EFFECT OF ELECTROCHEMICAL MACHINING PROCESS PARAMETERS ON METAL MATRIX COMPOSITES COMPOSED OF SCRAP ALLOY WHEEL MATRIX

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ABSTRACT: *Electrochemical machining (ECM) is an anodic dissolution process in which cathode is a tool electrode and anode is a workpiece and these two electrodes are bridged by electrolyte. In this research scrap alloy wheel metal matrix composite (SAWMMC) was produced using stir casting setup, the Honda wheel was used as a base metal and 5% alumina (Al2O3) as a reinforcement. Using an ECM setup, the machinability studies on SAWMMC specimen was performed. The various input parameters such as voltage, duty cycle and electrolyte concentration on machining rate, overcut and surface corrosion factor were studied. The range of voltage significant for OC is7 to 8V. The MR increases gradually for 50% duty cycle and significant range of duty cycle is between 60 to 80%. The significant range of duty cycle for lesser OC is 60 to 80% and for lesser SCF is 70 to 90%.Hole surface quality is studied using FESEM images. The significant electrolyte concentration is 20 to 30gm/l for obtaining the higher MR. For electrolyte concentration of 15 to 30gm/l the OC decreases and increases to the maximum value for electrolyte concentration range of 30gm/l to 35gm/l. The significant range of electrolyte concentration for lower SCF is 25gm/l to 35gm/l. The hole analysis shows surface pitting/corrosion along the circumference and it is due to long exposure of stray current.*

KEYWORDS: *Scrap alloy wheel, Aluminium, Machining rate, Overcut, Surface corrosion factor*

1 INTRODUCTION

The market for advanced materials, estimated at US$5 billion in 2021, is projected to grow at a speed of roughly 10-12%. Composites, ceramics, and performance alloys are currently driving the increased penetration of modern materials in the aerospace/defense, medical, and renewable energy industries [1]. Research on development of various aluminum metal matrix composites(AMMCs), pursued by the researchers on improving the mechanical behaviour like strength, wear, fatigue, micro structural integrity, assembling of particles, cracking and feeble matrix-reinforcement attachment thermal property and quality. Non Traditional Machining Processes (NTMP) namely Wire Electric Discharge Machining process (WEDM), Electric Discharge Machining (EDM), and Electrochemical Machining (ECM) process are suitable for difficult to cut materials. Due to the presence of reinforcement researchers prefer NTMP for machining AMMCs. Among these NTMP, ECM is found suitable for its advantages such as faster material removal, improved surface quality and no tool wear. Research on machining of AMMCs is pursued to understand the interaction of ECM process variables. Annamalai & Dhavamani (2023) have ECMM to machine a workpiece material made utilizing the stir-squeeze casting method, reinforced with Al_2O_3 and SAW. By adjusting variables including voltage, duty cycle, electrolyte concentration, and stirrer speed using an L_{18} Orthogonal Array (OA) experimental design, the produced material is machined for micro-holes using an ECMM. The stirrer rpm contributes 31.91% to the ECM process, and according to ANOVA, the optimal factor levels are 10 V, 90% duty cycle, 25 g/l, and 140 rpm for MS, OC and conicity factor [2]. The LM6 Al/B4Cp composites have been attempted to be machined using the electrochemical machining process by Rao & Padmanabhan (2014). In the LM6 Al alloy matrix, 30 micron-sized B_4C particles are reinforced at 2.5%, 5%, and 7.5% by weight. In the ECM of Al/B_4C composites, the MRR is affected by the applied voltage (A), feed rate (B), electrolyte concentration (C), and percentage of reinforcement (D), in that order, by 22.84%, 52.67%, 10.54%, and 9.03%, respectively [3]. Senthilkumar *et al*. (2009) in order to effectively utilise ECM of LM25 Al/10%SiC composites formed using stir casting, the present work is so starting to examine the influence of some predominant electrochemical process parameters on the MRR and surface roughness (Ra), such as voltage, concentration of electrolyte, flow speed, and tool feed speed. Based on the developed mathematical model, the best combination of machining parameters was determined to achieve the maximum MRR of 0.8773 g/min and the minimum surface roughness of 6.5667 μm. This combination included the electrolyte concentration of 12.53 g/l, the electrolyte flow rate of 7.51 l/min, the applied voltage of 13.5 V, and the tool feed rate of 1 mm/min [4]. Rajan *et al.* (2023) have optimized the ECM parameters on AMMC reinforced with B_4C. The best combination for the machining speed, the diametral OC, and the delamination factor was determined to be 35 g/L of electrolyte concentration, 11 V of voltage, and 70% duty cycle. The duty cycle's 53.5% contribution to the ANOVA analysis's results indicates that it is a major element [5]. The effects of ECM parameters on MR, radial OC, and delamination factor in SAW+MMC have been studied by Kaliappan *et al*. (2024) [6]. According to the GRG, the best settings for a higher MR and a smaller radial OC and delamination factor are 8 V, 20 g/lit, 50%, and 40°C. AA-6082/ZrSiO4/TiC hybrid composite was produced and manufactured using ECM by Naga Swapna Sri et al in 2023[7].Based on the observational results, the parameter combination level of 0.20 mm/min for electrode feed rate, 25 V for voltage, 20 g/lit for electrolyte concentration, and 1.5 g/lit for electrolyte discharge rate achieves the highest MRR(0.00953 mg/min). The magnetic field effect in ECM has been employed by Palaniswamy & Rajasekaran (2023) to increase the accuracy and machining efficiency of the micro-hole machined [8]. The work piece was an alloy wheel matrix made of scrap that had been strengthened with Al_2O_3. For voltage levels between 9 and 10 V, the MR grew quickly, but for the voltage range between 6 and 10 V, the rate of change of the OC is less noticeable. Higher MR and a rapid degree of change in OC are observed in the duty cycle range of 70% to 90% when combined with the magnetic field effect. The experiments in Maniraj *et al.*'s (2023) study, which focused on the impact of temperature on responses including radial OC, MRR, and Conicity Factor (CF), were designed using the L_{18} mixed-level OA design [9]. Furthermore, the process of MCDM is engaged to identify the optimal alternatives by taking into account various weight assessment methods, including the Entropy-Based Weights Method (EBWM), the Analytic Hierarchy Process (AHP), and the Equal Weights Method (EWM). Out of the three approaches, AHP offers the highest improvement of 0.945, according to the results. It is evident from the above literatures that machinability studies on AMMCs through ECM is sparse and moreover detailed analysis of ECM parameters on machining rate, overcut and surface corrosion factor were absent in the current research. Hence in this research the experiments were planned by varying one parameter at a time on machining rate, overcut and surface corrosion factor. Additionally hole surface were analysed using SEM micrographs.

2 EXPERIMENTAL SETUP

The ECM setup shown in Figure 1 is used for the experiments. In house developed ECM setup was made with following specifications:

Make :Sivasakthy Electrical Services, Salem
Pump : Magnetic Type
Pump Model : PMP 15
Max. Flow : 16 – 18 lit/min
Motor : Stepper Motor
Motor resolution : 1.8°/step
Filter : 5 micron cartridge
Electrolyte tank capacity: Max. of 1.6 liters
Max. tool movement : 75 mm.

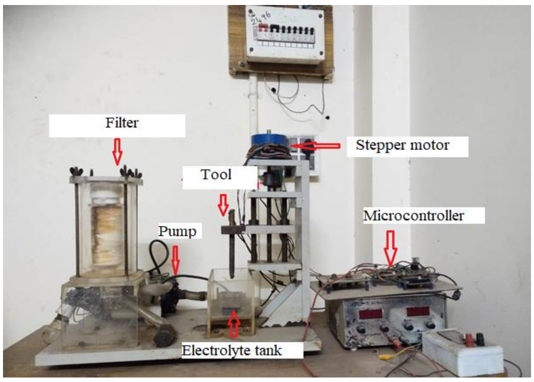


Fig. 1 ECM setup

The citric electrolyte is used for the experiments, the parameters namely voltage,electrolyte concentration,and duty cycle is varied on the machining speed overcut and surface corrosion factor. The Honda car scrapped alloy wheel was collected from the scrap yard and considered as a base metal and its composition is provided in the table1. The 5% Al2O3 is used as a reinforcement in the molten scrap wheel. The sample MMC of 50 × 50 × 3mm size is used as a workpiece and tool electrode of diameter 380µm was coated with bonding resin to prevent stray current.

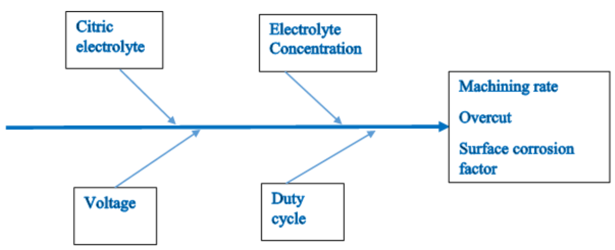
Table 1. Composition of scrapped alloy wheel [8]

Elements	**Si**	**Fe**	**Ti**	**Pb**	**Sn**	**Cu**	**Zn**	**Al**
Percentage	11.13	2.92	1.70	0.29	0.19	0.09	0.06	83.62

The citric electrolyte is prepared by mixing the different grams of citric salt in the one liter of the distilled water.

The machining speed is evaluated based on the machining time to complete and thickness of the workpiece.

Machining Speed (MS)



$$= \frac{thickness\ of\ workpiece\ in\ \mu m}{time\ taken\ to\ machine\ through\ hole\ in\ seconds}$$

The overcut is deliberate by calculating the difference amid the electrode diameter and machine hole diameter.

$$Overcut(OC) = diameter\ of\ the\ machined\ hole - diameter\ of\ the\ electrode$$

The surface corrosion factor is determined by finding the length ratio between the hole diameter and pitting area.The surface topography studies on the hole was performed using the FESEM.Table 2 shows the factors and levels for the preliminary experiments. The effect of variables on ECM performance were studied using preliminary experiments.The process variables such as voltage,duty cycle and electrolyte concentration is varied on MR,OC and Surface Corrosion Factor (SCF).

Table 2. Prelimnary experimental values

Expt No	**Voltage in volts**	**Duty cycle in %**	**Electrolyte concentration in gm/l**	**MR in µm/s**	**OC in µm**	**SCF**
1	5	90	35	0.119	340	1.803
2	6	90	35	0.125	320	1.697
3	7	90	35	0.135	264	1.592
4	8	90	35	0.167	240	1.484
5	9	90	35	0.200	220	1.434
6	9	50	35	0.104	420	1.895
7	9	60	35	0.132	354	1.774
8	9	70	35	0.147	330	1.763
9	9	80	35	0.161	300	1.605
10	9	90	35	0.200	270	1.553
11	9	90	15	0.116	404	1.879
12	9	90	20	0.125	355	1.847
13	9	90	25	0.139	300	1.721
14	9	90	30	0.156	250	1.537
15	9	90	35	0.179	164	1.342

3 RESULTS AND DISCUSSIONS

3.1 Effect of voltage on MR

The effect of voltage on MR is depicted in Figure 2 it is clear that increase in voltage shows increasing trend of MR. The voltage level is increased from 5 to 9V and MR found to increase slowly for 5 to 7V and increases linearly for the range of 7 to 9V.The MR is associated with Faradays law of electrolysis in which the MR depends on the amount of electric charges supplied [9]. The electrode is supplied with negative pulsed power supply and workpiece is supplied with positive power supply. The citricacid electrolyte is used to close the circuit. When electricity is passed through the electrodes the electrolysis occurs in the electrochemical cell. During electrolysis process dissolution of workpiece material happens and quantity of material removal depends on the amount of electricity passed between the electrodes.

The MR is at lower level for voltage of 5 to 7, at this voltage range the electric charges available for machining is less so lower material removal takes place. At higher voltage the electric charges available for generation of strong current in between the electrodes, leading to more MR.

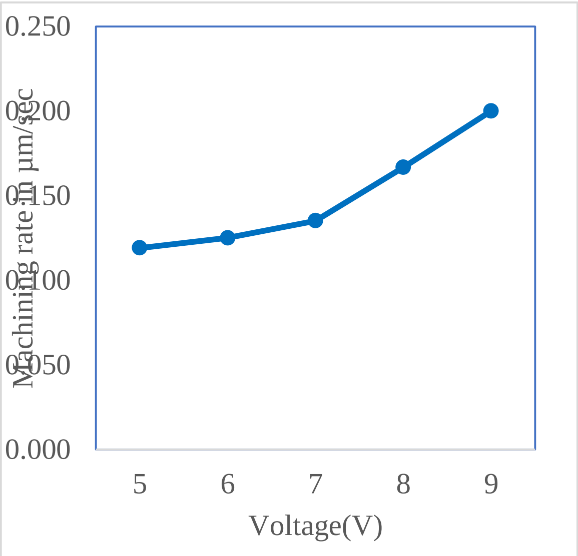


Fig. 2 Effect of voltage on MR

3.2 Effect of voltage on OC

Figure 3 shows the higher OC for higher voltage and it is due to the reason at higher voltage more current is available for machining. The electrolysis occurs at faster rate at higher voltage and dissolute products coming out of workpiece materials create short circuits resulting sparks[10]. These sparks removes the wanted materials from the workpiece. Moreover the debris in the electrolyte distracts the current density required for machining and uneven material removal happens on the surface of the material. At lower voltage the lesser dissolute products hence the OC is comparatively lower. The OC is insignificant for 5 to 7V and an increase for voltage level of 7 to 9V. The range of voltage significant for OC is 7 to 8V.

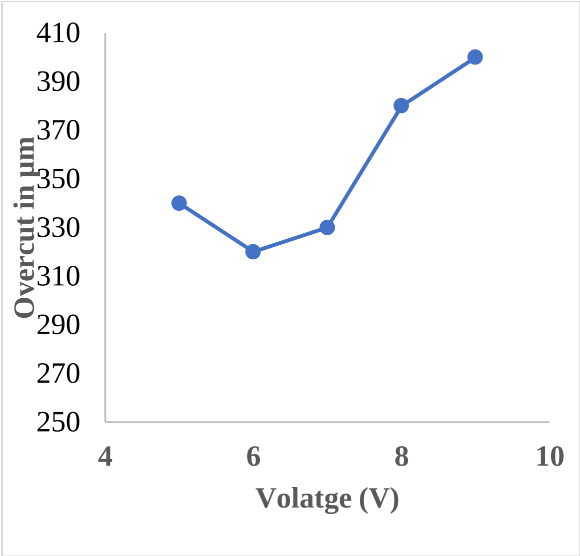


Fig. 3 Effect of voltage on OC

3.3 Effect of voltage on SCF

The effect of voltage on SCF is shown in figure 4, the SCF decreases with increase in voltage. The tool electrode is insulated using bonding resin to prevent stray current effect [11]. The lower voltage level shows more SCF compared to higher voltage level. The SCF is higher due to the fact that at 5V the electric current available for machining is less which results in long dissolution period. During this long period interaction of tool electrode and workpiece, results in corrosion of workpiece due to stray current effect. At higher level of voltage the current density is more and MR is faster, which reduce the interaction time of the electrodes attributing for lesser SCF.

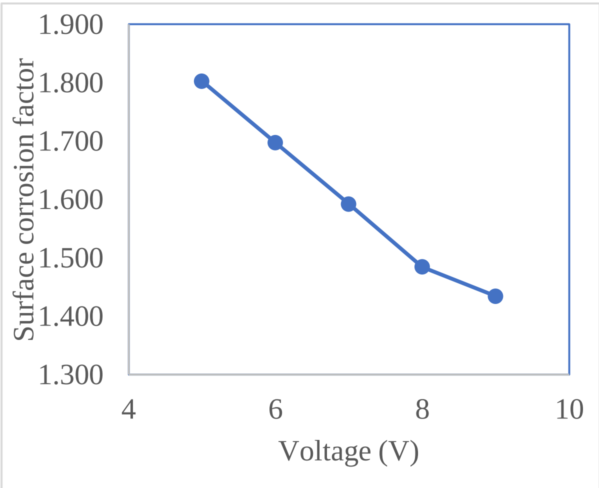


Figure 4. Effect of voltage on SCF

3.4 Effect of duty cycle on MR

Figure 5 shows the result of duty cycle on MR and MR increases with rise in duty cycle. The duty cycle is the ratio of pulse on time to the total time, at lower duty cycle the pulse on time available for machining is less. During the lesser pulse time the current density essential for machining is less attributing for lesser MR and with rise in pulse on time more electric current required for machining increases [12]. This phenomenon rises the MR for higher duty cycle. The MR rises gradually for 50% duty cycle and significant range of duty cycle is between 60 to 80%. At duty cycle range of 80 to 90% the duty cycle rises more rapidly.

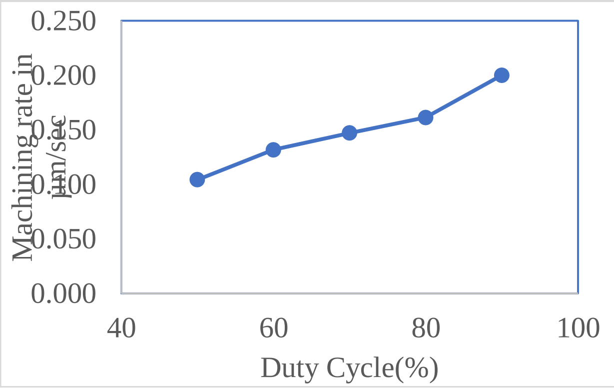


Figure 5. Effect of duty cycle on MR

3.5 Effect of duty cycle on OC

Figure 6 shows the outcome of duty cycle on OC, the trend of the graph is increasing and decreasing in nature. The OC is at higher side for 50% duty cycle and decreases to lower-level duty cycle range of 50 to 80%. Again, OC increases to higher value for the duty cycle range of 80 to 90%. The significant range of duty cycle for lesser OC is 60 to 80%.

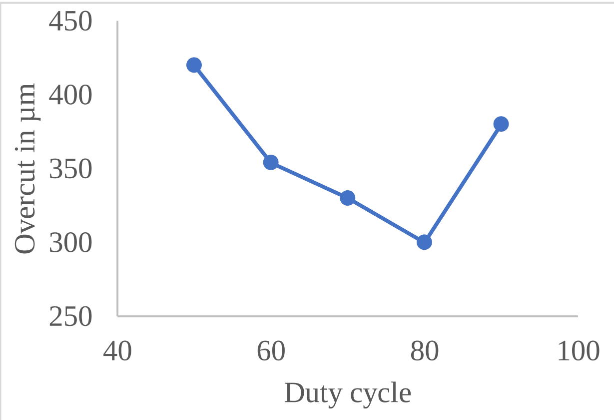


Fig. 6 Effect of duty cycle on OC

3.6 Effect of duty cycle on SCF

The outcome of duty cycle on SCF is plotted in the figure 7 and it shows that the increase in duty cycle reduces the SCF. The SCF is higher for 50% duty cycle and gradually reduces to lower level of 90% duty cycle. At higher duty cycle the relation of pulse on time to over-all time is more which leads quicker machining of the hole and hence the stray current if present will have lesser encounter time with the workpiece surface. Although tool electrode is coated with bonding resin for insulation of stray current, over the period of electrochemical reaction the coating detach from the side wall of the electrode attributing for escape of current on the side wall of the electrode[13]. The significant range of duty cycle for lesser SCF is 70 to 90%.

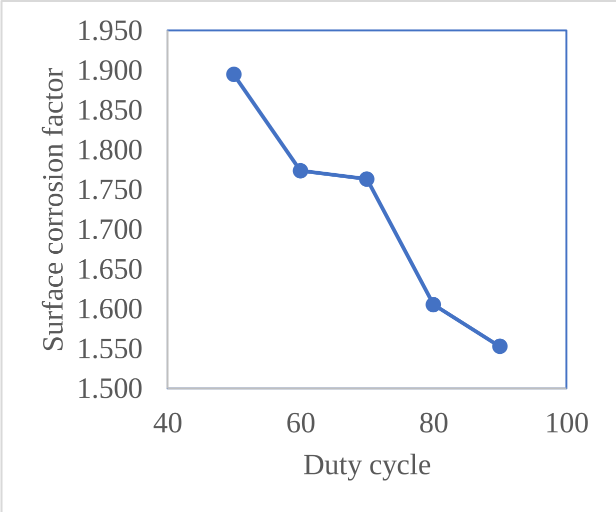
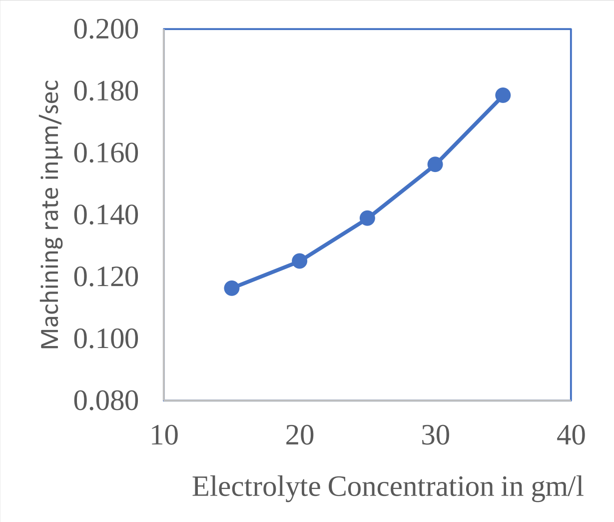


Figure 7. Effect of duty cycle on SCF

3.7 Effect of electrolyte concentration on MR

The result of electrolyte concentration on MR is shown in figure 8, which shows that the MR increases with citric electrolyte concentration. The electrolyte solution is prepared from citric salt which is diluted in 1 litre of purified water. The well stirred electrolyte is prepared in different concentration ranging from 15gm/l to 35gm/l. The concentration of the electrolyte has substantial influence on the MR, i.e. increase in concentration of electrolyte, the availability of ions required for machining is more [14]. The MR mainly depends on the ions present in the electrolyte and mobility of ions which is again depends on the electricity [15]. The graph shows that the MR increases to higher value for 35gm/l electrolyte concentration. The significant electrolyte concentration is 20 to 30gm/l for obtaining the higher MR. At higher electrolyte concentration number ions essential for machining exist resulting in higher MR.



Fig, 8. Effect of electrolyte concentration on MR

3.8 Effect of electrolyte concentration on OC

Figure 9 shows the result of electrolyte concentration on OC and the OC tends to decrease with rise in electrolyte concentration. Owing to the fact that reaction products coming out of the workpiece is more at higher concentration and these reaction products may result in conductive bridge formation between tool and workpiece[16]. These conductive bridges may generate the micro sparks resulting delaminated surface on the workpiece. For electrolyte concentration of 15 to 30gm/l the OC decreases and increases to the maximum value for electrolyte concentration range of 30gm/l to 35gm/l.

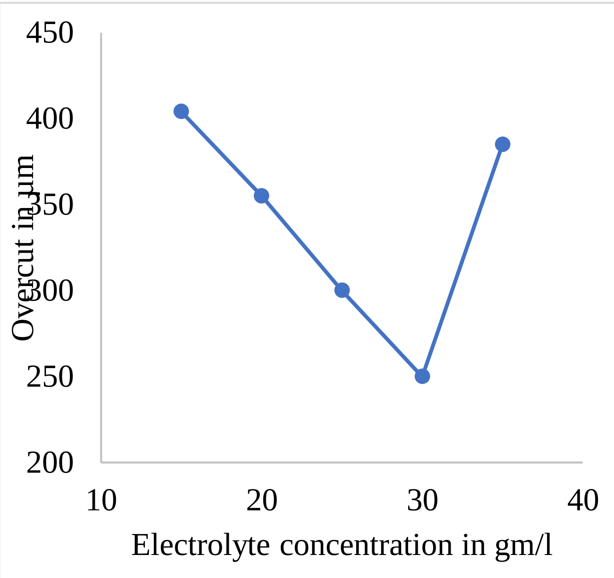


Fig. 9 Effect of electrolyte concentration on OC

3.9 Effect of electrolyte concentration on SCF

Figure 10 shows the consequence of electrolyte concentration of SCF and it is keep on decreasing for rise in electrolyte concentration. The significant range of electrolyte concentration for lower SCF is 25gm/l to 35gm/l. At lower concentration the number of ions existing in the electrolyte is less and longer duration of electrochemical reactions attributes for higher SCF and while increasing the concentration, the quantity of ions increases which reduces the tool exposure on the workpiece for through hole machining[17].

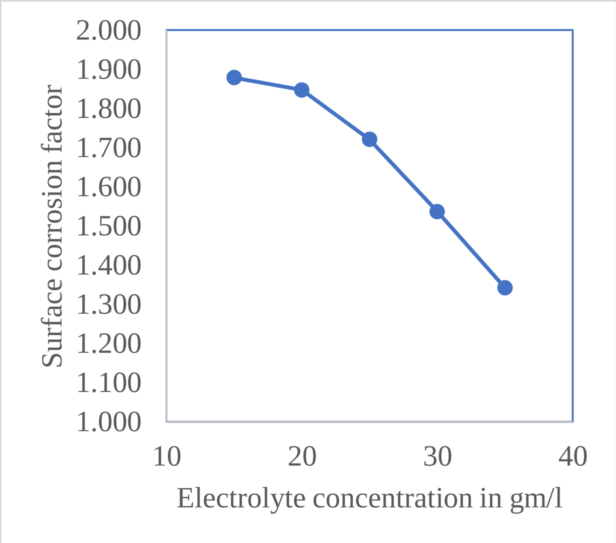


Figure 10 Effect of electrolyte concentration on SCF

4 ANALYSIS OF HOLE

The Figures 11&12 shows the SEM micrographs of the machine surface, it is evident that during ECM process the circumference of the hole is sited with delaminated surface and aggregation of alumina. The hole is machined at 9V, 95% duty cycle and 35gm/l electrolyte concentration. The aggregation of Al_2O_3 is due to the fact that during stirring process the reinforcement moves towards the center (Bahl 2021). While machining with ECM this amalgamation of Al_2O_3 detaches from the base metal attributing for bulk material removal resulting in delaminated surfaces [18]. Figure 13 shows the hole machined at parameter combination of 5V, 95% duty cycle and 35gm/l electrolyte concentration. The hole shows surface pitting/corrosion along the circumference and it is due to long exposure of stray current. Figure 14 at former parameter combination shows the over etched surface.

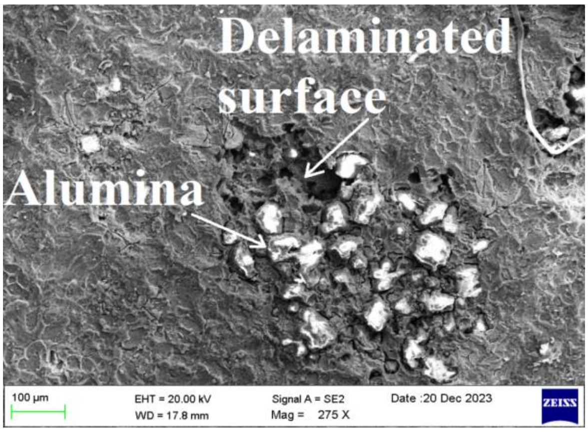


Fig. 11 SEM of hole surface

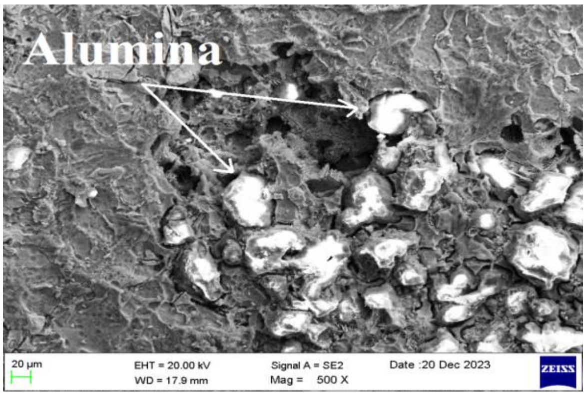


Fig. 12 SEM of hole surface with Al2O3

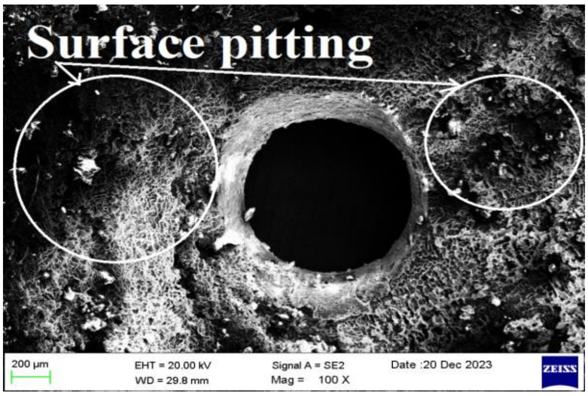


Fig. 13 SEM hole with surface pitting

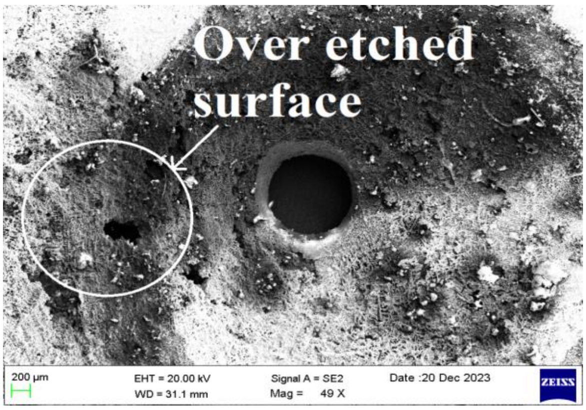


Fig. 14. SEM hole with overetched surface

5 CONCLUDING REMARKS

The ECM experiments is planned by changing one factor at a time and voltage, duty cycle and electrolyte concentration at 5 levels ranging from 5-9V,50-90% and 15-35gm/l respectively were considered for the machining the hole on AMMC.

The voltage level is increased from 5 to 9V and MR found to increase slowly for 5 to 7V and increases linearly for the range of 7 to 9V. The OC is insignificant for 5 to 7V and an increase for voltage level of 7 to 9V. The range of voltage significant for OC is 7 to 8V. The SCF is higher due to the fact that at 5V the electric current available for machining is less which results in long dissolution period. The MR increases gradually for 50% duty cycle and significant range of duty cycle is between 60 to 80%.The significant range of duty cycle for lesser OC is 60 to 80% and for lesser SCF is 70 to 90%.The significant electrolyte concentration is 20 to 30gm/l for obtaining the higher MR. For electrolyte concentration of 15 to 30gm/l the OC decreases and increases to the maximum value for electrolyte concentration range of 30gm/l to 35gm/l. The significant range of electrolyte concentration for lower SCF is 25gm/l to 35gm/l. The hole analysis shows surface pitting/corrosion along the circumference and it is due to long exposure of stray current.

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