Investigation of process parameters by abrasive assisted electrochemical micro drilling process on Al - 6061 with SiC and Fly ash composites

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Abstract: This attempt investigates on upgrading the required parameters of micro hole machining process like frequency, voltage, electrolyte concentration of abrasive assisted Electrochemical machining process. This work focuses on optimizing the methodology of abrasive assisted ECM process parameters and comparing it with straight ECM process. The experimentation is done on AL6061 with hybrid reinforced SiC and Fly ash particles at constant percentage weight. Upgrading process parameter is a statistical technique, where the independent input process parameters such as frequency, voltage, electrolyte concentration were imported to initiate the AECM process. The process performance is measured in terms of material removal rate (MRR) and precision of micro hole dimension (OC) and the results obtained were compared for both process (abrasive and without abrasive ECM for AL6061-10 wt% of SiC -10 wt% of Fly ash). The hybrid composites of AL6061 containing 10 wt% of (SiC & Fly ash) particles were prepared by using liquid metallurgy route. The microstructure, wear and mechanical properties of the fabricated AMCs were analyzed.

Keywords: Aluminium metal matrix composite, Material removal rate, Electrochemical machining, overcut, ANOVA

1. INTRODUCTION

Hemanth.I, Himanshu Kala et al [1,7] aluminium matrix composites are most required material in the industrial field due to its excellent mechanical as well as physical properties. RohatgiP.K, S. Basavarajappa et al[2,4] in his study stated that the stir casting method is the simplest way for fabricating AMMc. Ramesh, K.Umanath et al [3,5] in his study concluded that the mechanical properties of AMMc is increased by adding reinforcement materials such as ZrO₂, SiC, B₄C, TiB₂, Gr, and FlyAsh. David Raja.J et al[6] in his study fabricated AMMc produced by combining SiC and Fly ash through modified stir casting method illustrated that the mechanical properties is increased due to increases in weight percentage of SiC and FlyAsh.

Data.M etal[9] conveys that the electrochemical machining is 21st generation machining process used for manufacturing the various micro components and sophisticated parts in very hard and exotic materials using the principle of Faraday. D.Deconicket al[8] in his research of traditional machining process on hard Al composites, achieved the rapid tool wear with a poor surface quality. S.Dharmalingam,P.Satishkumar et al[10,11] the quality of work piece is achieved by controlling the
various process parameters such as electrolyte concentration, applied voltage, and frequency on improving the MRR and minimizing overcut. In order to avoid this drawback and to determine the optimal process parameters abrasive based ECM method can be used.

2. EXPERIMENTAL PROCEDURE

2.1. Fabrication of AL6061 hybrid composites

Stir casting is one of the simplest way to fabricate the AMMC. 800 grams AL6061 graphite crucible coated rod is used as a base material was kept in the electrical furnace and melted at 935±20°C temperature level. Zirconia coated mechanical stirrer is used at a speed if 800 rpm and stirred for 15 minutes to form a fine vertex molten metal from the melted material. The reinforcement particles (figure 1) of SiC, Fly ash (each 100 grams) were preheated at 850±30°C for 60 minutes to increase the wettability. 10 grams of Magnesium is used as a wetting agent and the preheated reinforcement is added into the molten aluminium with a constant feed rate of 2 g/s. Stirring is carried out in every stage to ensure homogeneous distribution of reinforcement particles in the aluminium melt. The AL6061 hybrid composites is maintained at 850°C for a period of 5 min and is poured into a steel moulds of size 100x100x12 mm.

| Elements | Fe | Mg | Si | Pb | Zn | Cu | Ni | Mn | Cr | Ti | Al |
|----------|----|----|----|----|----|----|----|----|----|----|----|
| % weight | 0.7 | 0.8 | 0.43 | 0.24 | 0.25 | 0.24 | 0.05 | 0.139 | 0.25 | 0.15 | Balance |

| Elements | Al_2O_3 | SiO_2 | K_2O | CaO | MnO | Na_2O | Fe_2O_3 | TiO_2 | Others |
|----------|---------|--------|------|-----|-----|-------|---------|-------|--------|
| % weight | 13.25 | 12.49 | 16.65 | 17.6 | 14.1 | 15.1 | 18.9 | 19.12 | 20.21 |

| Parameters | Unit | Value |
|------------|------|-------|
| Furnace temperature | °C | 935 |
| Stirring speed | Rpm | 800 |
| Stirring Time | Minutes | 15 |
| Preheating temperature of reinforcement | °C | 850 |
| Preheating time | Minutes | 60 |
| Preheat temperature of mold | °C | 250 |
| Reinforcement feed rate | g/s | 2 |

Figure 1. Scanning Electron Micrograph
2.2. Non conventional machining process (AECM & ECM)
The Non conventional machining process is an modernistic machining process. Electro chemical machining is used for removal of atoms from the work piece by electrochemical dissolution. Electrolysis process (ECD) is based on the principle of Faraday. And is applicable for electrically conductive materials. ECM process is used in wider range of application because of its precision dimension, good surface quality and is obtained without affecting metallurgical properties. During this process, work piece act as anode and tool act as cathode. The electron transfer reaction carried out at both anode and cathode. In this experimental setup, Sodium Nitrate (NaNO3) is used as electrolyte concentration and 450μm cylindrical brass tool electrodes with 20μm SiC particles is used as abrasive medium, 50 x 50 x 0.4 mm dimension AL6061+10% SiC+10% Fly Ash is used as work piece. The electrode feed mechanism is controlled by microprocessor assisted stepper motor with resolution of 2μm along Z-axis control.

| Experimental setup | Sodium Nitrate (NaNO3) | Electrolyte concentration |
|--------------------|------------------------|---------------------------|
| 450μm Cylindrical Brass Tool | Electrode (Both AECM & ECM) |
| 20μm SiC particles | Abrasive medium |
| AL6061+10% SiC+10% Fly Ash (50X50X0.4 mm) | Work piece |

Table 4. Experimental Setup.

| Symbol | Factors                  | Level1 | Level2 | Level3 |
|--------|--------------------------|--------|--------|--------|
| E      | Electrolyte Flow rate (g/l) | 20     | 25     | 30     |
| V      | Voltage (V)              | 10     | 12     | 14     |
| F I    | Frequency(μm)            | 30     | 40     | 50     |
| D      | Current(μA)              | 0.8    | 0.8    | 0.8    |
|        | Gap                      | 0.2    | 0.2    | 0.2    |

Table 5. Machining Input Process Parameter Level’s.

3. RESULTS AND DISCUSSION

3.1. Microstructure studies
The Microstructure of fabricated AL6061+10% SiC+10% Fly Ash alloy and AL6061 alloy, exposed the formation of branch line network structure and the precipitation of Mg_2Si is clearly visible in the microstructure is shown in the below figure 2.
The AL6061+10%SiC+10%Fly Ash microstructure clearly shows that the aluminium have build a branch line network called as dendritic structure. Figure 2 B-C clearly expose the Fly ash &SiC particles are distributed in the metal matrix homogenously without crack and porosity. Fly Ash &SiC particles are not in the direction of aluminium grains and it is caused due to the solidification that offers the resistance to the growth of AL phase during solidification. The formation of Al₄C₃is completely avoided due to the proper distribution of SiC and Fly Ash in the matrix because of proper stirring action which indicates SiC and Fly Ash are well bonded to the aluminium matrix.

3.2. MechanicalProperties

![Figure 3. The effect of SiC & Fly Ash in Al6061](image)

Table 6. Wear and Friction test result.

| Sample ID : Al6061+10%SiC+ 10% Fly Ash Process parameters | Wear in (Micron) | COF | Frictional Force(N) (Average) |
|-----------------------------------------------------------|-----------------|-----|-------------------------------|
| Speed (RPM)                                               | 500             | 82.97 | 0.2878                         |
| Load (N)                                                  | 40              |      | 11.51                         |
| Time duration (Sec)                                       | 600             |      |                               |
| Sliding velocity (m/s)                                    | 2.617           |      |                               |

![Figure 4 Fracture surface](image)

Figure 3 clearly expose the The presence of Sic and Fly Ash particles in AL6061 provides high resistance against plastic deformation and increases the component hardness. Presence of these reinforcement improves the rock well hardness from 43 to 76 and also improves the tensile strength from 146.7 MPa to 223.4 MPa. Figure 4 clearly expose the AL6061 fracture surface shows the large size dimples network which expresses the high number of plastic flow prior to failure. But fracture surface of AL6061 + 10%SiC + 10% Fly Ash shows smaller size dimples network compared to AL6061 alloy matrix which leads to reduced ductility.
3.3. Experimental results of Straight ECM and Abrasive Assisted ECM

Table 7 shows the experimental results of abrasive assisted ECM and Straight ECM. Material removal rate (MRR) was achieved during the machining time. Measurement of Over Cut (diameter of tool electrode – diameter of micro hole) is achieved with the help of optical microscope.

| Run No | Electrolyte Flow rate (g/h) | Voltage (V) | Frequency (Hz) | MRR (mg/min) | OC (μm) | MRR (mg/min) | OC (μm) |
|--------|-----------------------------|-------------|----------------|--------------|---------|--------------|---------|
| 1      | 30                          | 10          | 30             | 0.261        | 192.43  | 0.355        | 193.17  |
| 2      | 30                          | 10          | 40             | 0.217        | 169.13  | 0.306        | 168.98  |
| 3      | 30                          | 10          | 50             | 0.352        | 143.69  | 0.445        | 143.11  |
| 4      | 30                          | 12          | 30             | 0.43         | 157.17  | 0.525        | 157.21  |
| 5      | 30                          | 12          | 40             | 0.417        | 128.31  | 0.509        | 128.13  |
| 6      | 30                          | 12          | 50             | 0.375        | 146.44  | 0.468        | 146.51  |
| 7      | 30                          | 14          | 30             | 0.461        | 148.25  | 0.557        | 147.97  |
| 8      | 30                          | 14          | 40             | 0.354        | 174.68  | 0.446        | 174.31  |
| 9      | 30                          | 14          | 50             | 0.385        | 171.36  | 0.48         | 171.43  |
| 10     | 25                          | 10          | 30             | 0.3          | 131.69  | 0.399        | 131.61  |
| 11     | 25                          | 10          | 40             | 0.217        | 173.14  | 0.308        | 173.51  |
| 12     | 25                          | 10          | 50             | 0.317        | 146.62  | 0.407        | 146.37  |
| 13     | 25                          | 12          | 30             | 0.187        | 117.73  | 0.274        | 117.28  |
| 14     | 25                          | 12          | 40             | 0.475        | 145.73  | 0.564        | 145.65  |
| 15     | 25                          | 12          | 50             | 0.227        | 158.27  | 0.312        | 158.14  |
| 16     | 25                          | 14          | 30             | 0.292        | 91.27   | 0.398        | 91.2    |
| 17     | 25                          | 14          | 40             | 0.316        | 153.25  | 0.411        | 153.39  |
| 18     | 25                          | 14          | 50             | 0.307        | 98.52   | 0.396        | 98.47   |
| 19     | 20                          | 10          | 30             | 0.159        | 164.72  | 0.245        | 164.53  |
| 20     | 20                          | 10          | 40             | 0.237        | 188.35  | 0.325        | 188.3   |
| 21     | 20                          | 10          | 50             | 0.268        | 164.03  | 0.359        | 164.17  |
| 22     | 20                          | 12          | 30             | 0.357        | 150.14  | 0.443        | 150.27  |
| 23     | 20                          | 12          | 40             | 0.197        | 214.41  | 0.291        | 213.78  |
| 24     | 20                          | 12          | 50             | 0.208        | 168.87  | 0.303        | 168.17  |
| 25     | 20                          | 14          | 30             | 0.321        | 144.13  | 0.419        | 144.21  |
| 26     | 20                          | 14          | 40             | 0.437        | 157.04  | 0.523        | 157.11  |
| 27     | 20                          | 14          | 50             | 0.416        | 128.37  | 0.505        | 128.27  |

3.3.1 Factors affecting the Material Removal Rate (MRR)

In this process voltage, Frequency and Electrolyte concentration acts as a major influencing process parameter on the material removal rate of AL6061 + 10%SiC + 10%Fly Ash Alloy. The material removal rate obtained from experiment with different level of process parameters is shown in figure 5.
Table 7 shows that the AECM process produces maximum material removal rate than the ECM process and produces burrs free machining surface. Figure 5 shows the minimum level of electrolyte concentration produces minimum amount of material removal rate because of ionic particles present in the concentration. The MRR is increased when increased the electrolyte concentration level. Figure 5 shows the MRR is proportional to the voltage rating. In low rate of voltage yields minimum amount of MRR compared with high rate of voltage because low voltage produces low potential changes between the electrode and work piece. Figure 5 shows when the frequency was 30 Hz the material Removal Rate is low. The maximum MRR obtained at 40 Hz frequency then it is gradually decreased when increasing frequency. Based on ANOVA result (Figure 6, Table 8 & 9 ) voltage and electrolyte concentration levels are directly affecting MRR and OC.

4. CONCLUSION

The Al6061+10%SiC+10% Fly Ash composites were fabricated by liquidized stir casting route and the microstructure, mechanical properties were evaluated and micro drilling experiments were conducted. From this experimental the following results are derived.

1. The microstructure clearly shows that the Fly Ash and SiCp particles distributed in the metal matrix homogeneously without crack & porosity and the Al4C3 phase formation was avoided.
2. The reinforcement of SiCp and Fly Ash particles has enhanced the micro hardness and is increased from 69 HV to 79.13 HV and macro hardness is increased from 43 RHN to 76RHN.
3. The reinforcement of SiCp and Fly Ash particles has enhanced the tensile strength from 146MPa to 223.4Mpa.
4. Abrasive assisted Electro Chemical micro machining brings better performance that exhibits higher MRR than straight ECM and produces burrs free machining surface. Based on ANOVA result voltage and electrolyte concentration levels are directly affecting MRR and OC.

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