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Experimental Investigation and Optimization on Hybrid Metal Matrix Composites through Electrochemical Micro Machining using Taguchi Method

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Abstract:

Nowadays, the usage of Ceramics in Industries is keep on improving due to its salient capabilities of good wear resistant, prone to thermal shock and oxidation resistant. This paper discusses a methodology for the optimization of the machining parameters on drilling of Al- Al_2O_3 Metal Matrix composites using ECMM. However, machining of Ceramics using conventional machining is almost impossible due to higher tool wear rate and temperature raise at the contact zone. Hence, Electrochemical Micromachining (ECMM) process is introduced to machine the Metal Matrix Composites (MMC). This paper investigates the influence of the process parameters like machining voltage, electrolyte concentration, frequency on the Material Removal Rate (MRR) overcut and high order of true positional tolerances on the drilled portion of chosen MMC. This is an anodic dissolution process of metal as anode ion by ion, and ECMM is one of the promising micromachining methods especially to produce at micro scale in non-electrically conductive materials of Ceramics. This paper to develop an ECMM setup, which helps to produce a micron size hole with help of NaCl, NaNO3 and KOH based electrolytes. Optimize the identified major influencing parameters will be done using Taguchi method. This work highly helps to, automobile and electronic industries, Micro level products.

Keywords: Metal Matrix Composite (MMCs), Material Removal Rate (MRR), Overcut, Electro chemical micromachining (EMM), Taguchi & Design of Experiment.

1. INTRODUCTION

ECMM is a nonconventional machining process in which material is removed by the electrolysis process and it is based on the mechanism of anodic dissolution process. This is non-contact [tool and work piece] metal removal process. Metal Matrix Composites (MMC) is widely used composite materials in aerospace, automotive, electronics and medical industries. They have outstanding properties like high strength, low weight, high modules, low ductility, high wear resistance, high thermal conductivity and low thermal expansion. 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, and heavy stuff components mechanical machine parts like turbine blades, engine castings, bearing cages, gears, dies and molds. ECM is often characterized as "reverse electroplating", in that it removes material instead of adding it. Electrochemical machining is widely recognized that has great potential and many applications in micromachining. The main thought of ECMM is the micro level products can be fabricated.

2. LITERATURE REVIEW

Though advantage of stir casting method is unique, it is very popular[1]. In automobile applications, Metal matrix composites are considered as an excellent material in sectors, which is fabricated by stir casting process where light weight, enhanced mechanical properties and wear resistance are prime consideration especially[2]. A successful adaptation to produce macro, micro components with complex features and high aspect ratios for biomedical is by ECM technology and other applications with the help of extensive research work needed in the area of machining parameter and tool design[3]. Because of the hard particles present in metal matrix, there is a serious problem in MMC machining[4]. Though the machining properties of MMC is poor, drilling MMC is a challenging task for manufacturing engineers. When drilling MMCs the experimental results should be in terms of tool life, quality of drilled hole, and applied force. The distance of IEG is small and has shorter pulsed period machining voltage, it also increases the metal removal[5]. For identifying the significant parameters affecting the responses, Analysis of variance (ANOVA) is used [6-8]. In Taguchi's analysis method, the product quality is considered because it influences the design parameters and noise parameters[9-14]. Electrochemical micromachining (ECMM) is used to produce micro/meso scale components an emerging nonconventional technology[15]. Electro chemical micro machining of 304 stainless steel that investigates the effect and parametric optimization process parameters[16]. Experiments determined with the developed setup by varying the machining voltage, electrolyte concentration, pulse-on time, and frequency on copper plate. By using machining voltage of 6–10 V, pulse-on time of 10–15 ms and electrolyte concentration of 15– 20 g/l, a considerable amount of MRR at a moderate accuracy can be achieved[17]. It is not easy to decide the optimal machining parameters for improving the output quality because complexity of the micro ECM process. For survival in today's dynamic market conditions, the optimization of process parameters is essential for the realization of a higher productivity, which is the preliminary basis of it. The combinational control of various process parameters can be generated with optimal quality of the work piece in ECM [18]. For study the effects of various parameters such as applied voltage, electrolyte concentration, feed rate, and percentage reinforcement on maximizing the MRR, machining of the aluminium A356/SiCp composite work material using the ECM process is done[19]. No tool wear was produced by the process due to the 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[20-22].

3. EXPERIMENTAL DETAILS

Figure 1.Stir casting setup **Figure 2.ECMM setup**

2.1 Preparation of the Hybrid Composites

The metal matrix casting is obtained by the process of stir casting. Two metals are used. They are aluminium and aluminium oxide of concentration 88% and 12% respectively are used. The tool to be used is made up of Inconel material. First aluminium in the form of rod of 1.5 kg is taken in the tilting furnace, where it is heated from room temperature to 1500^{o}c. The raise of temperature up to 900^{o}c takes place rapidly, after which the increment takes place gradually. After the treatment of 2 to 3 hours, the rod is obtained in the molten state. The second step starts with the heating of aluminium oxide in muffle furnace. The aluminium oxide is taken in the form of powder of 180g. A temperature of 540^{o}c is set in the furnace and it increases gradually from the room temperature. Once it is heated, it is mixed with the aluminium in molten form, after adding it kavarash is added to the mixture to remove the dust particles. Once the mixture is ready , it is poured into the casting of 15mm.the die is divided into two parts each of 7.5mm & then the mixture is poured into the casting mould release lubricant is added along the sides of casting to remove the final product without any alter in the shape. The final product is obtained in the form of plate. The obtained plate is then machined using CNC Milling machine to obtained required plate of 1.5mm.

Table 1. Chemical composition of Al 6061

Component	Cr	Fe	Cu	Mn	Mg	Si	Ti	Zn	Al
Wt %	0.16	0.25	0.31	0.08	0.99	0.66	0.02	0.01	max 97.52

2.2 Electrochemical Micro Machining (ECMM)

ECMM is one of the nonconventional machining processes. Hard-machined components offers the unique advantage and better accuracy with high surface integrity. Also it has wider application because it produces good quality surfaces without affecting the metallurgical properties of the work material. During ECM, electrodes are occur by the chemical reaction through the work-piece and tool along within the electrolyte. Interference between the work piece and tool in which that electrolyte pass which result in electron transfer that carried out by both anode and cathode. During machining it does not induce any deformation because there is no heat is generated. Electrolyte supply system, inter electrode gap control system, mechanical machining, system pulse rectifier system, tool electrode feeding system are the major components of the EMM. Servo motor contain the tool electrode feed mechanism, with resolution of 3 µm along Z axis and 8051 micro controller. Filter and pump arrangement are present in the electrolyte supply system. With varying voltage, current, and pulse contain the power supply of 20 v and 30 A capability was used[27-30]. The concentration of electrolyte are used to study the sodium nitrate ($NANO_3$) and Al- Al_2O_3 contain a thickness about 1.56 mm as the work piece contain. The initial process parameters are chosen by based on the preliminary experiments and literature review conducted, and under the corresponding levels. Experiment contain the work piece about thickness of 1.56 mm & machining current 4-12 V. Table 2 shows the investigation. Of machining parameters and their level was identified. Electrochemical micro machining

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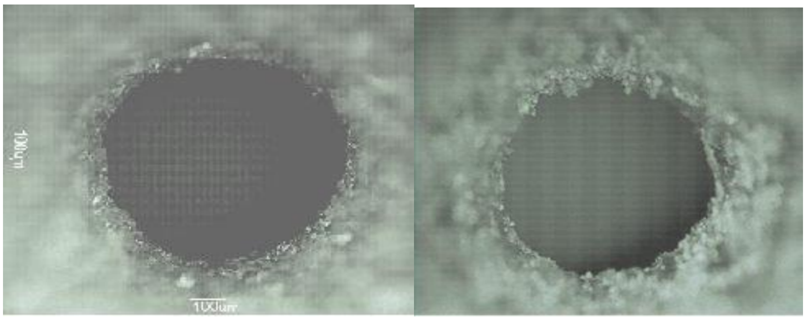
(EMM) and characteristics (MRR and Overcut) contain as output responses through micro – hole machining. Work piece are derived from EMM. The micro hole has been related with the machining accuracy through the overcutting. The diameters of the tool electrode and machined micro hole are been differentiate. With a support of optical microscope diameter of the machined micro – hole was measured.

Table 2 Machining process parameters and their corresponding levels

Symbol	Factors	Level 1	Level 2	Level 3
A	Machining Voltage (V)	4	8	12
B	Electrolyte concentration (g/l)	20	30	40
C	Frequency (Hz)	25	40	55



4 V/ 30g/l/55 Hz　　　　12 V / 25 g/l / 30 Hz

Figure 3.optical image for Micro hole

2.3. Methodology

The optimization of process parameters is the key step in the Taguchi method. Nine experimental runs (L_9) based on the Orthogonal Array (OA) of Taguchi methods have been carried out. The multi-response optimization of the process parameters viz. MRR, overcut has been performed for making a micro hole in the process of micro-ECM of hybrid Al- Al_2O_3 metal matrix composites, each experiment was replicated twice. In every trial machining time, over cut, MRR were noted.

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

$$S/N = - 10\log [\text{sum} (1/Y^2) /n)$$

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

Where Y = responses for the given factor level combination and

n = number of responses in the factor level combination.

Nominal is best (I)

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

The signal-to-noise (S/N) ratio is calculated for each factor level combination by using the formula mentioned above.

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

Nominal is best (II)

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

The signal-to-noise (S/N) ratio is calculated for each factor level combination by using the above mentioned formula.

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

$$S/N = -10 \log [\mathrm{sum}\, (Y^2) /n)]$$

The signal-to-noise (S/N) ratio is calculated for each factor level combination by using the above mentioned formula.

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 3 shows the experimental results for L_{27} orthogonal array.

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Trial No.	A	B	C	MRR mg/min	Over Cut (μ m)	S/N Ratio for MRR	S/N Ratio for Overcut
1	4	20	25	0.59	242.5	-4.583	-47.6942
2	4	20	40	0.53	194.36	-5.5145	-45.7721
3	4	20	55	0.43	168.44	-7.3306	-44.5289
4	4	30	25	0.29	183.28	-10.752	-45.2623
5	4	30	40	0.51	152	-5.8486	-43.6369
6	4	30	55	0.49	169.8	-6.1961	-44.5988
7	4	40	25	0.55	222.46	-5.1927	-46.945
8	4	40	40	0.39	200.36	-8.1787	-46.0362
9	4	40	55	0.46	96.42	-6.7448	-39.6833
10	8	20	25	0.32	156.48	-9.897	-43.8892
11	8	20	40	0.47	197.64	-6.558	-45.9175
12	8	20	55	0.49	165.3	-6.1961	-44.3655
13	8	30	25	0.5	148.34	-6.0206	-43.4252
14	8	30	40	0.21	212.28	13.5556	-46.5382
15	8	30	55	0.28	188.6	11.0568	-45.5108
16	8	40	25	0.53	123.44	-5.5145	-41.8291
17	8	40	40	0.44	186.46	-7.1309	-45.4117
18	8	40	55	0.38	110.2	-8.4043	-40.8436
19	12	20	25	0.54	196.4	-5.3521	-45.8628
20	12	20	40	0.4	220.88	-7.9588	-46.8831
21	12	20	55	0.29	195.42	-10.752	-45.8194
22	12	30	25	0.47	183.44	-6.558	-45.2699
23	12	30	40	0.53	142.68	-5.5145	-43.0873
24	12	30	55	0.49	170.26	-6.1961	-44.6223
25	12	40	25	0.45	111.64	-6.9357	-40.9564
26	12	40	40	0.37	192.4	-8.636	-45.6841
27	12	40	55	0.46	180.12	-6.7448	-45.1112

3. Major Results and Inferences

The analysis of the experimental work done by using Minitab 18 statistical software. 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%.

3.1 Analysis for MRR

Figure 4 shows the main effects at each level. Interpreting the main effects table, it can be seen that the optimal values for maximum MRR were machining voltage of 8 V, electrolyte concentration of 30 g/l, and frequency of 55 Hz.

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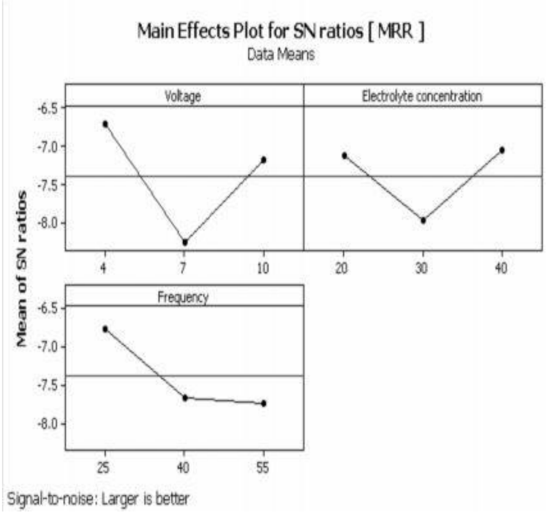

Figure 4. S/N ratio graph for MRR

Table 4. Taguchi Analyses: MRR Response Table for Signal to Noise Ratios (Larger is better)

Level	Voltage	Electrolyte concentration	Frequency
1	-6.705	-7.127	-6.756
2	-8.259	-7.966	-7.655
3	-7.183	-7.054	-7.736
Delta	1.555	0.913	0.98
Rank	1	3	2

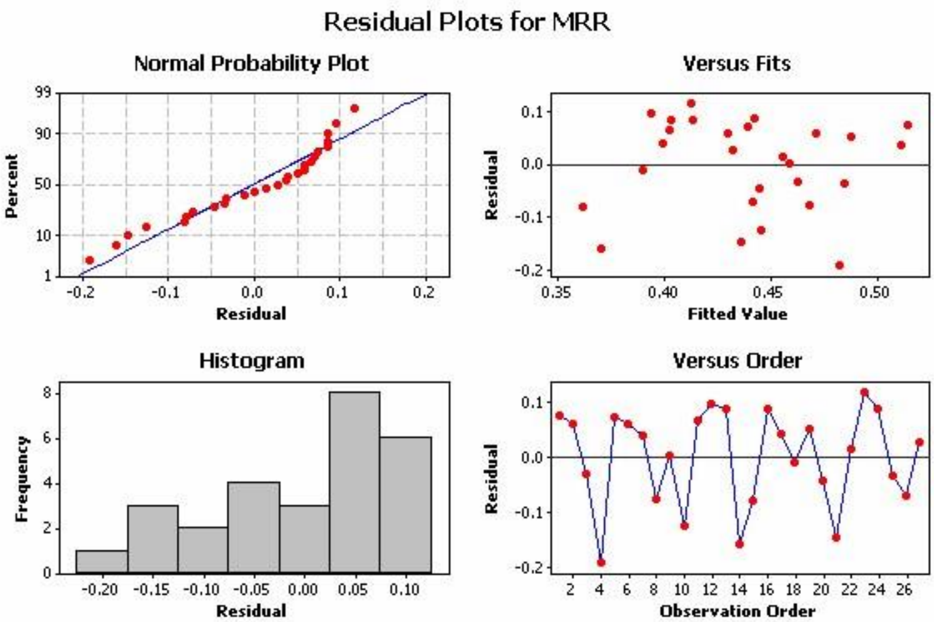

Figure 5. Residual graph for MRR

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3.2 Analysis for Over Cut

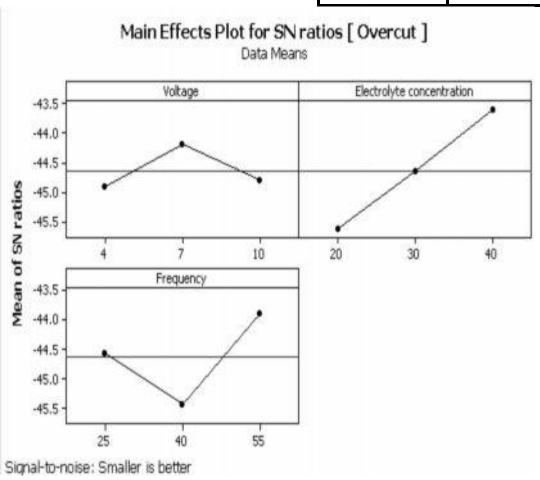
The MRR increases with an increase in pulse frequency then the dissolution efficiency increases rapidly, causing a rapid increment of MRR in the machining zone. Response Table for Signal to Noise Ratios (Larger is better) shown in Table 4. Figure 5 show the residual graph for MRR.

The response table 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. It is the difference between the highest and lowest averages for the factor chosen. Rank starting from 1 is assigned in the descending order of the delta values. Response Table for

Signal to Noise Ratios (Smaller is better) shown in Table 5. From Figure 6, it can be conclude that the optimal values for minimum overcut were machining voltage of 8 Electrolyte concentration of 40 g/l, frequency of 55 Hz.

Table 5. Taguchi Analysis: Overcut Response Table for Signal to Noise Ratios (Smaller is better)

Level	Voltage	Electrolyte concentration	Frequency
1	-44.91	-45.64	-44.57
2	-44.19	44.66	45.44
3	44.81	43.61	43.9
Delta	0.71	2.03	1.54
Rank	2	3	1



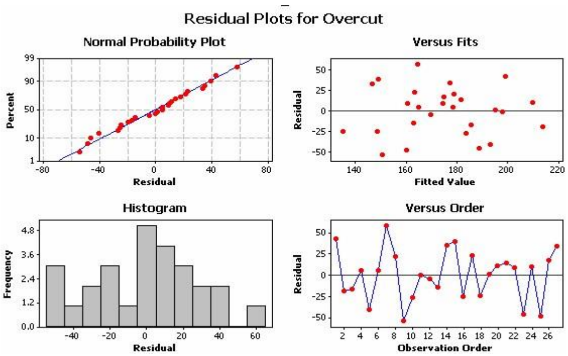


Figure 6. S/N ratio graph for Over cut **Figure 7. Residual graph for Over cut**

Figure 7 show the residual graph for Overcut. Figures 8 & 9 shows the interaction between the Voltages, Electrolyte concentration, Frequency to MRR & Overcut Respectively.

3.3. ANOVA for MRR and Over Cut

ANOVA is performed to identify the process parameters that influence the MRR and Over cut of this investigation. Table 6 and Table 7 shows the ANOVA result for the material removal rate and over cut of AlAl$_2$O$_3$ - B$_4$C under electrochemical micro machining. The F-ratio, which is used to measure the significance of factor at the desired significance level, is the ratio between variance due to the effect of a factor and variance due to error term. From Table 6 & 7 results it is obvious that all the selected factors have statistical and physical significances on the material removal rate and over cut during machining of composite at 95% confidence level. The results of ANOVA, the Voltage and Electrolyte concentration are the significant machining parameters for affecting the MRR. Based on the F value (1.10), Voltage is the most significant factor that influences the MRR with 9.12 % contribution. The second ranking factor is Frequency, which contributes 5.99%. Similarly the Electrolyte concentration were the significant machining parameters for affecting the Over cut with 16.61 % contribution. The second ranking factor is Frequency which contributes 10.79 %. 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 [18].

Table 6. ANOVA table for MRR

Factors	**DOF**	**Sum of squares**	**Mean square**	**F value**	**F 0.05**	**% of contribution**
Voltage	2	0.021719	0.010859	1.10	0.351	9.12
Electrolyte Concentration	2	0.005652	0.002826	0.29	0.753	2.37
Frquency	2	0.014052	0.007026	0.71	0.502	5.99
Error	20	0.196763	0.009838			
Total	26	0.238185				

S = 0.0991874 R-Sq. = 17.39% R-Sq (adj) = 0.00%

Table 7 ANOVA table for over cut

Factors	**DOF**	**Sum of squares**	**Mean square**	**F value**	**F 0.05**	**% of contribution**
Voltage	2	1189	594	0.52	0.604	3.57
Electrolyte Concentration	2	5540	2770	2.41	0.116	16.61
Frequency	2	3599	1800	1.56	0.234	10.79
Error	20	23020	1151			
Total	26	33348				

S = 33.9261 R-Sq = 30.97% R-Sq(adj) = 10.26%

3.4 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 8 and Table 9 .It is observed that the model close to agreeable degree of approximation. The errors were minimal and therefore the regression models can be effectively employed to predict the MRR and over cut during the

EMM of hybrid composites. Table 8 shows the S/N ratio of the predicted MRR and the actual MRR. Based on the confirmation test, the MRR is improved by 57.32 %. It is suggested for the higher MRR is machining voltage of 8 V, Electrolyte concentration of 30 g/l, and frequency of 55 Hz for the parameter combination. Table 9 shows the comparison of the S/N ratio of the predicted overcut with the actual overcut. Based on the confirmation test, the Over cut is improved by 12.06 %. The overcut is machining is suggested of voltage of 8 V, electrolyte concentration of 40 g/l, and frequency of 55 Hz for the parameter combination.

Table 8 Conformation test table for MRR

	Initial levels of machining parameters	**Optimal combination levels of machining parameters**	
		Prediction	**Experiment**
Level	A1B1C1	A3B3C1	A3B3C1
S/N ratio of MRR value (dB)	-4.583	-11.0568	-10.74

Table 9 Conformation test table for Over cut

	Initial levels of machining parameters	**Optimal combination levels of machining parameters**	
		Prediction	**Experiment**
Level	A1B1C1	A3B2C3	A3B2C3
S/N ratio of Overcut value (dB)	-47.6942	-40.8436	-41.94

4. Conclusion

The Present investigation is focused on optimization and analysis electrochemical micro machining of Al-6061 /12 % wt of Al_2O_3 metal matrix composites machining parameters. From the study of result in EMM was using Taguchi's techniques and ANOVA. The following can be concluded from the present study.

1. Based on the confirmation test, the improvements of the MRR from the initial machining parameters to the optimal machining parameters are about 57.32 %.
2. The optimal values for maximum MRR were machining Voltage of 8 V, Electrolyte concentration of 30 g/l, and Frequency of 55 Hz.
3. Based on the confirmation test, the improvements of the Overcut from the initial machining parameters to the optimal machining parameters are about 12.06 %.
4. The optimal values for minimum Overcut were machining Voltage of 8 V, Electrolyte concentration of 40 g/l, and Frequency of 55 Hz.
5. The results of ANOVA, the Voltage and Frequency are the significant machining parameters for affecting the MRR. Similarly the electrolyte concentration and Frequency are the significant machining parameters for affecting the Over cut.

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. Raviraj Shetty, Raghuvir Pai, Srikanth S. Rao, and Vasanth Kamath, 'Machinability study on discontinuously reinforced aluminium composites (DRACs) using response surface methodology and Taguchi's design of experiments' under dry cutting condition, Mj. Int. J. Sci. Tech. 2008, 2(01), 227239.
9. E. C. Okafor, C. C. Ihueze and S. C. Nwigbo, Optimization of hardness strengths response of plantain fibres reinforced polyester matrix composites (PFRP) applying taguchi robust design , IJE Transactions A: Basics Vol. 26, No. 1 (January 2013) 1-12 .
10. P. Senthil and K.S.Amirthagadeswaran, Enhancing wear resistance of squeeze cast AC2A aluminum alloy, IJE Transactions A: Basics Vol. 26, No. 4 (April 2013) 365-374.
11. K. Chandrasekaran, P.Marimuthu and K.Raja, Prediction model for CNC turning on aisi316 with single and multilayered cutting tool using box behnken design (research note), IJE Transactions A: Basics Vol. 26, No. 4 (April 2013) 401-410 .
12. N. Pourmahmoud, A.Jahangiramini and A.Izadi, Optimization of low pressure vortex tube via different axial angles of injection nozzles, IJE Transactions A: Basics Vol. 26, No. 10 (October 2013) 12551266.
13. T. T. Principal and K. Barnabas, Optimization of minimum quantity liquid parameters in turning for the minimization of cutting zone temperature, IJE Transactions C: Aspects Vol. 25, No. 4 (December 2012) 327-340.
14. M. Azadi Moghaddam and F. Kolahan, Improvement of surface finish when EDM AISI 2312 hot worked steel using taguchi approach and genetic algorithm, IJE Transactions C: Aspects Vol. 27, No. 3 (March 2014) 417-424
15. D. Saravanan, M. Arularasu and K. Ganesan, 'a study on electrochemical micromachining of super duplex stainless steel for biomedical filters', ARPN Journal of Engineering and Applied SciencesVOL. 7, NO. 5, MAY 2012

16. R.Thanigaivelan, RM Arunachalam ,'optimization of process parameters on machining rate and over cut electro chemical micro machining using grey relational analysis, Journal of scientific and industrial research ' ,Vol. 72, January2013, pp. 36-42.
17. Bhattacharyya B, Munda J (2003) Experimental investigation into electro-chemical micromachining (EMM) process. J Mater Process Technol 140:287–291.
18. R. Thanigaivelan & R. M. Arunachalam & Pelden Drukpa,' Drilling of micro-holes on copper using electrochemical Micromachining' Int J Adv Manuf Technol, DOI 10.1007/s00170-012-4093-4Senthil 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.
19. Dharmalingam, S, Marimuthu, P, Raja, K, Nithyapathi, C, Babu, B & Siva, M 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.
20. Ross PJ (2005) Taguchi techniques for quality engineering. Tata McGraw-Hill, New Delhi.
21. 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.
22. Bhattacharyya B., Mitra S. and Boro A. K. 2002.Electrochemical Micromachining: New possibilities for micromachining. Robotics and Computer integrated manufacturing. 18: 283-289.
23. 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.
24. 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.
25. Pandey A, Bains HS, Manna A (2007) Particulate reinforced Al-MMC: Opportunity and production. CPIE 22-24 March, NITJ-India.
26. 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.
27. 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.
28. Dharmalingam, S, Marimuthu, P & Raja, K 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, vol. 44, no.4, pp. 331-338.
29. Dharmalingam, S, Marimuthu, P, Raja, K, Pandyrajan, R & Surendar S 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 echnology, vol. 6, no. 2, pp. 519-529.
30. 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