order. Fig 6 show the main effects at each level it can be conclude that the optimal values for minimum overcut were electrolyte concentration of 25 g/l, machining voltage of 9 V and frequency of 25 Hz. Fig 7 show the residual plot for over cut.

Table 4 Taguchi Analysis: Over cut versus Voltage, Electrolyte concentration, Frequency

Response Table for Signal to Noise Ratios (Smaller is better)

Level	**Electrolyte concentration (E)**	**Voltage (V)**	**Frequency (F)**
1	-46.49	-9.068	-45.80
2	-45.35	-7.912	-46.79
3	-46.70	-6.678	-45.94
DELTA	1.35	1.00	0.97
RANK	**1**	**2**	**3**

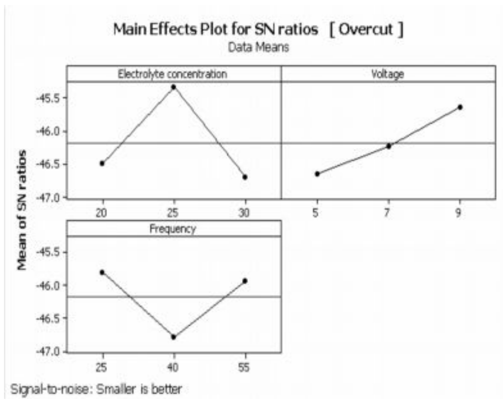

Fig.6 S/N ratio graph for Over cut

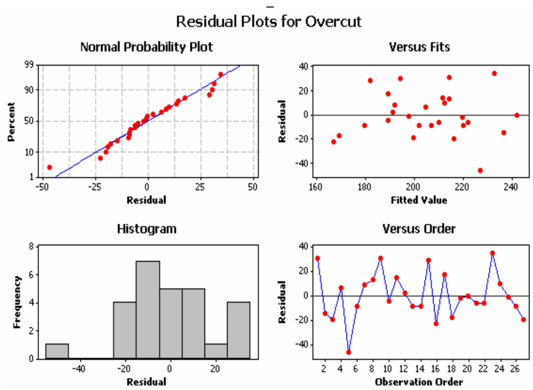

Fig.7 Residual graph for Over cut

4.3 Confirmation test

Confirmation test is carried out to verify the accuracy of the model developed. The experimental data obtained are compared with the values predicted by the developed model and presented in Table 5 and Table 6. It is observed that the model close to agreeable degree of approximation and the errors were minimal.

Table 5 shows the S/N ratio of the predicted MRR and the actual MRR. Based on the confirmation test, the MRR is improved by **37.5 %** with respect to the initial parametric setting. Therefore, the parameter combination suggested for the higher MRR is electrolyte concentration of 20 g/l, machining voltage of 9 V and frequency of 55 Hz.

Table 6 shows the comparison of the S/N ratio of the predicted overcut with the actual overcut. Based on the confirmation test, the Overcut is improved by **41.2 %** with respect to the initial parametric setting. The parameter combination suggested for the lesser overcut is electrolyte concentration of 25 g/l , machining voltage of 9 V and frequency of 25 Hz.

Table 5 : Confirmation test on MRR analysis

	Initial levels of machining parameters	**Optimal combination levels of machining parameters**	
		Prediction & Experiment	**% of Improvement**
Level	$A_1B_1C_1$	$A_1B_3C_3$	
MRR	0.36	0.495	**37.5 %**

Table 6 : Confirmation test on Overcut analysis

	Initial levels of machining parameters	**Optimal combination levels of machining parameters**	
		Prediction & Experiment	**% of Improvement**
Level	$A_1B_1C_1$	$A_2B_3C_1$	
MRR	245.46	144.4	**41.2 %**

5 Conclusions

Optimization of the single response problem using Taguchi method provided an effective methodology for the design optimization of EMM parameters on **Al 6061- 6% Gr** composites. The following can be concluded from the study:

a. The optimal values for maximum MRR was electrolyte concentration of 20 g/l , machining voltage of 9 V, and frequency of 55 Hz and the optimal values for minimum overcut is electrolyte concentration of 25 g/l , machining voltage of 9 V and frequency of 25 Hz.
b. Based on the confirmation test, the improvements of the MRR from the initial machining parameters to the optimal machining parameters are about 37.5 % and Overcut is about 41.2 %.
c. Voltage and Electrolyte concentration were the most significant factor that influences the MRR and Overcut.

References

1. Hashim, J., L. Looney and M.S.J. Hashmi, 1999. Metal matrix composites: Production by the stir casting method. J. Mater. Process. Technol., 92-93: 1-7.
2. P.Shanmughasundaram, R. Subramanian, G. Prabhu, ‘Some Studies on Aluminium– Fly Ash Composites Fabricated by Two Step Stir Casting Method, European Journal of Scientific Research, Vol.63 No.2 (2011), pp.204-218
3. Rajurkar, K.P., et al., Review of Electrochemical and Electrodischarge Machining. Procedia CIRP 6 (2013) 13 – 26.
4. S. Jahanmir, M. Ramulu, P. Koshy (Eds.), Machining of Ceramics and Composites, Marcel Dekker, New York, 2000.

5. Malapati Manoj Kumar Reddy, Influence of Pulse Period and Duty Ratio on Electrochemical Micro Machining (EMM) Characteristics, International Journal of Mechanical Engineering and Applications. Vol. 1, No. 4, 2013, pp. 78-86.
6. Marimuthu, P. and Chandrasekaran, K. (2012) 'Machinability study on stainless steel and optimum setting of cutting parameters in turning process using Taguchi design of experiments', Int. J. Materials and Product Technology, Vol. 43, Nos. 1/2/3/4,pp.122–133.
7. Ghani, J.A., Choudhury, I.A. and Hasan, H.H. (2004) 'Application of Taguchi method in the optimizations of end milling operations', J. Mat. Proc. Tech., Vol. 145, No. 1, pp.84–92.
8. Jeyapaul, R., Shahabudeen, P. and Krishnaiah, K. (2006) 'Simultaneous optimization of multi-response problems in the Taguchi method using genetic algorithm', Int. J. Adv. Manuf.Tech., Vol. 30, Nos. 9–10, pp.870–878.
9. H. Joardar, N.S.Das1, G. Sutradhar,' An experimental study of effect of process parameters in turning of LM6/SiCP metal matrix composite and its prediction using response surface methodology ', Int. Journal of Engineering, Science and Technology ,Vol. 3, No. 8, 2011, pp. 132-141.
10. Muthukrishnan; (2008,a) Optimization of machining parameters of Al/sic – MMC with ANOVA and ANN analysis, J.Mater.Process.Tech, Vol.209, pp.225-232.
11. Muthukrishnan; (2008,b) Machinability issues in turning of AlSiC(10p) metal matrix composites, Int.Journal of Adv. Mfg.Tech, Vol.39, pp.211-218.
12. S. Dhanabalan, K. Sivakumar, C. Sathiya Narayanan, Optimization of Machining Parameters in EDM of Inconel 718 for Form Tolerance Using Grey Relational Analysis, International Review of Mechanical Engineering (IREME) ,(2012), Vol. 6 N. 7, pp. 1453-1460.
13. L. Savadamuthu, S. Muthu, T. Rakhul, S. Jothimani, Multi Characteristic Optimization in Wire Cut EDM by Using Taquchi Data Envelopment Analysis Based Ranking Methodology, International Review of Mechanical Engineering (IREME),(2013), Vol 7 N. 3, pp.468-473.
14. R. Hussin, R. Mohd Saad, R. Hussin, M. R. M. Hafiezal, M. A. Fairuz, Optimization of the Plastic Injection Molding Parameters for Sport Equipment by Using Design of Experiment , International Review of Mechanical Engineering (IREME)(2013), Vol 7 N. 3, pp.453-462.
15. S.Dharmalingam , P.Marimuthu and K.Raja , (2014) , Machinability study on Al- 10% TiC composites and optimum setting of drilling parameters in electrochemical micro machining using grey relational analysis , Int. Journal of Latin American Applied Research .
16. S. Dharmalingam, P. Marimuthu, K. Raja, C. Nithyapathi, B. Babu, M. Siva , (2014) Experimental Investigation on Electrochemical Micro Machining of Al-10%wt SiCp Based on Taguchi Design of Experiments , Int. Journal Review of Mechanical Engineering , Vol 8, No 1,pp 80 - 88
17. S.Dharmalingam, P.Marimuthu, K.Raja, R.Pandyrajan, S.Surendar, (2014) Optimization of Process Parameters on MRR and Overcut in Electrochemical Micro Machining on Metal Matrix Composites Using Grey Relational Analysis , International Journal of Engineering and Technology , vol. 6, no. 2, pp 519-529.
18. Dharmalingam Soorapparaju, Marimuthu Perumal, Raja Kandhasamy, Pandyrajan Rajendran , (2014),Simulation analysis of EMM on Metal Matrix Composites Using Taquchi , International Journal of Information Technology & Computer Sciences Perspectives , Vol 3 , No 1, pp 843 – 850.
19. Bhattacharyya B, Munda J (2003) Experimental investigation into electro-chemical micromachining (EMM) process. J Mater Process Technol 140:287–291.
20. R. Thanigaivelan & R. M. Arunachalam & Pelden Drukpa,' Drilling of micro-holes on copper using electrochemical Micromachining' Int J Adv Manuf Technol, DOI 10.1007/s00170-012-4093-4
21. Senthil Kumar KL, Sivasubramanian R, Kalaiselvan K (2009) Selection of optimum parameters in non conventional machining of metal matrix composite. Portugaliae Electrochimica Acta 27 (4):477–486.
22. Bhattacharyya B., Doloi B. and P.S. Sridhar. 2001. Electrochemical micro machining: new possibilities for micro manufacturing. Journal of Material Processing Technology. 113: 301-305.
23. Ross PJ (2005) Taguchi techniques for quality engineering. Tata McGraw-Hill, New Delhi.
24. Bhattacharyya B., Malapati M., Munda J. and Sarkar A. 2007. Influence of tool vibration on machining performance in electrochemical micro-machining of copper. International Journal of Machine Tools and Manufacture. 47(2): 335-342.
25. Bhattacharyya B., Mitra S. and Boro A. K. 2002.Electrochemical Micromachining: New possibilities for micromachining. Robotics and Computer integrated manufacturing. 18: 283-289.
26. S.Senthil babu, B K.Vinayagam ,' Study of some parameters on drilling of Al based Metal Matrix Composites – a review', International Journal of Scientific & Engineering Research Volume 3, Issue 7, June-2012

27. Riaz Ahamed A, Asokan P, Aravindan S (2008) EDM of Hybrid Al-SiCp-B4Cp and Al-SiCp-Glass metal matrix composites. J Adv Manuf Technol. doi:10.1007/s00170-008-1839-0
28. Pandey A, Bains HS, Manna A (2007) Particulate reinforced Al-MMC: Opportunity and production. CPIE 22-24 March, NITJ-India
29. Riaz Ahamed A, Asokan P, Aravindan S ,Prakash.M.K ,'Drilling of hybrid Al-5%SiCp-5%B4Cp metal matrix composites. Int J Adv Manuf Technol (2010) 49:871–877,DOI 10.1007/s00170-009-2453-5.
30. Balasubramanian L, Dharmalingam S, 'Performance study on Influence of Tool design on Electro Chemical Micrmachining 'International Journal of Information Technology & Computer Sciences Perspectives Vol 2, No 1 (2013) , 426-430.

*****