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Optimisation of Machining Parameters in Electrochemical Machining (Ecm) of Aluminium 6082 T87

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***Abstract* - The main objective is to find the optimal machining condition at which the electrochemical machining of Aluminium 6082 T87 will be done in an highly economical, efficient and in an effective way. The effect of process parameters such as electrolytic concentration and voltage on performance characteristics such as material removal rate (MRR) and surface roughness (SR) during Electro Chemical Machining of Al 6082 T87 was investigated. The microstructure of machined surfaces which reflects the performance of electrochemical machining at various machining parameters was also studied. ANOVA was used to investigate the influence of process parameters on performance characteristics during machining. It was observed that MRR increased with increase in voltage whereas SR decreased.**

***Keywords*- Al 6082 T87, Microstructure, Taguchi, ANOVA, Surface Roughness (SR), Material Removal Rate (MRR).**

I. INTRODUCTION

Electrochemical machining (ECM) is one of the most popularly known and widely used non-traditional machining process belonging to electrochemical category in which the material removal takes place by anodic dissolution of workpiece in an electrolytic solution. ECM process is independent of hardness of workpiece material with very less tool wear and stress free surface generation, generally preferred when highly finished machined surface is required along with less tool wear.

ECM finds its use into various sectors such as defense, automotive, aerospace, electronic industries etc. Machining parameters mainly decides the accuracy and precision of the machining. So it is mandatory to find the optimal machining parameters for obtaining better process performance along with process economics. With regards to this, various researchers have carried out electrochemical machining of different materials and applied various optimization techniques to find optimal condition. With regards to this, various researchers have carried out electrochemical machining of different materials and applied various optimization techniques to find optimal condition.

Bhattacharya et al. investigated the use of response surface methodology (RSM) for the maximization of MRR and minimization of overcut during electrochemical machining of EN19 steel and developed mathematical model to analyze the effects of the process parameters [1]. Hoecheng et al. found out that by increasing electrical voltage, molar concentration of electrolyte, time of electrolysis and by reducing electrode gap, MRR can be increased during electrochemical machining of SKD 61 stainless steel using NaNO3 as an electrolyte [2]. Senthil Kumar et al. carried out electrochemical machining of LM25 Al/10% SiCp composites to obtain empirical relation between process parameters and responses using RSM. They found MRR to be greatly affected by voltage and tool feed while surface roughness being affected by electrolytic concentration [3].

To determine optimal machining parameters in ECM of hardened steel Asokan developed multiple regression models and artificial neural network (ANN) model. They concluded ANN to be better prediction model [4]. Chakradhar et al. used L9 orthogonal array of Taguchi and used grey relation analysis to determine the optimal machining parameters on ECM of EN-31 steel [5]. SenthilKumar et al. have investigated the ECM of AL/15% SiCp through non-dominated sorting genetic algorithm-II (NSGA II).

They considered MRR and surface roughness as responses and developed multiple regression analysis [6]. Acharya adopted RSM to study the influence of electrolyte flow rate, interelectrode gap, voltage and current on MRR and SR. NSGA II was employed to find the optimal condition on ECM of hardened steel [7]. From the above literature survey it can be concluded that modelling and optimization in ECM was carried out on

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different grades of steels and composites materials. However there is hardly any research work on ECM characteristics of Aluminium based superalloys. Today they are widely used in the field of defense, aerospace, aviation, nuclear plants and marine owing to their mechanical properties like high yield strength, high ultimate tensile strength, hardness and resistance to creep and corrosion. However some of the properties like poor thermal conductivity, chemical reactivity and work hardening tendency make these superalloys difficult-to cut using conventional machining techniques. Although EDM has been extensively used for machining some of these superalloys, particularly Aluminium 6082 T87, the potential of ECM in machining of the same still remains unexplored. Aluminium 6082 T87 is particularly suited for ECM operation because of its superior resistance to corrosion under hostile environment. Therefore the current investigation aimed at study and optimization of process variables (electrolytic concentration and voltage) for MRR of Al 6082 T87. Emphasis will also be given for the effect of machining parameters on as machined surfaces.

II. MATERIALS AND METHODS

1. Experimental setup

All the experiments were carried out on the ECM setup (MAKE: METATECH), the photograph of which is shown in Fig 1 .It mainly consists of three parts: machining chamber, control panel and electrolyte circulation system. The machining takes place in the chamber while voltage can be regulated through control panel. Electrolyte is pumped through the reservoir where electrolyte flow rate cannot be varied.

Fig.1. ECM Set up.

2. Selection of work piece, tool material and electrolyte

A rectangular block of 51mm length, 10mm breadth and 1.2mm thickness made up of Aluminium 6082 T87 was selected as work piece. The tool made up of copper with circular cross section was selected as anode. A central hole through the tool was used to axially feed the electrolyte into the machining zone. The outer diameter of the tool was 9mm with central hole of 6mm diameter for the passage of electrolyte. Aqueous solution of NaCl with varying concentration was taken as electrolyte. A circular profile made of dielectric material was taken to project the shape of our required machining area. The profile was shown in fig 2 and the work pieces before machining were shown in fig 3. Albeit Aluminium 6082 is a levity material, the suffix T87 denotes that it was cold worked and heat treated to increase its hardness. This material was chosen based on its wide range of applications from airplane parts to household utensils. Experiments using this ECM were conducted in our highly venerated institution. The composition of Al 6082 T87 includes: Si- 1.3%, Fe- 0.5%, Cu -0.1%, Mn-1.0%, Mg -1.2%, Zn -0.2%, Ti0.1%, Cr-0.25%, Al-95.35%.

3. Machining parameters and responses

The machining efficiency depends largely on machining parameters. So the judicious selections of parameters are of prime importance. From the literature review the process parameters like voltage, tool feed rate and concentration of electrolyte have chosen for current study since they were find to have significant influence on MRR and SR The MRR can be defined as rate of dissolution of material from the workpiece.

Fig 2

Fig 3

MRR of Aluminium 6082 T87 has been considered as one of the performance measures was calculated by following expression:

MRR= (Initial weight – Final weight) ÷ (Machining Time)

Initial and final weights of the work pieces were measured by electronic weighing balance machine with accuracy up to 0.001 g. Surface roughness is the variation or irregularity of a machined surface from its ideal atomic value. Arithmetic mean of surface roughness (Ravg) which is the average of all the peaks and valleys height in a specified range was used as a measure of surface roughness. EN ISO 4287 standard was used to measure Surface Roughness with Talysurf (Model: Taylor Hobson) with parameters cutoff length (Lc) as 0.8 mm and sample length (Ln) of 4 mm.

III. RESULTS AND DISCUSSION

1. Design of Experiment

The experiment was planned as per 3 levels L9 Taguchi orthogonal array. The design was generated and analyzed using MINITAB 16 statistical software. Three factors at three levels were considered for the experimentation. The

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L9 orthogonal array (OA) for the MRR is represented by Table 1. The machining was carried out for fixed duration of 10 minutes for all the experimental run.Traditional Experimental design such as full factorial utilizes large number of experimental run with more factors. Thus they are of much time consuming and complicated. But Taguchi design of experiment uses small number of runs to study the effect of process parameters by using orthogonal array in its design.

Table -I: Ttaguchi L9-Orthogonal Array for MRR and SR.

Plate no	Run	C (g/lit)	V (V)	MRR (mg/s)	SR
44	1	30	10	6.850	0.753
45	2		15	3.366	0.842
46	3		20	6.483	0.946
47	4	40	10	0.760	1.773
48	5		15	2.850	1.130
49	6		20	4.966	1.013
50	7	50	10	5.733	1.126
51	8		15	5.466	1.600
52	9		20	10.714	0.366

Taguchi method mainly focuses on the average performance characteristics data close to the ideal target data rather than any other data within specified range, thereby improving the quality of product. Taguchi method is easy and time saving, thus can be directly applied to any engineering situations. Taguchi design employs statistical tool called ANOVA (Analysis of variance) developed by Sir Ronald Fisher in order to determine significance and percentage contribution of individual process parameter on the performance characteristics or responses measured.

2. Main Effects Plot of MRR, SR in ECM of Al 6082 T87

The main effect plot is the graph of the average or means of response at each level of the factor or input parameter. The main effect plot helps one to determine the influence of individual input parameters on the responses measured, by disregarding the effect of any other input parameter present.

3. Main effects plot for Material Removal Rate (MRR)

Although the material removal rate in electrochemical process is very low as compared to that of conventional machining but it's still a preferable option for machining of difficult-to-cut materials such as cold worked heat treated super alloy, Al 6082 T87. The productivity of ECM can be determined through MRR, so it is necessary to know the influence of the machining parameters on the MRR during ECM of Al 6082 T87. Figure 4 shows the main effect plot of the MRR depicting the effect of various machining parameters on MRR. As seen from the graph obtained, the MRR increased with increase in voltage. This is due to the fact that with increase in voltage the current increases in the inter electrode gap thus increasing the MRR. An overall increase in the MRR was also observed with increase in the concentration.

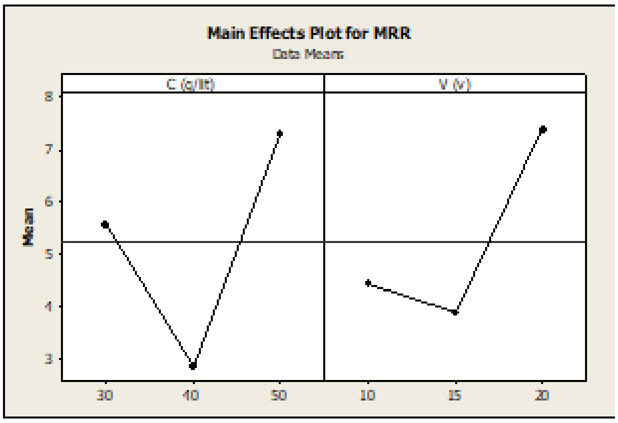

Fig.4. Main effects plot for MRR.

4. Main effects plot for Surface Roughness (SR)

The quality of the machined surface can be determined by its surface texture. During the ECM process the surface quality obtained is of high order such that no further finishing operation is required for the electrochemical machined surface.From the main effect plot of the SR (Figure 5) it can be seen that when concentration of electrolyte increase from 30 g/lit to 40 g/lit there is increase in the surface roughness but at high electrolytic concentration there is reduction in the surface roughness. Also noted was decrease in the surface roughness with increase in the voltage. The non-uniform removal of material during ECM of Al 6082 T87 at low voltage leads to high surface roughness but as the voltage increases uniform dissolution of material takes place resulting in lowering of surface roughness.

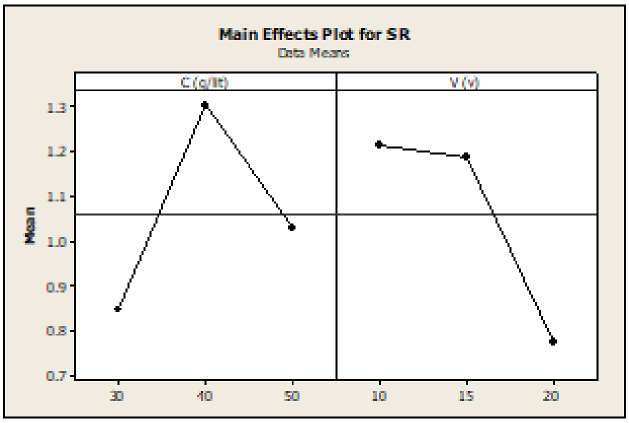

Fig.5. Main effects plot for SR.

5. Analysis of variance (ANOVA)

ANOVA developed by Sir Ronald Fisher is a very powerful statistical tool to determine the significance of the process parameters on the responses measured. The F-

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test in the table gives factors which are significant and insignificant. Generally a large F-value signifies the higher significance of the process parameters on the performance characteristics. Percentage of contribution of each factor can also be deducted from the ANOVA table which is calculated by following expression:

$$\% \text{ of contribution} = \left\{ \frac{\text{Sum of square of variation}}{\text{Total sum of square of variation}} \right.$$

Table (2) here presents combined ANOVA table for all the response MRR. From which it can be observed that the electrolyte concentration and voltage were contributing towards the MRR with percentage contribution of 47.23 % and 33.18%. In case of SR it was 22.05% of electrolyte concentration and 25.05% of voltage were contributing the process characteristic as shown in table (3).

Table II: ANOVA Table for MRR.

Source of variation	DOF	Sum of squares	F-Value	% Contribution on
C	2	30.116	4.82	47.23
V	2	21.156	3.39	33.18
ERROR	4	12.493		19.60
TOTAL	8	63.765		

6. Response table for outputs

Response tables can be used to indicate which process parameters has greater influence on the responses measured by giving the process parameter a rank. Also one can infer the optimal condition from the response table. For the response table of MRR, the level which holds the highest value in terms of concentration and voltage will be considered as the optimal level for MRR and for the response table of SR, the level which holds the lowest value in terms of concentration and voltage will be taken as the optimal level for SR.

Table III: .ANOVA Table for SR

Source of variation	DOF	Sum of squares	F-Value	% Contribution on
C	2	0.3192	0.84	22.05
V	2	0.3691	0.97	25.50
ERROR	4	0.7594		52.45
TOTAL	8	1.4478		

Table IV.Initial consideration of concentration and voltage.

LEVEL	CONC	VOLTAGE
1	30	10
2	40	15
3	50	20

Table V: Response table for metal removal rate.

LEVEL	CONC	VOLTAGE
1	5.5663	4.4476
2	2.8586	3.8940
3	**7.3043**	**7.3876**
DELTA	4.4457	3.4936
RANK	1	2

Table VI: Response table for surface roughness.

LEVEL	CONC	VOLTAGE
1	**0.8470**	1.2173
2	2.8586	3.0526
3	7.3043	**0.7750**
DELTA	6.4573	2.2776
RANK	1	2

From the response table for MRR as shown in Table (5), it was found that concentration was the most influential parameter for the ECM of ALUMINIUM 6082 T 87.And also inferred that the optimal value was found at concentration of 50g/lit(level 3)and at the voltage of 20v(level 3) for better MRR. From the response table for SR, It was found that the optimal machining occurs at the concentration of 30g/lit(level 1) and at the voltage of 20V (level 3) for obtaining good surface roughness.

3. Microstructure study of machined surface

The microstructure study was made for the machined surfaces of the work pieces. The Scanning Electron Microscope (SEM) has been used to magnify the machined surfaces 1000x, 3000x and 5000x the original view.

The following figures demonstrate the SEM micrographs depicting the morphology of machined surfaces. It is evident that the ECM resulted in very distinct microstructure without any chemical treatment of the surface indicating electrolytic etching of Al 6082 T87 during the process.

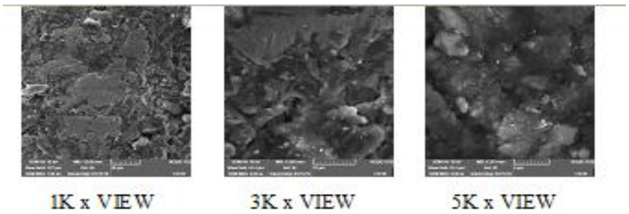

Fig.6.Microstructure of Plate No: 44.

Concentration: 30 g/lit
Voltage :10 V
MRR : 6.850 mg/s and SR: 0.753

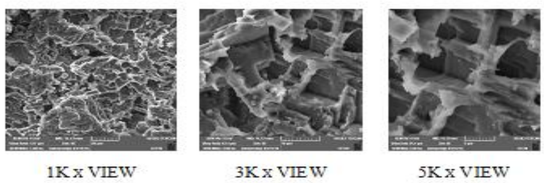

Fig.7.Microstructure of Plate No: 48.

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Concentration: 40 g/lit
Voltage :15 V
MRR : 2.850 mg/s and SR: 1.130

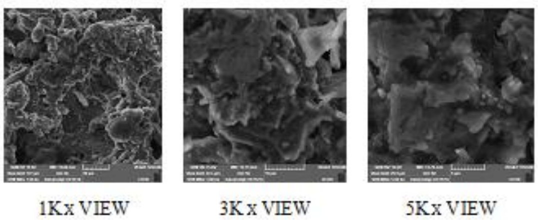

Fig.8.Microstructure of Plate No: 52.

Concentration: 50 g/lit
Voltage :20 V
MRR : 10.714 mg/s and SR: 0.366

It can be concluded from the microstructure that at low voltage of 10V there is non-uniform anodic dissolution which leads to low MRR and high surface roughness. But at high voltage of 20 V the material removal is uniform, hence increase in MRR and decrease in SR were observed.

IV. CONCLUSION

The process parameters such as voltage and salt concentration in electrolyte were optimized to obtain effective MRR and good SR in ECM of Al 6082 T87 .The following conclusions can be made based on the experimental results and analysis:

- The MRR increased with increase in voltage.
- The SR initially increased with increase in electrolyte concentration but it decreased at higher concentration.
- Both voltage and electrolyte concentration play a crucial role in affecting the MRR and SR.
- The percentage contribution of voltage towards the MRR and SR was found to be 33.18% and 25.50% respectively and the percentage contribution of electrolyte concentration towards the MRR and SR was found to be 47.23% and 22.05% respectively.
- Optimal condition for MRR was found to be at 50g/lit concentration of electrolyte (level 3), 20v voltage (level 3).
- The optimal condition for SR was found to be at 30 g/lit concentration of electrolyte (level 1), 20v voltage (level 3).

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