# Identification of Surface Roughness and Removal rates of EDM machining of Al-SiC-FA Metal Matrix Composite

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**Abstract**

Electrical discharge machining (EDM) is a process of eroding material through a series of successive sparks between the sample and the electrode with the conversion of electrical energy to thermal energy over the work piece material by neglecting physical contact with electrodes which is having good contact with electrodes and also it possesses good electrical and thermal conductivity. For the purpose of characteristics evaluation and machining performance, Al6063 alloy was preferred and used with Silicon Carbide (SiC) which has high thermal conductivity and melting point. In view of improving hardness, strength and effective grain size, the hybrid metal matrix composite specimen were prepared by stir casting method with suitable weight percentages. For achieving excellent Material removal rate (MRR) and improvement of machining characteristics, the process was made by the comparison of Cu and Cu-Cr electrodes machining with positive as well as negative polarities. Therefore, the objective of the present work extracts the machining performance of Al-SiC-Fly ash in EDM was evaluated in terms of Material removal rate(MRR), Electrode wear rate (EWR) and surface roughness and also find out the hardness improvements by the addition of reinforcements. The experiments were carried out to expel the effective machinability and surface quality of hybrid metal matrix composite.

***Key words:*** Stir casting, EDM, Surface roughness, Metal Matrix Composite, Electrode wear rate.

## 1. INTRODUCTION

Electrical discharge machining (EDM) is one of the unconventional process has been accepted globally, generated in the 1940s, it is well established machining option which is capable of machining complex geometrical components as well as hard materials components. [5][7] Factories expecting the components which is having advanced level of applications like die and mould making, aerospace, aeronautics, nuclear industries and defense. For the justification of applications unconventional processes has been discovered to overcome the problem arises in the conventional method. Present advancements in EDM due to its applications and challenges new materials to be introduced, made some innovations in the region of materials engineering. The materials will play a major role for machining components which is having excellent mechanical properties and characteristics. [4][7] Especially Metal matrix composites will provide high quality and cost effective manufacturing due to its benefits of hardness, low weight, high strength, improved wear resistance and high elastic modulus. [8] This is composed of constituents first being a matrix phase other it may be ceramic fiber or different reinforcement phase. It possesses good strength, mechanical and physical properties, furthermore improvements are made on the MMC based on its heat treatments and some process methodologies. Difficulties in machining using conventional method to be change over to EDM method. Aluminium MMCs are becoming excellent combination of properties having wide range of applications. To enhance the combined properties of MMCs, addition of more than two materials will offer hybrid structure. Many researchers were conducted EDM operation on Al350/SiC, Al/SiC/Gr, AlSiMg/SiCetc with corresponding weight ratios and volume fractions. Moreover, this work also reveals that the composite electrodes obtained a higher MRR than Cu metal electrodes. R. Kumar et al [5] investigated various input parameters on the operation responses on hybrid metal matrix composites. [10] Conducted drilling operation on Al356/SiC MMC and Al356/SiC/Mica HMMC, the authors was observed that higher surface roughness SR in HMMC than MMC.[9] Singh et al. conducted EDM operation on Al/10%SiC as cast MMC with variables as current, pulsu on time and flushing pressure. [12] Ramulu investigated the strength with increase in MRR in machining of Al/15%SiC MMC. [13] Songmene and Balazinzki were investigated the drilling and milling of Al/SiC, Al/SiC/Gr, variation of hard particles improves machinability. Stir casting method is used to produce cast specimen.

In this investigation, for various weight percentages, hybrid composites were fabricated as specimens using stir casting method which is advantages lie in its simplicity, flexibility and applicability to large quantity production. Al6063 was preferred as matrix phase reinforcement with Silicon Carbide (SiC) and fine particles of Fly ash is added. After EDM machining, Material Removal Rate, Electrode Wear Rate, Surface Roughness and process time has been evaluated for different combination of cast specimens. The influence of polarity changes will cause changes in machining performance of MMC has been investigated and the machining performance by the Cu and Cu-Cr composite electrodes has been compared for each samples.

## 2. EXPERIMENTAL METHOD AND MATERIALS

### 2.1. Materials selection

Alloys possess uncommon casting characteristics and very smooth surface properties. [5] Aluminium alloy 6063-T6 is used as matrix material having low density, high strength, more hardness and excellent thermal conductivity. [5] Kumar et al, found that the acceptable values of MRR, TWR and SR was obtained on Al6063/SiC/$Al_2O_3$/Gr hybrid MMC. [7] Abishek Singh developed Al6063/10%SiC MMC through stir casting and squeeze casting. Most of turbine components, valves, bearings and architecture frames in construction made up of Al6063 alloys.

Table 1. Chemical composition of Al6063-T6

| Si | Ti | Zn | Mn | Mg | Fe | Cu | Cr | Al |
|---|---|---|---|---|---|---|---|---|
| 0.2t o 0.6 | Max 0.1 | Max 0.1 | Max 0.1 | 0.45t o 0.90 | Max 0.35 | Max 0.1 | Max 0.1 | Rem |

Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. H.M. [14] Zakaria investigated increase in volume fraction and/or the SiC particles size reduce the corrosion rates of the Al/SiC composites. [15] The effect of particle size was analyzed and the high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities based on the percentages in table 1 and 2. Silicon carbide ceramics with little or no grain boundary impurities maintain their strength at very high temperatures.

Table 2. Chemical composition of Silicon Carbide

| C | O | Si | Al | Cl | S | Ca | Fe | Mg | Ti |
|---|---|---|---|---|---|---|---|---|---|
| 29.78 | 0.216 | 69.64 | 0.13 | 0.038 | 0.014 | 0.052 | 0.091 | 0.007 | 0.016 |

[8] Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly shapeless in nature. The carbonaceous material in fly ash is composed of angular particles. Although sub bituminous coal fly ashes are also silt-sized, they are generally slightly coarser than bituminous coal fly ashes. The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area may range from 170 to 1000 $m^2$/kg. The color of fly ash can vary from gray to black depending on the amount of unburned carbon in the ash. Bituminous fly ashes are usually some shade of gray, with the lighter shades of gray generally indicating a higher quality of ash.

Table 3. Chemical composition of Fly ash

| O | Si | Al | Fe | Ti | K | Ca | LOI |
|---|---|---|---|---|---|---|---|
| 38.88 | 26.43 | 16.73 | 3.82 | 1.42 | 0.99 | 0.5 | Rem |

In the view of improving mechanical properties of the composites fine particle Fly ash can be included with the matrix alloy and is collected from the industrial waste with major constituents of $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ and micro constituents of oxides of Mg, Ca, Na etc. The density of Aluminium will be reduced for developing low weight applications.

### 2.2. Preparation of specimen

Metal matrix composite was developed by stir casting method, [8] it is liquid state method of composite materials fabrication in which dispersed phase is mixed with the molten matrix metal by means of mechanical stirring and it was carried out by Al6063 alloy with reinforcement of 15%SiC fine particles of size 30µm added with 5 wt.% Fly ash and 10wt% Fly ash of particle size 10µm. Three samples were prepared. [7] based on the experimentation casting was done in crucible furnace and it was carried out to around 10-15 minutes at an average mixing speed 200 rpm at a composite temp of $700^0$C. The micro structure shows that the uniform distribution of SiC and fly ash particles will provide hybrid MMC with the average composite density of 2.714g/$cm^3$.Here the specimen was primed in the form of rectangular plate of size 90mm x 40mm x 10mm and is homogenized for the uniform distribution of extremely small particles distributed uniformly throughout the work material.

### 2.3. Comparison of hardness

Hardness test was conducted for the specimen prepared above in SGI-BHTM-J-3000 Brinell hardness tester. The indentation was created by 5 mm diameter ball end for the load of 750 Kgf. High material hardness to be achieved with the help of advanced ceramic compound Silicon Carbide (SiC) act as a stiff reinforcement with Fly ash added with Al6063 alloy matrix.

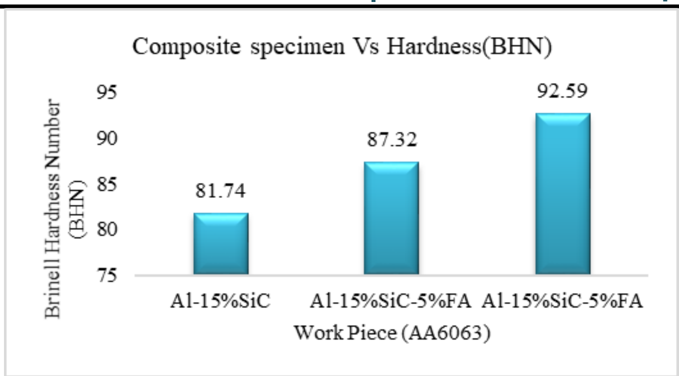



Figure 1. Hardness values of different samples

In the above figure 1 mentioned that the X axis represents three different samples of Al6063 MMC and Y axis represents the value of Brinell Hardness Number. Based on valued experimentation, hardness was obtained more on sample III as shown in figure 1 which is having Al/15%SiC/10%Fly ash for the average indentation diameter of 4.075 mm. The initial properties of the hybrid metal matrix composite will be changed by the addition of SiC has been interrelated with the increase in mechanical properties such as yield strength, ultimate tensile strength and elastic modulus. The presence of reinforcement has been distributed evenly then improved its hardness by the gradual addition of fly ash and correlated with the sample during the micro structural evaluation.

### 2.4. Process EDM

EDM is an unconventional machining process used to form desired shapes to be machined. Based on the experimentation, H.C.Tsai et al [1] preferred Cu electrode ad Cu-Cr composite electrode for the machining of AISI 1045 steel material and also EDM characteristics of the two different electrodes were discussed and verified. It is accomplished with the system of components electrode, work piece and power supply. [1] A mixing ratio of Cu–0wt%Cr on electrode and a sinter pressure of 20 MPa obtained an excellent MRR. Plate shaped Cu and Cu-Cr composite electrode having thickness of 3.4 mm is used as tool electrode. Kerosene is used as a dielectric fluid during sink type EDM machining.

Table 4. EDM process conditions

| Experimental conditions | Report |
|---|---|
| Work piece | Al 6063-SiC-Fly ash MMC |
| Electrode | Cu, Cu-Cr electrode (Coated) |
| Dielectric fluid | Kerosene |
| Polarity | Positive / Negative |
| Peak current | 12A |
| Pulse duration | 25,100,200,400 µs |
| Open circuit voltage | 240 V |

Straight slots of size 3.50mm wide to be machined over the surface of each sample by using different electrodes of size 26mm x 20mm x 3.5mm such as Cu and Cr (5µm) coated Cu electrode which was made by sputtering process in PVD method. Two polarities (positive and negative) were considered during machining. The specimens with 15wt%SiC 5wt%Flyash and 15wt%SiC 10wt%Flyash and 15wt%SiC reinforced with Al6063. These three specimens were included for the EDM machining, MRR, EWR can be calculated for the samples at $200^0$C and 20mpa as mounting temperature and pressure for both positive and negative polarities. Constant pulse duration was maintained as 100µs. Following this for different pulse duration 20µs,100µs,200µs,400µs the machining was made on three specimens with the polarity changes as positive and negative. Working time also verified for the corresponding experiments. Finally, the machining properties MRR, EWR and SR to be analyzed and evaluated for the corresponding polarities of each samples.

## 3. RESULTS AND DISCUSSION

The results showed that the three various proposed characteristics Material removal rate, Electrode wear rate and Surface roughness were evaluated for the first set of operation. In figure 2, 3, 4 and 5, X axis represents three different work piece materials and Y axis represents metal removal rate and electrode wear rate. Figure 2 shows that during the positive polarity machining, by comparing MRR that was achieved in the specimen which is having 15wt%SiC is good as compared with the remaining samples. Due to good bonding strength highest MRR was attained. Optimum MRR to be formed during the negative polarity machining because of many electrode particles are dropped and stick on to the machined surfaces.

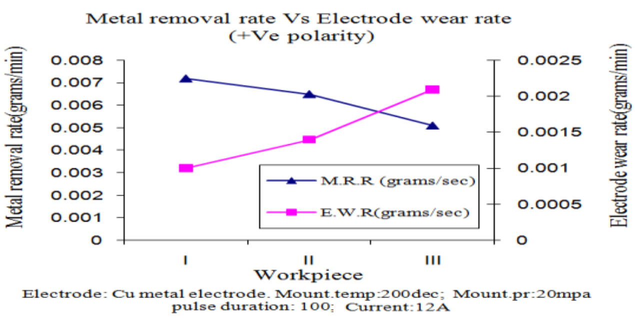


Figure 2. Variation in MRR and EWR for positive polarity machining

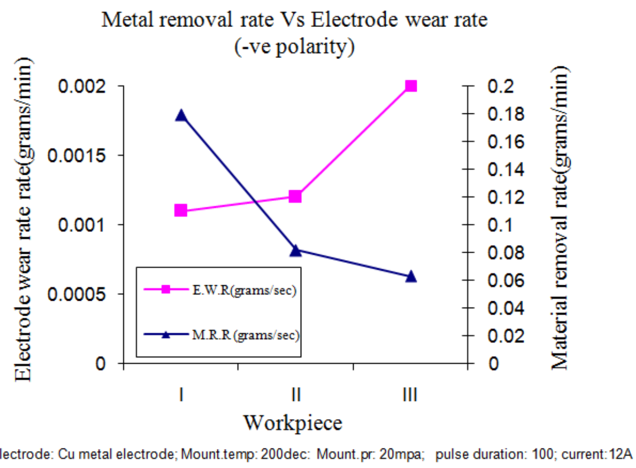



Figure 3. Variation in MRR and EWR for negative polarity machining

EWR reduced in both polarity machining. Figure 2 and 3 shows that the comparison of MRR and EWR for EDM machining at both positive and negative polarity by comparing the results exposed that from figure 5 represents excellent MRR was performed by using Cr coated Cu electrode than Cu electrode and it was taken more time to complete machining. EWR is best possible during polarity machining. During positive polarity, the MRR is more in 15wt%SiC with 5wt%Flyash and 10wt%Flyash components and EWR was obtained minimum when Cu and Cu-Cr electrode is used as tool electrode.

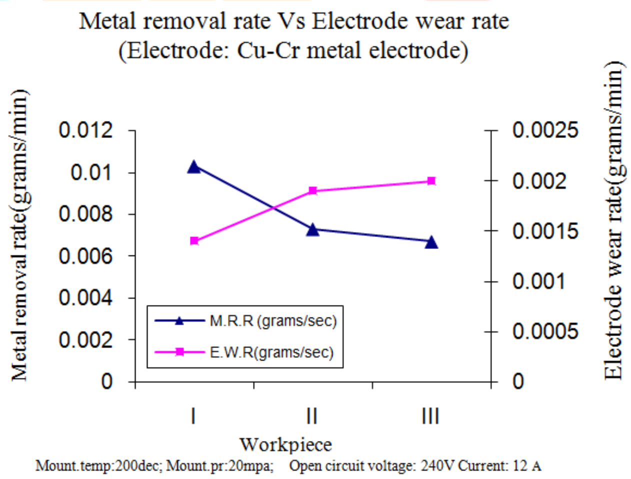



Figure 4. Variation in MRR and EWR for Cu electrode machining

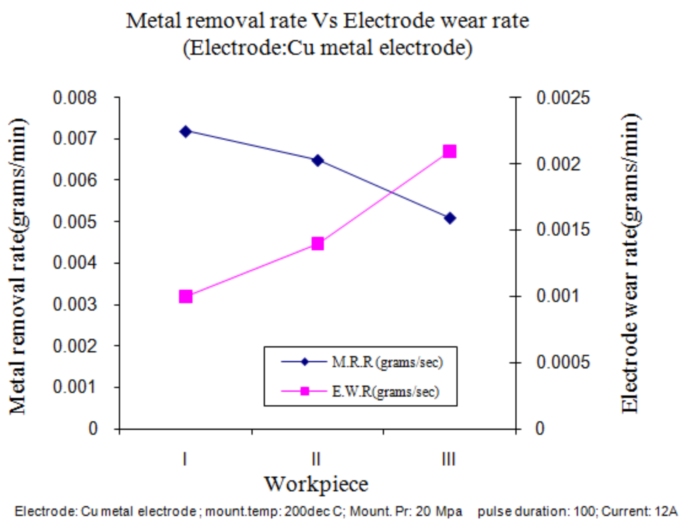
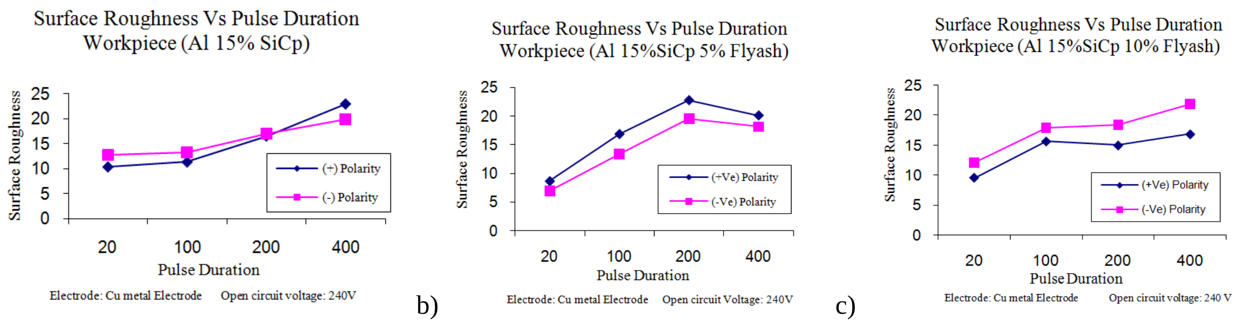



Figure 5. Variation in MRR and EWR for Cu electrode machining

For various pulse duration the machining was made on the three samples, thus the surface roughness is maintained well during the positive polarity as mentioned in figure 6. Here X axis represents pulse duration in microseconds and Y axis represents surface roughness $R_a$in microns. By comparing the negative polarity machining the SR is maintained poor for the increase of pulse duration. Thus the surface roughness was affected effectively by the increase of pulse duration between 20µs and 400µs.




a) b) c)

Figure 6. Relationship between surface roughness and different pulse duration of

a) Al-15%SiCp b) Al-15%SiCp5%Flyash c) Al-15%SiCp10%Flyash

Maintaining the working time of machining is an important criterion. Identification of this is referred as maximum process time was attained during positive polarity, at the same time random process time was happened during negative polarity machining.

## 4. Abbreviations

HMMC – Hybrid Metal Matrix Composite.
EDM – Electrical Discharge Machining (Unconventional Non-contact machining process)
MRR – Material Removal Rate [cutting speed ($V_c$) x width of cut (b) x Thickness (t)]
EWR – Electrode Wear Rate [Tool mass loss/Machining time]
SR – Surface Roughness ($R_a$)
PVD – Physical Vapour Deposition [Deposition of thin film with high purity]

## 5. Conclusion

Thus the performance and characteristics of each samples were evaluated through EDM fabrication by using different electrodes. Performance of different electrodes influences on surface condition of various hybrid MMC structures was evaluated through EDM. Considerable machining characteristics also examined and verified.

- The MRR is obtained higher during positive polarity machining but in negative polarity MRR is minimum for the specimen which is having 5wt% and 10 wt% Fly ash. Similarly, EWR is maximum during the machining of sample II and III as mentioned in figure 2, the reason behind this is nothing but more hardness is attained by the addition of SiC and Fly ash particles. Porosities also avoided by the deposition of fly ash distribution.

- Better machining performance by Cu-Cr electrode was obtained. Corrosion resistance also improved with the fine percentage of Cr coatings. So the composite electrodes were used to improve the corrosion resistance on the surface of the specimen. Excellent MRR is achieved by the machining of Cu-Cr electrode and optimum EWR is obtained. During positive polarity, the MRR is more in 15wt%SiC with 5wt%Flyash and 10wt%Flyash components and EWR was obtained minimum when Cu and Cu-Cr electrode is used as tool electrode.

- The tests were revealed that the Surface Roughness value is maintained good during the positive polarity machining by the addition of Fly ash. This will provide good results of Surface roughness compare with other samples. Furthermore, the changes in pulse duration will cause some variations in the surface roughness. The values of Surface roughness become poor when the negative polarity machining due to the increase of pulse duration. Alternatively, for the sample II the surface roughness becomes poor during the positive polarity machining.

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