EXPERIMENTAL INVESTIGATION OF MICRO-ELECTROCHEMICAL MACHINING ON ALUMINIUM COMPOSITESTITLE

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ABSTRACT

Aluminium metal matrix composites (AMMCs) are highly used in aerospace and automotive industries. Among many AMMCs, Aluminium metal matrix reinforced with Silicon Carbide (SiC) is one of the widely used composites because of its high wear resistance, high strength to low weight ratio, and high stiffness. The presence of hard ceramic reinforcement in metal matrix makes it is very hard to machine by conventional methods. Electrochemical machining (ECM) is an advanced machining process that is used for the machining of hard components, difficult to machine contour parts, dies and molds. In this project, electrochemical micromachining is used to make micro holes on aluminium metal matrix composites. The present work is carried out to investigate the influence of ECM process parameters, such as applied voltage (V), tool feed rate electrolyte concentration (EC), on material removal rate (MRR) and overcut during machining of aluminium metal matrix composites. An aqueous sodium chloride (NaCl) is used as a basic electrolyte in the electrochemical machining. The effects of process parameters are investigated and are optimized through the Taguchi's orthogonal array and response surface methodology.

Keyword: - *Electrochemical Micromachining, AA-6061, electrolyte concentration, tool feed rate.*

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1. INTRODUCTION

The need for precisely manufactured components became necessary. Accuracy and precision are now two key concepts in manufacturing industry. Researchers are engaged in lots of research activities for developing new manufacturing techniques of higher precision. Miniaturization of products will continue as people require efficient space utilization and better quality products, it follows that micromachining technology will be of immense importance in the future. Some of the major micro machining processes is laser jet machining, ultrasonic machining, abrasive water jet machining, electro discharge machining and electro chemical machining. Electrochemical Micro Machining is one of the unconventional machining processes. Electrochemical micro machining is the process of metal removal in micron level through electric discharge. Electrochemical micromachining (ECM) is a technique used for manufacturing components with extreme precision. The term micromachining literally means the removal of small amount of material in the range 1-999 µm. Small and micro holes, slots and complex surfaces need to be produced in large numbers, sometimes in a single work piece, especially in electronic and computer industries where electrochemical micro machining is invaluable. It is also environmentally acceptable and permits machining of chemically resistant materials Titanium, copper alloys, super alloys, composites and stainless steel. Electrochemical machining (ECM) is an advanced machining process that is used for the machining of aerospace and automotive components, dies and moulds, etc. In electro chemical machining there is no significant subsurface damage and heat affected zone to the work piece. ECM has traditionally been used in with difficult-to-cut materials and with complex geometry. Electrochemical micromachining (EMM) appears to be very promising as a future micromachining technique since in many areas of applications it offers several advantages that include higher machining rate, better precision and control and a wide range of materials that can be machined (Font-10, justify)Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work.

2. MICRO ECM SETUP

During ECM, a high value of direct current (may be as high as 40000 A) and a low value of electric potential (in range of 5 - 25 V) across IEG (inter electrode gap) is desirable. The highest current density achieved so far is around 20000 A/cm2. A full wave rectified DC supplies continuous voltage, where the current efficiency depends on the current density. Hence, with the help of a rectifier and a transformer, three phase AC is converted to a low voltage, high current DC. Silicon controlled rectifier (SCRs) are used both for rectification as well as for voltage regulation because of their rapid response to the changes in the process load and their compactness. Voltage regulation of ± 1% is adequate for most of the precision ECM works.

2.1 Electrolyte supply system

The electrolyte supply and cleaning system consists of a pump, filter, piping, and control valves, heating or cooling coils, pressure gauges, and a storage tank (or reservoir). Electrolyte supply ports may be made in the tool, work or fixture, depending on the requirement of the mode of electrolyte flow. Small inter electrode gap of <1mm should be made to get high MRR and high accuracy. For this, smooth flow of electrolyte should be maintained to remove the particles between the tool and work piece. The electrolyte should be continuously purified by filters to remove impurities during machining.

Fig -1 **ECM SET-UP**

Table -1 **Technical specification of table top ECMM**

Work table	260 mm x 110 mm x 100 mm
Max. travel	130 mm x 75 mm x 75 mm
Spindle type	ER11 Cullet system
Spindle motor	BLDC Motor (300-3000 rpm)
Repeatability	±10 µm
Slide straightness	±3 µm
Voltage	1-30 v
Current	0-3 A
Pulse ON	1 µs-10 µs
Pulse OFF	2 µs-100 µs
Gap control	Constant current condition

2.2 Machining and Work holding system

Machining chamber rests on the base of the setup, which is just below the tool-holding device. The machining chamber is made up of corrosion resistant, electrically non-conductive and transparent material. Inside the chamber a job holding device is mounted. Different clamps and other parts of the setup are made up of corrosion resistant materials. The chamber is well equipped for circulation of the electrolyte flow. Like machining chamber, the work holding device is made up of corrosion resistant material. The job holding device is so precise that it can hold work piece material of a thickness of as low as 200 µm. The work piece is clamped by two taper angled plates, which are made up of insulating material on the main base plate of the machining chamber. On side of the clamp, a copper plate is connected for electrical power supply to the anode work piece.

2.3 Servo control system

The servo system controls the tool motion relative to the work piece to follow the desired path. It also controls the gap width within such a range that the discharge process can continue. If tool electrode moves too fast and touches the work piece, short circuit occurs. Short circuit contributes little to material removal because the voltage drop in electrodes is small and the current is limited by the generator. If tool electrode moves too slowly, the gap becomes too wide and electrical discharge never occurs. Another function of servo system is to retract the tool electrode when deterioration of gap condition is detected. The width cannot be measured during machining; other measurable variables are required for servo control.

2.4 Tools and fixtures

Use of anti-corrosive material for tools and fixtures is important because they are required for a long period of time to operate in the corrosive environment of electrolyte. High thermal conductivity and high electrical conductivity are main requirements of the tool material. Easy machining of tool material is equally important because dimensional accuracy and surface finish of the tool directly affect the work piece accuracy and surface finish. Aluminum, Brass, Bronze, Copper, Carbon, stainless steel are few of the materials used for this purpose. Use of non-corrosive and non-conductive material for making fixtures is recommended. The fixtures and tools should be rigid enough to avoid vibration or deflection under the high hydraulic forces to which they are subjected. Copper tool is chosen for machining because of its availability and also for its higher material removal rate.

Table -2 Properties of copper ECMM Tool

Electrical conductivity (S/m)	59.6
Thermal conductivity (W/mK)	401
Corrosion resistant	low
Electrochemical stability	moderate
Stiffness and hardness	Highly malleable and ductile
Machinability	good
Availability	Abundant

3. PROCESS PARAMETERS

Material removal rate: MRR depends chiefly on feed rates. The feed rate determines the current passed between the work and the tool. As the tool approaches the work, the length of the conductive current path decreases and the magnitude of the current increases. This continues until the current is just sufficient to remove the metal at a rate corresponding to the rate of tool advance. A stable cut is then made with a fixed spacing between the work and the tool termed as the equilibrium machining gap. If the tool feed rate is reduced, the tool advance will momentarily lag behind increasing the gap and thus resulting in a reduction of current. This happens until a stable gap is once again established.

Overcut: Overcut depends on the voltage and majorly on tool insulation. If the overcut happens in the machine, it is mainly due to the passivating electrolyte. The inter electrode gap should be properly maintained to avoid overcut. Under ideal conditions and with properly designed tooling, ECM is capable of holding tolerance of the order of 0.02 mm and less. Repeatability of the ECMM process is also very good. This is largely due to the fact that the tool wear is virtually non-existent on a good machine; tolerance can be maintained on the production basis in the region of 0.02-0.04 mm. as a general rule, the more complex the shape of the work the more difficult is to hold tight tolerances and the greater is the attention required for developing a proper tooling and electrode shape.

4. ECMM OPERATING PARAMETERS

The operating parameters which are within the control of the operator and which influence ECMM process capabilities can be described as follows:

4.1 Tool Feed Rate: A high feed rate results in higher metal removal rate but, it decreases the equilibrium machining gap resulting in poor surface finish. Tool feed rate is maintained at optimal level to improve the material removal rate.

4.2 Voltage: At low voltage, the equilibrium machining gap will be maintained results in better surface finish and tolerance control. Voltage supply is increased to increase the MRR.

4.3 Electrolyte: The electrolytes used in electrochemical micromachining can be broadly classified into two categories passive and non-passive. Passivity electrolyte containing oxidizing anions e.g. sodium nitrate and sodium chlorate etc. and non-passivity electrolyte containing relatively aggressive anions such as sodium chloride. Passivity electrolytes are known to give better machining precision. This is due to their ability to form oxide films and evolve oxygen in stray current region.

To calculate the metal removal rate, the following equation, is considered:

$$\mathbf{MRR = (m_i - m_f) / t}$$

Where mi, mf are masses (in mg) of the work material before and after machining, respectively, and‘t’ is the time of machining in minutes. An electronic weighing machine with an accuracy of 1 mg is used to weigh the material.

To calculate overcut, the following equation is used:

$$\mathbf{Overcut\ (OC) = D_{hole} - D_{tool}}$$

Where D_{hole} is diameter of the hole and D_{tool} is the diameter of the tool used. The dimensions of the holes are measured using the Vision Measuring System (VMS).

4.4 Theoretical Calculations

Mass of the material removed from the work piece can be calculated theoretically by using volume of the material and the density of the material.

Volume of the material to be removed (Vol) = $\pi r^2 h$
Diameter of the tool = 0.5mm
Thickness of the material =0.1mm
Volume = 0.00196349 mm^3
Density of the aluminium 6061 = 2.7g/cc
Theoretical Mass to be removed = Volume * Density
= 0.00196349 * 2.7
= 0.005301mg

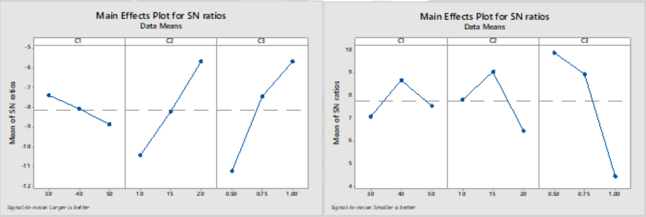
5. DESIGN OF EXPERIMENT

The experimental plan for the machining parameters using the L9 orthogonal array was used in this study. This array consists of three control parameters and three levels. In the taguchi method, most all of the observed values are calculated based on „the higher the better‟ and „the smaller the better‟. Thus, the observed values of MRR and surface roughness were set to maximum and minimum respectively. Each experimental trial was performed with three simple replications at each set value. Next, the optimization of the observed values was determined by comparing the standard analysis and analysis of variance (ANOVA) which was based on the taguchi method

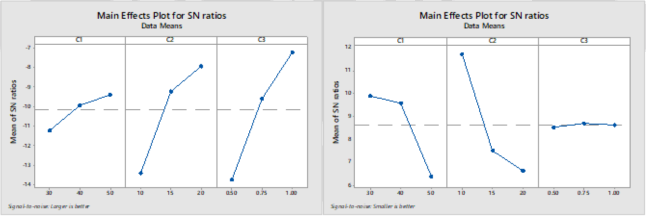
Table -3 Taguchi's three level design: Orthogonal array

Row	**Column**		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

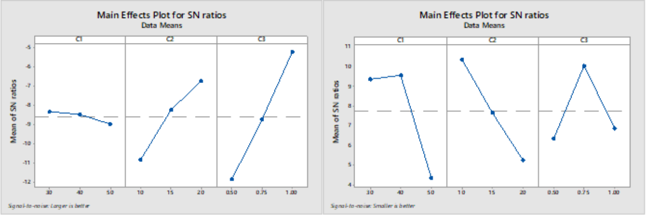
Graph -1 S/N ratio graphs for MRR and Overcut on Al-SiC (2 wt %)



Graph -2 S/N ratio graphs for MRR and Overcut on Al-SiC (4 wt %)



Graph -3 S/N ratio graphs for MRR and Overcut on Al-SiC (6 wt %)



6. ANALYSIS OF VARIANCE

6.1 General Linear Model: MRR 2 versus EC, V, TFR

Factor coding (-1, 0, +1)
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
EC	2	0.004550	0.002275	2.12	0.321
V	2	0.049850	0.024925	23.19	0.041
TFR	2	0.137450	0.068725	63.93	0.015
Error	2	0.002150	0.001075		
Total	8	0.194000			

6.2 Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.0327872	98.89%	95.57%	77.56%

6.3 Regression Equation

MRR 2 = 0.3983 + 0.0267 EC_30 + 0.0017 EC_40 - 0.0283 EC_50 - 0.0983 V_10 + 0.0167 V_15
+ 0.0817 V_20 - 0.1383 TFR_0.50 - 0.0233 TFR_0.75 + 0.1617 TFR_1.00

6.4 General Linear Model: 1/overcut 2 versus EC, V, TFR

Factor coding (-1, 0, +1)

6.5 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
EC	2	2.6209	1.3104	1.10	0.476
V	2	1.5534	0.7767	0.65	0.605
TFR	2	0.8235	0.4117	0.35	0.743
Error	2	2.3800	1.1900		
Total	8	7.3777			

6.6 Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
1.09086	67.74%	0.00%	0.00%

6.7 Regression Equation

1/OVERCUT 2 = 2.434 + 0.316 EC_30 + 0.444 EC_40 - 0.760 EC_50 + 0.436 V_10 + 0.123 V_15
- 0.559 V_20 - 0.334 TFR_0.50 + 0.398 TFR_0.75 - 0.064 TFR_1.00

7. CONCLUSION

The various levels of parameters are taken and the work piece is machined, the corresponding readings are noted. The experiments are conducted on aluminium metal matrix composite of (2, 4, 6 wt %) silicon carbide reinforcement having thickness of 1 mm and the copper is used as a tool material and NaCl as the electrolyte. The preliminary results show that machining of work piece occurs at higher electrolyte concentration level with high overcuts. Hence from the preliminary experiments conducted, the range of parameter values to be used for optimizing has been found out.

An attempt has been made in this work to highlight the influence of ECM process parameters on the machining performances, i.e., MRR, overcut. The work piece is machined by various parameters such as electrolytic concentration, change in voltage, tool feed rate by Taguchi’s orthogonal array of design of experiments to get the results. Mathematical models have to be developed for correlating the MRR and Overcut with process parameters. The entire values are optimized using Taguchi’s orthogonal array and ANOVA (Analysis of Variance). The microscopic image of machined work piece is taken to check the precision and accuracy of the micro ECM. A better performance criterion for accurate and precise machining is identified. Graph is drawn for MRR against other process parameters like electrolyte concentration, voltage and tool feed rate. 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; therefore nominal concentration value is selected.

The Present investigation is focused on optimization and analysis electrochemical micro machining of Al-6061 – (2, 4, 6 % wt) of SiC metal matrix composites machining parameters. From the study of result in ECM using Taguchi methodology and ANOVA, the following can be concluded from the present study.
1. Based on the confirmation test, Material Removal Rate, Overcut is improved.
2. The parameter combination suggested for the higher MRR and lesser overcut are:
  a) For Al-6061 – (2 wt %) of SiC - EC 40 g/L, 20V, 0.75µm/s
  b) For Al-6061 – (4 wt %) of SiC - EC 40 g/L, 15V, 0.75µm/s
  c) For Al-6061 – (6 wt %) of SiC - EC 50 g/L, 10V, 1µm/s
3. The results show that Electrolyte concentration and Voltage are the most significant machining parameter affecting Overcut. Tool feed rate influences the Material removal rate (MRR).
4. Confirmation test results proved that the determined optimum combination of machining parameters satisfy the real requirements of ECM operation of Aluminium metal matrix composites.

8. REFERENCE

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