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A Study On Machining Of Al 6061/Sic (10%) Composite By Electro Chemical Discharge Machining (ECDM) Process

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ABSTRACT

To successfully compete in today's global market, there is a dire need of rapid product development reducing the lead-time between the designs of the product to its arrival in the market. Moreover the market demands are changing fast. To respond to fast changing demands, manufacture of newly designed products requires several innovative manufacturing processes. Engineering Composite Materials are gradually becoming very important material for their scope and use in advance manufacturing industries due to their high fatigue strength, thermal shock resistance, high strength to weight ratio etc. However machining of advance composites like Aluminium Matrix with Silicon Carbide reinforced particulates is very difficult by utilizing conventional machining method. Hence, it is essential for searching an advanced non-conventional machining method which may help to machining such composite. To meet the requirement of micro machining of such important material, it is essential to develop a new machining method. Not only that but also production of through and blind holes, grooves, slots and odd shape contour on composite part have also been difficult to obtain with the traditional process. For effective machining of AL6061/SiC (10%) composite, a electrochemical discharge machining (ECDM) has been developed. The developed ECDM has been utilized to machine holes on AL6061/SiC (10%)-MMC and subsequently tests results which are utilized to analyse the developed ECDM set up performance characteristic. The practical research analysis and test results on machining of holes onAL6061/SiC (10%)-MMC by developed ECDM set up will provide a new guideline to researchers and manufacturing engineers.

1. INTRODUCTION

Fuelled by a growing need for high strength materials in technologically advanced industries and supported by the advances in the field of material science, there has been an increase in the availability and use of difficult-to-machine materials. Non-traditional machining processes are necessary for machining of such materials. EDM, ECM and ECDM are such process which is widely used to machine electrically conductive materials.

ECDM is basically a hybrid process which is combination of ECM and EDM, as includes characteristics of both the process. In ECDM a tool which is cathode in nature and a work piece to be machined as anode in nature. The gap between tool and work piece are maintained by automatic feed mechanism. The current from the tool was sent to chemical electrolyte which further will send to the work piece and erode it to get the required shape on work piece. Materials that can be machined are commonly electrically conductors. An electric DC voltage is applied to both work piece and tool for machining. A feed mechanism is controlled by low rpm motor so that tool move slowly and there is no vibration and restriction in motion of tool.Electrochemical Discharge Machining (ECDM) is suitable machining process to fabricate features and components. Each process has differing characteristics in its material removal mechanism. The former removes the material from the work piece by electric discharges whereas the latter uses the electrochemical reaction to dissolve material. In EDM, material is removed by vaporization and melting during each electric discharge. Therefore, the machined surface is made up of thermally damaged layers consisting of the white layer and the heat affected zones. After each discharge, a small amount of material is removed leaving a crater on the surface. Hence, the generated surface is covered with numerous overlapping discharged craters. Consequently, the surface machined by EDM usually has high surface roughness due to its asperity. On the other hand, the material is removed not only from the work piece but also from the electrode, which manifests as electrode wear. In ECM, the material is removed based on the dissolution of metal from anode. The dissolution rate of electrochemical reaction is relatively low, especially as short pulses, low voltage and small current must be used in ECM to assure required accuracy. Hence, the material removal rate of ECM process is considerably lower than EDM. Since the material removal mechanism is based on ionic dissolution, the surface machined by ECM is very smooth. The generated surface does not have thermally affected layers and it is stress-free with no burr as well as micro-cracks. There is no tool wear in ECM. Hence, an appropriate combination of EDM and ECM could yield the advantages of these two processes while mitigating their adverse effects. Many attempts have been made to combine EDM and ECM in the last two decades. However, it has encountered a challenging obstacle due to their different material removal mechanisms.

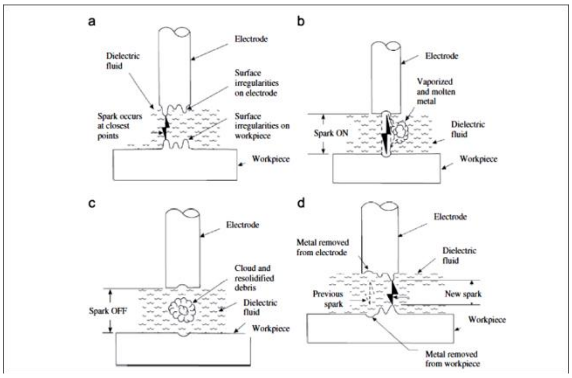

Figure1: Schematic representation of (a) die sinking EDM, (b) WEDM, (c) drilling EDM, and (d) milling EDM.

2. AIM AND OBJECTIVE OF CURRENT WORK

From the available literature it could be seen that ECDM is a feasible process. It is also fairly established that tool feed can be controlled with the help of Programmable Logic Controller (PLC). Apart from being and environment friendly process ECDM also has additional advantages in precision cutting.

- The current work aims was to develop a machining unit for ECDM, perform the test and then deduce the results.
- To manufacture the Al 6061/ SiC (10%) metal matrix composite with the help of Stir Casting Method.
- Use of appropriate tool for optimization of the results such as Taguchi method.
- Apply additivity test to compare the developed and experimental results

3. DESIGN, DEVELOPMENT AND FABRICATION OF MICRO ECDM

As we know that the supporting base is used to support all the components of ECDM set up. The supporting base was made of a mild steel sheet of thickness 3 mm so as to give strength to base for support. Basic dimensions of supporting base are 360mm x 225mm x 3mm.Supporting pillar was made of a hollow rectangular section of pipe having thickness 4 mm which used to support the mechanical actuator which controls the tool feed towards the work piece. Material used for supporting pillar was mild steel. It consists of two holes of diameter 4 mm. It was welded to the base at one side with the help of supporting ribs. Basic dimension of supporting pillar are 345mm x 25mm x 50mm.

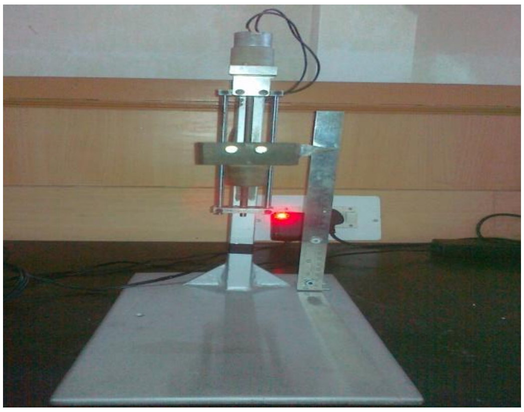

Figure2: Experimental Setup for ECDM

Supporting ribs were used to hold the supporting pillar in its position. They were fabricated from mild steel. Basic dimensions of Supporting Ribs are 40mm x 40mm x 5mm.The function of Linear Motion or Vertical Actuator was to control the tool feed during machining as the tool moves downwards the motion to the tool is given by the tool slide which is mounted on the screw which in turn coupled with the D.C. geared motor. The motor was run with the help of PLC which control the rotation per minute (rpm). This actuator consists of the two fixed bases one is upper fixed base and other one is lower fixed base. The actuator also consists of moving tool slide which mount the tool holder on it. There were two supporting rod for the tool slide on which it slides. The motor gives the linear up and down motion to tool slide.

A tool holder was used to hold tool (electrode). It was fabricated from Bakelite an insulating material. The basic dimensions of the tool holder are80mm x 50mm x 63mm.Bolt of diameter 8 mm was used to give linear vertical motion to tool holder which mounted on it. Material for bolt is steel with a pitch of 1 mm.

Supporting rods were used to support the tool slide on which tool holder is mounted. They were used to only guiding the tool slide and constraint its motion in one direction only. Material used for guiding tool was steel.D.C. geared motor was used to rotate the screw in both clockwise and anti-clockwise direction as per the requirement. Motor has 30 rpm, 24 V DC supply.

4. EXPERIMENTAL PLANNING, DESIGN METHODOLOGY AND WORKING OF ECDM SETUP

To predict the effect of various electrochemical discharge machining parameters on the machining characteristics e.g. material removal rate, average depth radial overcut, a series of experimentation are carried out by varying the parametric setting values. On the basis of trial experiments parametric levels are setup for further experimentation. The specific numbers of experiments are carried out according to the Taguchi method based design of experiments to investigate the parametric effect during ECDM of AL6061/SiC(10%) –MMC.

Table 4a: Details of Experimental Conditions

Machine tool used	Developed ECDM set up
Electrolyte used	Sodium Hydroxide (NaOH) + Distilled Water
Concentration	25g of NaOH / Litre of Distilled Water
	50g of NaOH / Litre of Distilled Water
	75g of NaOH / Litre of Distilled Water
	100g of NaOH / Litre of Distilled Water
	125g of NaOH / Litre of Distilled Water
Work piece	Electrically conductive high strength AL6061/SiC(10%)-MMC
Workpiecethickness	2 mm
Tool Used	Brass of diameter 1.5 mm

Table 4b: Developed ECDM parameters and their levels

Parameters, their symbols and units	**Parametric Levels**			
	1	2	3	4
A: DC supply voltage (X_1, Volt)	10	15	20	25
B:Electrolyte concentration (X_2, NaOH, g/l)	25	50	75	100
C: Electrolyte flow rate (X_3, l/hr)	70	110	150	190
D: Bare tool Tip length (X_4, mm)	0.5	1.0	1.5	2.0

4.1 TAGUCHI METHOD BASED ROBUST DESIGN FOR EXPERIMENTATION

According to Taguchi Method, L_{16} (4^5) orthogonal array was used for experimental investigation. Table 4c shows the L_{16} (4^5) orthogonal array which was used for experimentation.

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Table 4c: L_{16} (4^5) Orthogonal Array

Exp. No.	Column			
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

a. WORKING OF DEVELOPED ECDM SETUP

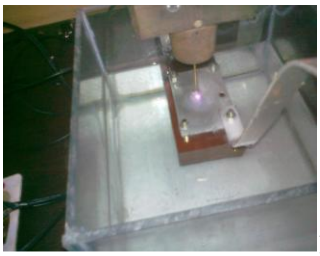
First of all the electrolyte chamber is cleaned properly and dried so that there should be no impurities in the electrolyte chamber. The exact 25 gm of NaOH is weighed in the fraction weighing machine and the weighed quantity of NaOH flakes is mixed together in the distilled water with the help of a plastic rod. A composite work piece (about 72 mm X 50 mm) is weighed in the weighing machine of least count 0.001 gm. This composite work piece is hold in the job holder. The job holder along with the composite work piece is dipped in the electrolyte 2-3 mm below the upper layer of electrolyte.

A supply of 220 volt AC is supplied to the DC generator which produces DC supply in the range of 5 volt DC to 30 volt. A pre-planned constant supply is obtained from the DC generator with the help of regulator and this DC voltage is supplied to the electrode (tool) and to anode (work piece) dipped in the electrolyte chamber. Now 220 volt AC is supplied to step down transformer which steps down the supply voltage to 20 volt AC. A Programmable Logic Controller (PLC) is used to control the motion of the electrode. From PLC the motor is turned on by operating the control switch which will start moving the tool to the forward direction. The erosion will start when a proper gap is maintained between the tool and the work piece. The forward and backward movement of tool is controlled by the speed of the stepped motor. Automatic feed to the tool is set to produce continuous erosion with maintained gap. The ECDM setup is operated for a pre-defined time. After completing the defined duration of time, all the electric supplies are switched off.

Now the composite work piece is weighed again. Material removal rate (MRR) is obtained by subtracting final weight from the initial weight and dividing it by time taken for the machining. This experiments is repeated for different set ups and MRR (mg/min) is calculated for these setups. The experiment was repeated by varying the voltage at constant gap between the anode and cathode at a particular electrolyte concentration. In the same manner experiment was repeated by varying the gap between anode and cathode at constant voltage at a particular electrolyte concentration. Similarly the experiment was repeated by varying the electrolyte concentration at constant gap between anode and cathode at predetermined voltage. In all the above experiment setups material removal rate (MRR) was calculated and average depth of radial overcut (ADRO) on the generated hole is checked at various stages of performance of the experiments. The reading of MRR and ADRO was recorded for further analysis.


Figure 4a


Fugure 4b


Fugure 4c

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Figrue 4d

Figure 4a, 4b, 4c, 4dComplete micro ECDM setup, Bubble formation during machining, Spark formation during machining and work piece after machining.

5. RESULTS AND DISCUSSIONS

A series of experiments have been carried out with variations of different cutting parameters and presented the results for discussions. Different graphs have been plotted to analyse the effect of various electrochemical discharge machining (ECDM) parameters on the machining characteristics e.g. material removal rate, average depth of radial overcut. The test results are analysed to identify the most effective parameters of the developed ECDM setup. Different scanning electron micrographs SEM show the characteristics of the generated micro holes during ECDM operation.

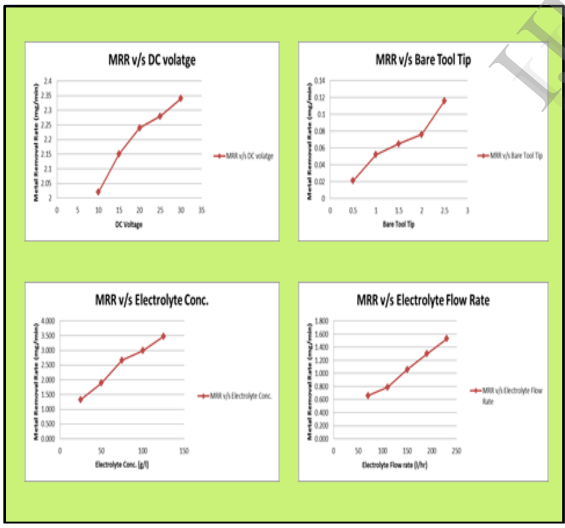

Figure 5a shows the various graphs of metal removal rate v/s DC voltage, Bare tool tip, Electrolyte concentration, Electrolyte flow rate.

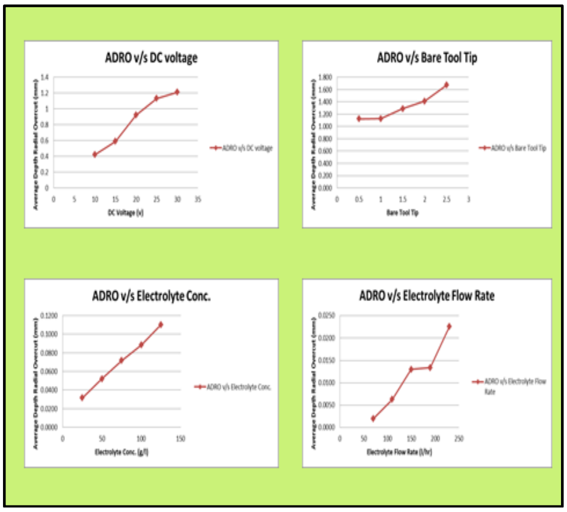

Figure 5b shows the various graphs of average depth radial overcut v/s DC voltage, Bare tool tip, Electrolyte concentration, Electrolyte flow rate.

Clearly seen from figure 5a and figure 5b the metal removal rate and average depth radial overcut is increases with increase in DC voltage, Bare tool tip length, Electrolyte concentration and Electrolyte flow rate respectively.

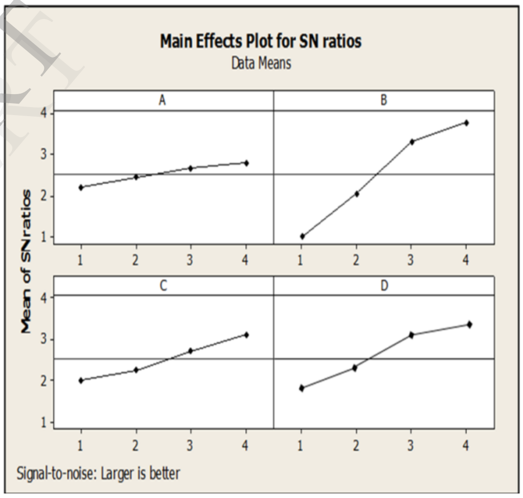

Figure 5c: S/N ratio by their factor level for MRR.

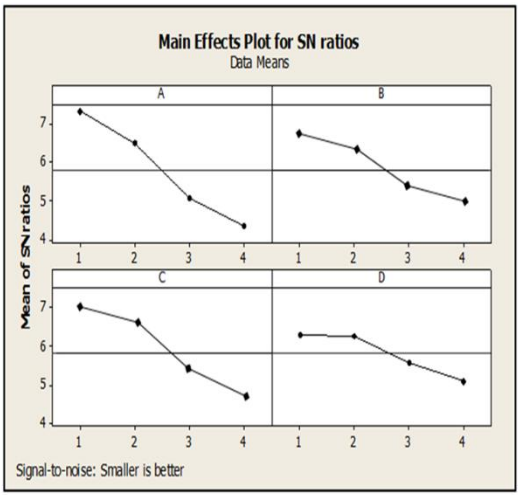

Figure 5d: S/N ratio by their factor level for ADRO

From figure 5c, it is concluded that optimal parametric combination for maximum MRR is $A_4B_4C_4D_4$ and from figure 5d, it is concluded that optimal parametric combination for maximum ADRO is $A_1B_1C_1D_1$.

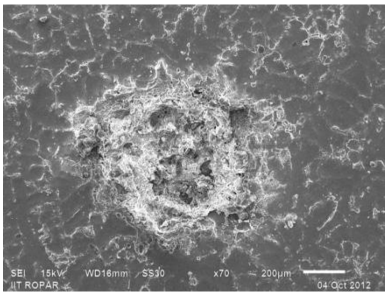
Figure5e

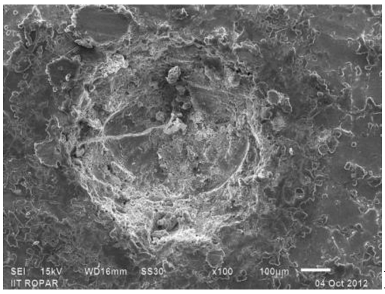
Figure 5f

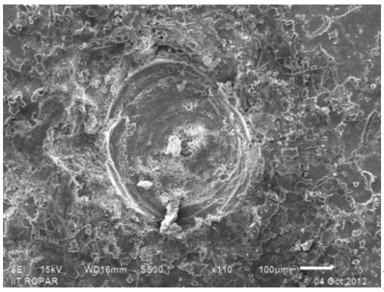
Figure 5g

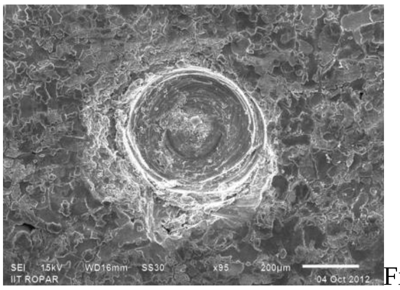
Figure 5h

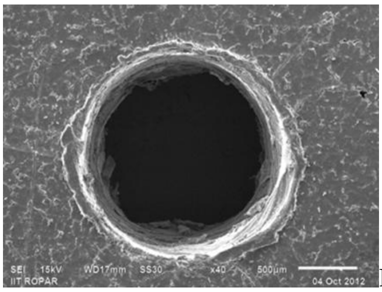
Figure 5i(a)

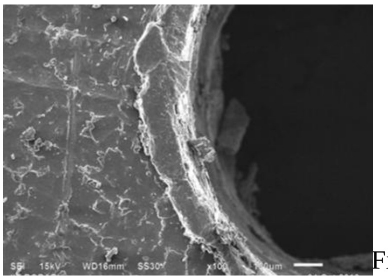
Figure 5i(b)

Figure 5e: SEM of generated micro hole at 10 volts DC supply voltage, 110 l/hr electrolyte flow rate, 0.5 mm bare tool tip length and 50 g/l electrolyte concentration utilizing 200 micro meter diameter micro tool.

Figure 5f: SEM of generated micro hole at 15 volts DC supply voltage, 110 l/hr electrolyte flow rate, 1 mm bare tool tip length and 75 g/l electrolyte concentration utilizing 200 micro meter diameter micro tool.

Figure 5g:SEM of generated micro hole at 25 volts DC supply voltage, 190 l/hr electrolyte flow rate, 1.5 mm bare tool tip length and 100 g/l electrolyte concentration utilizing 200 micro meter diameter micro tool.

Figure 5h: SEM of generated micro hole at 30 volts DC supply voltage, 190 l/hr electrolyte flow rate, 2 mm bare tool tip length and 100 g/l electrolyte concentration utilizing 200 micro meter diameter micro tool.

Figure 5i (a) and Figure 5i (b): SEM of generated micro hole at 30 volts DC supply voltage, 230 l/hr electrolyte flow rate, 2 mm bare tool tip length and 125 g/l electrolyte concentration utilizing 200 micro meter diameter micro tool.

5.1 ANOVA TABLE FOR MATERIAL REMOVAL RATE & AVERAGE DEPTH RADIAL OVERCUT

Table 5a shows the ANOVA and F Test values with percentage of contribution i.e. effectiveness of individual machining parameter on material removal rate. This ANOVA table is prepared by utilizing the experimentally obtained results during drilling of on electrically conductive high strength AL 6061/SiC (10%) – MMC by utilizing developed ECDM set up. From ANOVA table it is observed that electrolyte concentration has a most significant parameter on DC Voltage with 53.88 % contribution. Electrolyte concentration is another significant parameter on material removal rate with 25.71 % contribution. Electrolyte flow rate and bare tool tip length have less significant parameters with 20.06 % and 0.32 % contribution respectively.

Table 5a ANOVA for MRR using developed ECDM setup

Factors	Sum of Squares	Degree of Freedom	Mean Square	F	% Contribution
A: DC supply voltage (X1, Volt)	7.6257	3	2.5419	5.28	53.88
B: Electrolyte concentration (X2, NaOH, g/l)	3.6392	3	1.213	2.52	25.71
C: Electrolyte flow rate (X3, l/hr)	2.8394	3	0.9464	1.96	20.06
D: Bare Tool Tip length (X4, mm)	0.0464	3	0.0154	0.032	0.32
Error	0	0	-		
Total	14.1507	12	-		
Error	2.8858	6	0.4809		

Table 5b shows the ANOVA and F Test values with percentage of contribution i.e. effectiveness of individual machining parameter on average depth radial overcut. This ANOVA table is prepared by utilizing the experimentally obtained results during drilling of on electrically conductive high strength AL 6061/SiC (10%) – MMC by utilizing developed ECDM set up. From ANOVA table it is observed that Bare Tool Tip Length has a most significant parameter on material removal rate with 50.57 % contribution. DC voltage is another significant parameter on material removal rate with 38.65 % contribution. Electrolyte concentration and electrolyte flow rate have less significant parameters with 8.11% and 2.65 % contribution respectively.

Table 5b ANOVA for ADRO using developed ECDM setup

Factors	Sum of Squares	Degree of Freedom	Mean Square	F	% Contribution
A: DC supply voltage (X1, Volt)	9.3524	3	3.1174	7.18	38.65
B: Electrolyte concentration (X2, NaOH, g/l)	1.9635	3	0.6545	1.51	8.11
C: Electrolyte flow rate (X3, l/hr)	0.6429	3	0.2143	0.49	2.65
D: Bare Tool Tip length (X4, mm)	12.235	3	4.0783	9.39	50.57
Error	0	0	-		
Total	24.19381	12	-		
Error	2.6064	6	0.4344		

6. MATHEMATICAL MODEL FOR METAL REMOVAL RATE AND AVERAGE DEPTH RADIAL OVERCUT

Considering the significant ECDM parameters different mathematical models are developed for the various characteristics of ECDM set up during drilling of AL6061 / SiC (10%) MMC. The mathematical models for metal removal rate and average depth of radial overcut are developed and described in this chapter. The additivity test results shows that the predicted determined values utilizing developed mathematical models make a good agreement with experimental results.

Mathematical Model for MRR (mg/min)

$$Y_{MRR} = 0.4123 – 0.0446*X_1 – 0.00132*X_2 + 0.00416*X_3 + 0.000004*X_4 + 0.00118*X_1*X_2 + 0.00020*X_1*X_3 + 0.00765*X_1*X_4 + 0.000034*X_2*X_3 + 0.002315*X_2*X_4 + 0.000007*X_3* X_4 – 0.00231*X_1^2 – 0.000036*X_2^2 – 0.000020*X_3^2 – 0.05577*X_4^2 \quad \text{.........}\textbf{Eqn. 6.1}$$

$R^2 = 0.9562$

Mathematical Model for ADRO (mm)

$$Y_{ADRO} = 0.7772 – 0.0421*X_1 + 0.0103*X_2 – 0.00384*X_3 + 0.0000020*X_4 – 0.0025*X_1*X_2 – 0.00027*X_1*X_3+ 0.00723*X_1*X_4 \; 0.0000083*X_2*X_3 – 0.0000645*X_2*X_4 – 0.000451*X_3* X_4 + 0.00144*X_1^2 – 0.0000153*X_2^2 + 0.00000022*X_3^2 + 0.6645*X_4^2 \quad \text{......}\textbf{Eqn. 6.2}$$

$R^2 = 0.952$

Where,
X_1 = D.C. supply voltage (volts)
X_2 = Electrolyte Concentration (g/l)
X_3 = Electrolyte Flow Rate (l/hr)
X_4 = Bare Tool Tip Length (mm)

6.1 ADDITIVITY TEST FOR MATERIAL REMOVAL RATE AND AVERAGE DEPTH RADIAL OVERCUT

Table 6a shows the comparative statement of the experimentally obtained and calculated values based on developed mathematical equation (6.1) during machining of AL 6061/ SiC (10%) –MMC.

Table 6a Table for additivity test for material removal rate

S.No.	MRR (mg/min)		
	Experimental	Developed	% of Error
1	1.1864	1.1334	4.46
2	1.5094	1.3892	7.96
3	1.4573	1.4075	3.48

Figure 6a shows the graphical representation of the developed mathematical model equation (6.1) and actual experimental results obtained from different 16 sets of experimental investigation. From figure, it is concluded that the developed equation for material removal rate bears a good agreements with the experimental test lines.

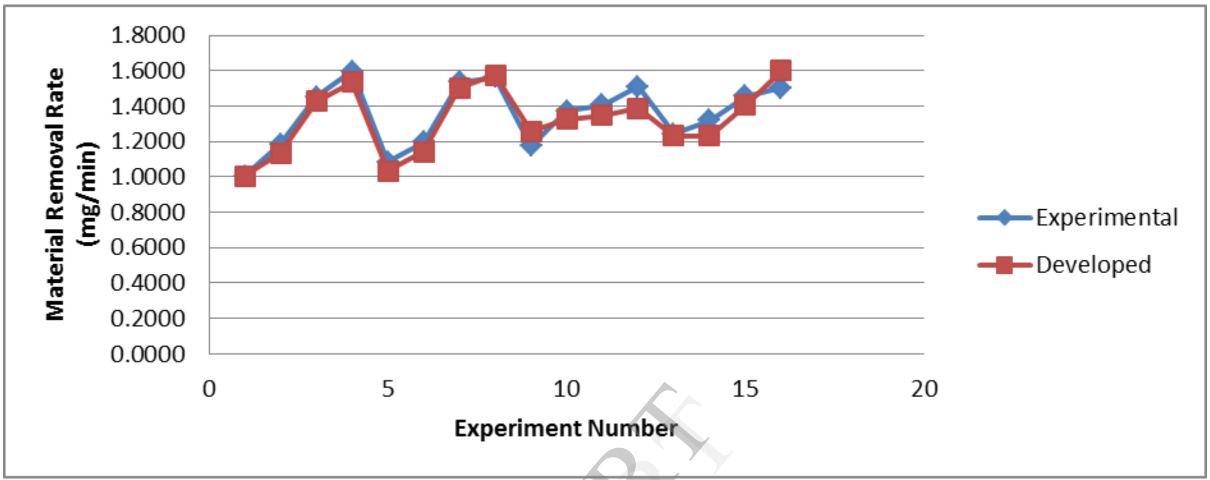

Figure 6a Comparison of MRR by experiment and developed mathematical model

Table 6b shows the comparative statement of the experimentally obtained and calculated values based on developed mathematical equation (6.1) during machining of AL 6061/ SiC (10%) –MMC

Table 6b: Table for additivity test for average depth radial overcut

S.No.	ADRO (mm)		
	Experimental	Developed	% of Error
1	0.4830	0.4692	2.83
2	0.4538	0.4368	3.74
3	0.5307	0.5179	2.41

Figure 6b shows the graphical representation of the developed mathematical model equation (6.2) and actual experimental results obtained from different 16 sets of experimental investigation. From figure, it is concluded that the developed equation for material removal rate bears a good agreements with the experimental test lines.

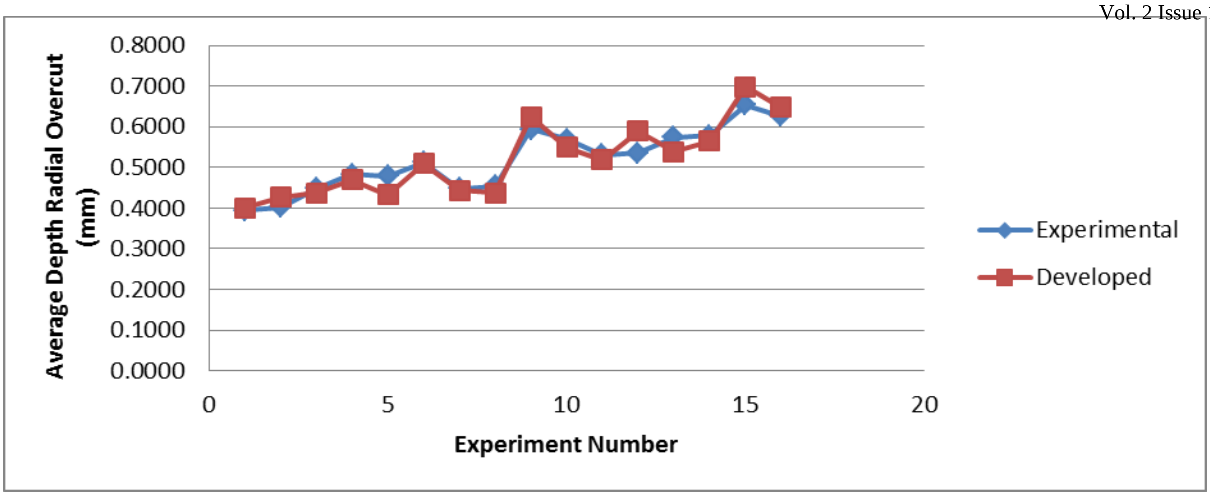

Figure 6b: Comparison of ADRO by experiment and developed mathematical model

6.2 FUTURE SCOPE

For further research work on machining of holes on electrically conductive AL6061/SiC (10%) MMC by utilizing the developed Electrochemical Discharge Machining (ECDM) setup, the below mentioned research areas may be explored in future.

1. To identify and measure the temperature during drilling of holes on electrically conductive AL6061 / SiC (10%) MMC by utilizing the developed Electrochemical Discharge Machining (ECDM) setup
2. To identify and measure surface roughness of the hole during drilling of holes on electrically conductive AL6061 / SiC (10%) MMC by utilizing the developed Electrochemical Discharge Machining (ECDM) setup
3. To investigate and eliminate the irregularities around the surface of the hole during drilling of holes on electrically conductive AL6061 / SiC (10%) MMC by utilizing the developed Electrochemical Discharge Machining (ECDM) setup.

7. CONCLUSIONS

On the basis of the experimental results during machining of micro holes on electrically conductive high strength Aluminium 6061/Silicon Carbide (10%) (AL6061/SiC (10%))-MMC by utilizing the developed electrochemical discharge machining (ECDM) set up andthereafter discussion on the investigated results the following conclusions are drawn as listed below.

1. The DC voltage and electrolyte concentration are the most significant parameters on material removal rate with 53.88 % and 25.71 % contribution respectively. But electrolyte flow rate and bare tool tip length are less significant parameters as compared to above mentioned with 20.06 % and 0.32 % contribution respectively.
2. The Bare tool tip length and DC voltage are the most significant parameters on average depth radial overcut with 50.57 % and 38.65 % contribution respectively. But Electrolyte concentration and Electrolyte flow rate are less significant parameters as compared to above mentioned with 8.11 % and 2.65 % contribution respectively.
3. For maximum material removal rate, the optimal parametric combination is $A_4B_4C_4D_4$ i.e. material removal rate is maximum at 25 volts DC voltage, 100 g/l electrolyte concentration, 190 l/hr electrolyte flow rate and 2 mm bare tool tip length.
4. For average depth radial overcut, the optimal parametric combination is $A_1B_1C_1D_1$ i.e. average depth radial overcut is minimum at 10 volts DC voltage, 25 g/l electrolyte concentration, 70 l/hr electrolyte flow rate and 0.5 mm bare tool tip length.
5. From the SEM graphs, it is concluded that at the initial stage of drilling the shape of hole is like removal of material from surface of work piece but after few hours the shape of drilled hole is visible at 30 volts DC supply voltage, 190 l/hr electrolyte flow rate, and 2 mm bare tool

tip length and 100 g/l electrolyte concentration. During machining it is also observed that overcut around the machined hole but this can be minimized by controlling the gap between the bare tool tip and work piece.

6. During experiment it is also observed that overcut and dimensional ovality was high that may due to cause of deflection of tool and increased the sparkling area during drilling. This was observed at 25 volts DC supply voltage, 190 l/hr electrolyte flow rate, and 1.5 mm bare tool tip length and 100 g/l electrolyte concentration.
7. From the SEM graph of through holes, it is concluded that the irregularities around the surface of the hole are noticed, which may reveals that the very fine micro hole machining is really a typical exercise on electrically conducting composite material.
8. Rough machined surface texture was observed when machining is done, utilizing electrolyte NaOH + Distilled water, this may be the cause of erosion on the work piece surface. This may be due to chemical reaction occurs between AL 6061/SiC (10%) – MMC and electrolyte solution.
9. The other cause of poor surface finish is erosion of some particles comes out from the surface of work piece and some again adhere to the surface of work piece which observed as burrs.
10. The mathematical models for material removal rate and average depth of radial overcut are successfully proposed for evolution of parametric value in advance for effective machining of electrically conductive high strength AL 6061/ SiC (10%) – MMC.

8. REFERENCES

1. Frank Muller and John Monaghan, (2001), “Non-conventional machining of particle reinforced metal matrix composite”, *Journal of material processing Technologies*, Vol. 118, pp. 278-285.
2. J. Hashim, et al., (2001), “The wettability of SiC particles by molten aluminum alloy”, *Journal of Materials Processing Technology*, Vol. 119 (1-3), pp. 324-328.
3. Paulo Carlos Kaminski and Marcelo Neublum Capuano, (2003), “Micro hole machining by conventional penetration electrical discharge machine”, *International Journal of machine tools and manufacture*, Vol. 43, pp. 1143-1149.
4. M K Surappa, (2003), “Aluminium matrix composites: Challenges and opportunities”, *Sadhana*Vol. 28, Parts 1 & 2, February/April 2003, pp. 319–334.
5. D. Landolt et al., (2003), “Electrochemical Micro machining, Polishing and surface structuring of metals: fundamental aspeects and new developments”, *ElectrochemiciaActa*, Vol. 48, pp. 3185-3201.
6. Kai Egashira et al., (2004), “EDM at low Open- Circuit Voltage”, *Koyoto Institute of technology*, Sakyo Ward, Koyoto, Japan.
7. S. Das, (2004), “Development of Aluminium Alloy Composites for engineering Applications”, *Trans Indian Institute of Metallurgy*, Vol. 4, pp. 325-334.
8. Yılmaz and HamdiSencer, 2004, “Characterization of Silicon Carbide particulate reinforced squeeze cast Aluminum 7075 matrix composite”, *Journal of Materials Processing Technology*, Vol. 119 (1-3), pp. 453-459.
9. Z. Katz and C.J. Tibbles, (2005), “Analysis of micro scale EDM process”, *International Journal of advance manufacturing Technology*, Vol. 25, pp. 923-928.
10. Yan et al. (2005), “The effect in EDM of a dielectric of a urea solution in water on modifying the surface of titanium”, *International Journal of machine tools and manufacture*, Vol. 45, pp. 194-200.
11. Sen and Shan, (2005), “A review of electrochemical macro to micro hole drilling process”, *International Journal of machine tools and manufacture*, Vol. 45, pp. 137-152.
12. Kansal et al., (2007), “Technology and Research development in powder mixed electric discharge machining”, *Journal of material processing Technologies*, Vol. 184, pp. 32-41.
13. Anjali V Kulkarni, (2007), “Electrochemical Discharge Machining

Process", *Defence Science Journal*, Vol 57, pp. 765-770.

14. Mahardika and Mitsui, (2008), "A new method for monitoring micro electric discharge machining processes", *International Journal of machine tools and manufacture*, Vol. 48, pp. 446-458.
15. Tsujimoto et al., (2008), "A new approach on determination of ease of machining by EDM Processes", *International Journal of machine tools and manufacture*, Vol. 48, pp. 746-760.
16. Manoj Singla et al., (2008), "Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite"*Journal of Minerals & Materials Characterization & Engineering*, Vol. 8, No.6, pp. 455-467.
17. A Włodarczyk–Fligier et al., (2008), "Manufacturing of aluminium matrix composite materials reinforced by Al2O3 particles", *Journal of the European Ceramic Society* 29.
18. S.S. Sundarram, (2008), "Development of Electrochemical Micro machining", *International Journal of machine tools and manufacture*, Vol. 56, pp. 45-52.
19. B, Izquierdo et al., (2009), "A numerical model of the EDM process considering the effect of multiple discharges", *International Journal of machine tools and manufacture*, Vol. 49, pp. 220-229.
20. Prihandana et al., (2009), "Effect of micro powder suspension and ultrasonic vibration of dielectric fluid in micro EDM processes Taguchi Approach", *International Journal of machine tools and manufacture*, Vol. 49, pp 1035-1041.
21. Muralidhara et al., (2009), "Investigations on a directly coupled piezoactuated tool feed system for micro electro discharge machine", *International Journal of machine tools and manufacture*, Vol. 49, pp. 1197-1203.
22. Jose Duarte Marafona et al., (2009), "Influence of work piece hardness on EDM performance", *International Journal of machine tools and manufacture*, Vol. 49, pp. 744-748.
23. GursoyArslan and AyseKalemtas, (2009), "Processing of silicon carbide–boron carbide aluminium composites", *Journal of the European Ceramic Society*, 29.
24. Zhu et al., (2010), "Electrochemical drilling of multiple holes with electrolyte extraction", *CIRP Annuals-Manufacturing technology*, Vol. 59, pp. 239-242.
25. Koyano and Kunieda, (2010), "Achieving high accuracy and high removal rate in micro EDM by electrostatic induction feeding mechanism", *CIRP Annuals-Manufacturing Technology*, Vol. 59, pp 219-222.
26. KuldeepOjha et al., (2010), "MRR improvement in Sinking Electrical Discharge Machining: A Review", *Journl of Minerals and Materials Characterization & Engineering*, Vol 9, pp. 709-739.
27. Rahul Pachoriya et al. (2010), "Design of electrode in electrochemical machining for the surface reduction at rotary position of work piece with different shape of tool use", *International Journal of Engineering Science and Technology*, Vol. 34, pp. 76-84.
28. Kunieda et al., (2011), "Electrochemical micro machining using flat electrolyte jet", *CIRP Annals- Manufacturing Technology*, Vol. 60, pp. 251-254.
29. E. Brinksmeier and S. Fangmann, (2011), "Drilling of Composites and resulting surface integrity", *CIRP Annuals-Manufacturing Technology*, Vol. 60, pp 57-60.
30. Cheng-Kuang Yang, (2011), "Enhancement of ECDM efficiency and accuracy by spherical too electrode", *International Journal of machine tools and manufacture*, Vol. 51, pp 528-535.
31. P. Koshy and J. Tovey, (2011), "Performance of electrical discharge textured cutting tools", *CIRP Annuals-Manufacturing technology*, Vol. 60, pp. 153-156.
32. Rie Tanabe et al., (2011), "Development of peeling tool for micro EDM", *CIRP Annuals-Manufacturing Technology*, Vol. 60, pp. 227-230.
33. I. S. Jawahirei al., (2011), "Surface integrity in material removal processes: Recent advaces", *CIRP Annuals-Manufacturing Technology*, Vol. 60, pp. 603-626.
34. L Giorleo et al., (2011), "ALD coated tools in micro drilling of Ti Sheet", *CIRP*

Annuals-Manufacturing Technology, Vol. 60, pp. 595-598.

35. S.H. Tomadi et al., (2011), "Analysis of the influence of EDM parameter on Surface Quality, material Removal rate and Electrode Wear Rate of tungsten carbide", *International Journal of machine tools and manufacture*, Vol. 53, pp. 125 -131.
36. Gu et al., (2012), "Electrical Discharge machining of Ti6AL4V with bundled electrode", *International Journal of machine tools and manufacture*, Vol. 53, pp. 100 -106.
37. Nguyen et al., (2012), "Simultaneous micro EDM and micro ECM in low resistivity deionised water", *International Journal of machine tools and manufacture*, Vol. 54-55, pp 55-65.
38. KostyantynMalukhin et al. (2012), "A shape memory alloy based tool Clamping device", *Journal of Materials Processing Technology*, Vol. 212, pp. 735–744.
39. A Cuba Ramos et al., (2012), "Characterization of the transition from ploughing to cutting in micro machining and evaluation of the minimum thickness of cut", *Journal of Materials Processing Technology*, Vol. 212, pp. 594-600.
40. M. Malekian et al., (2012), "Modelling of minimum uncut chip thickness in machining of aluminium", *Journal of Materials Processing Technology*, Vol. 212, pp. 553-559.
41. Hongto Ding et al., (2012), "Thermal and mechanical modelling analysis of laser assisted micro milling of difficult to machine alloys", *Journal of Materials Processing Technology*, Vol. 212, pp. 601-613.
42. Ruben Phipon and B.B. Pradhan, (2012), "Optimization of Electrochemical Discharge machine process using Genetic Algorithm", *Journal of Engineering*, Vol. 2, pp. 106-115.