Multi -Response optimization of Electric Discharge Machining (EDM) process parameter for Aluminum based Hybrid Metal Matrix Composite using GRA

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Abstract Aluminum based hybrid metal composite (MMC) have been applied to many various applications in the area of automobiles and aerospace. This research article shows the multi-response optimization of EDM of process parameter for Aluminum based metal matrix hybrid composite (Aluminum 6061/Al2O3/TiO2). The optimum process parameter of EDM as like pulse on time (Ton), current (Ip), duty cycle (t), voltage (V) on material removal rate and surface roughness were investigated. Hybrid Aluminum metal matrix composite was machined by using tool which is made of copper materials, of φ12 mm for experimentation. The mechanical stirring procedure is used to fabricate the hybrid MMC. The design of experiments was conduct through the Response Surface Methodology (RSM). The experimental result declares that the main influencing input parameter is current.

Key Words: EDM, Metal Matrix Composite, MRR, Surface roughness, GRA,

1. Introduction- In conventional machining process machining of MMCs is very difficult due to high tool wear rate, less production, poor economy of get accuracy from the new method of material removal which is different from conventional machining process as compared to non-traditional machining (NTM) processes as like EDM, ultrasonic machining (USM), Abrasive Jet Machining(AJM), Abrasive water jet machining (AWJM), Laser Beam Machining(LBM), from the above EDM is the most widely useable to machine MMCs, because these material are hard, high strength, temperature resistance and electric conductive material [1, 2]. V. Suresh et.al [3] attempt to fabricate the hybrid MMC using stir casting technique with Aluminum alloy (LM25) reinforced with graphite (Gr), boron carbide (B₄C) and analyze the machining parameter such as material removal rate, surface roughness, tool wear rate using wire EDM. The result shows that the most influencing input parameter is current, which affect directly on removal of material. The maximum removal of material is obtained from the combination of current 7, pulse duration 4μs, pulse of time 6μs and less influencing parameter for MRR is pulse duration and pulse off. M. Mastana et.al [4] investigate the machining parameter of EDM on aluminum alloy AA6063. The result shows that material removal rate of AA6063 increased with increases of pulse on time and pulse of time and decrease with duty factor and gap voltage. S. Manish et. al [5] investigated that machining parameter MRR, tool wear rate, radial overcut, flatness of Aluminum LM-6/SiC/B₄C hybrid composite fabricated by stir casting method and result show that the current is the most influencing parameter for affecting the multiple performance. K. Alip et.al [6] in this paper analyze the tribological and microstructure behavior of aluminum alloy reinforced with SiC/TiC hybrid metal MMC and result show that higher reinforcement content increases the microstructure of aluminum composite. Hardness increased with increment of reinforcement material and also wear rate of composite material increase with increase in load. Natryan et.al [7] optimization of hybrid metal matrix composite of aluminum AA606/SiC/Al₂O₃/SiC was done by using the squeeze casting method and Taguchi based method was used to analyze and optimize the process parameter. The optimized result shows that A2, B2, C2 such as load 20N (level), sliding
velocity 1m/s (level) and sliding distance 1200m (level) and respectively. K. Arun et al. [8] light weight as well as light weight is the most widely required property for the advance industries. Research is ongoing to address the difficulties identified in the growth of metal matrix composite. Yadv. R et al. [9] this paper shows main focus is on the tribological behaviour of aluminium based MMC fabricated by stir casting process. The result shows that mechanical properties increased with increment of reinforcement particle and improve hardness and reduce ductility and also in addition of silicon carbide in aluminium based MMCs increase in the hardness and strength and fly ash increase the wear rate of MMC, this paper show that very less research are done in the area of organic reinforcement.

2. Material and Method

2.1 Material

The AL6061 is used as a matrix material with feature of hardened alloy exhibits better mechanical and wear properties. It is most widely used alloy in area of automobile sector and also in aerospace [10]. It has included with high melting element which is magnesium and silicon. The chemical and mechanical properties of matrix and reinforced material are shown in Table 1 & Table 2. The reinforcement Al2O3 & TiO2 of the average particle size 20 μm respectively used in aluminum matrix composite. The cooper is most widely and appropriate material use for machining of aluminum-based metal matrix composite. Copper has better electrical and thermal properties which are fulfill the requirement of machining of composite material as well as for Electric Discharge Machining [11-12].

| Density (g/cm^3) | Strength (MPa) | Modulus (GPa) | Fracture Toughness (MPa)m^1/2 | Coefficient of thermal expansion |
|------------------|----------------|---------------|-------------------------------|-----------------------------|
|                  | 2.7            | 180           | 75                           | 30                          | 23.8                        |

Table 1.Mechanical Properties of Aluminum6061 [13]

| Density (g/cm^3) | Melting point (°C) | Boiling Point (°C) | Thermal conductivity(W/m.k) | Strength (MPa) |
|------------------|---------------------|--------------------|------------------------------|----------------|
| Al2O3            | 3.9                 | 2040               | 2977                         | 6.9            |
| TiO2             | 4.23                | 1843               | 2972                         | 20-30          |

Table 2. Properties of Al2O3 and TiO2 [14]

2.2 Fabrication of composite material using stir casting method

The work material was fabricated by stir casting method. The composition of fabricated specimen is equal weight for aluminum oxide (5%) and titanium oxide (5%) with metal matrix composite alloy AA6061(90%). The Aluminum 6061 was heated at 660 °C in muffle furnace to melt it completely [15]. The Al2O3 and TiO2 reinforced particle were preheated at 500 °C to reduce the
oxide on the surface. The preheated reinforcement particle was added in molten metal slowly and mixing performed through the mechanical stirrer approximate 10 to 20 minute to uniformly distribution of matrix [16]. Finally, the melted metal poured into the mould dimension of 75mm*55mm*10mm and left for cooling at room temperature and figure 1 (a) show the workpiece after machining. The experiment was performed on EDM (SMART-ZNC) powered with 3 phase servo stabilizers. There are 27 experiment runs were performed for machining of AL 6061 composite material.

![Figure 1](image1.png)

**Figure 1 (a) Workpiece after Machining**

2.3 Machining parameter and characteristics

| Process Parameter       | Low  | Level | High |
|-------------------------|------|-------|------|
| Pulse current (Ip)      | 4    | 6     | 8    |
| Voltage (V)             | 40   | 60    | 80   |
| Pulse on Time (Ton)     | 100  | 200   | 300  |
| Duty Cycle (t)          | 6    | 7     | 8    |

The machining parameter are taken as Pulse on time (Ton), current (Ip), voltage (V), duty cycle (t), So these are taken as low, medium, high level which is different. The machining output parameter is obtained in the form of MRR and surface characteristics. The MRR is calculated to take the weight of workpiece after machining and before machining, and the quality of surface is calculated by the roughness tester device Taylor and Hobson.

MRR calculated by given formula

\[
MRR = \frac{\text{Initial weight} - \text{Final weight}}{\text{Time}} \text{ gram/min} \quad (1)
\]

| S.No. | Current (Ip) | Voltage (V) | Ton (µm) | Duty cycle (t) | MRR gm/min | Ra (µm) |
|-------|--------------|-------------|----------|----------------|-------------|---------|
| 1     | 4            | 40          | 200      | 7              | 0.027       | 5.50    |
| 2     | 8            | 40          | 200      | 7              | 0.118       | 4.00    |
|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 3 | 4 | 80 | 200 | 7 | 0.026 | 6.30 |
| 4 | 8 | 80 | 200 | 7 | 0.094 | 4.40 |
| 5 | 6 | 60 | 100 | 6 | 0.086 | 6.40 |
| 6 | 6 | 60 | 300 | 6 | 0.051 | 3.90 |
| 7 | 6 | 60 | 100 | 8 | 0.078 | 6.90 |
| 8 | 6 | 60 | 300 | 8 | 0.057 | 7.00 |
| 9 | 4 | 60 | 200 | 6 | 0.029 | 6.80 |
| 10 | 8 | 60 | 200 | 6 | 0.133 | 4.60 |
| 11 | 4 | 60 | 200 | 8 | 0.027 | 6.30 |
| 12 | 8 | 60 | 200 | 8 | 0.118 | 8.40 |
| 13 | 6 | 40 | 100 | 7 | 0.076 | 7.10 |
| 14 | 6 | 80 | 100 | 7 | 0.075 | 6.60 |
| 15 | 6 | 40 | 300 | 7 | 0.047 | 7.50 |
| 16 | 6 | 80 | 300 | 7 | 0.037 | 7.90 |
| 17 | 4 | 60 | 100 | 7 | 0.053 | 5.60 |
| 18 | 8 | 60 | 100 | 7 | 0.158 | 7.80 |
| 19 | 4 | 60 | 300 | 7 | 0.016 | 5.20 |
| 20 | 8 | 60 | 300 | 7 | 0.086 | 10.60 |
| 21 | 6 | 40 | 200 | 6 | 0.071 | 7.70 |
| 22 | 6 | 80 | 200 | 6 | 0.054 | 10.00 |
| 23 | 6 | 40 | 200 | 8 | 0.079 | 7.20 |
| 24 | 6 | 80 | 200 | 8 | 0.070 | 8.60 |
| 25 | 6 | 60 | 200 | 7 | 0.077 | 6.80 |
| 26 | 6 | 60 | 200 | 7 | 0.088 | 8.40 |
| 27 | 6 | 60 | 200 | 7 | 0.069 | 10.40 |

2.4 Conduct of Experiment

Grey Relational Multi Response Optimization process is used to evaluate experiment. According to the L27 experiment from Response surface methodology, the experiment planned and performed. The following steps are used in grey relational analysis to obtain better value [17-19].

Normalization of MRR and TWR

(a) For smaller the better
\[ X_i(k) = \frac{\max X_i(k) - X_i(k)}{\max X_i(k) - \min X_i(k)} \]  

Where
\[ X_i(k) = \text{the value of quality characteristic after GR generation} \]
\[ \max X_i(k) = \text{maximum value of } X_i \]
\[ \text{min}X_i(k) = \text{minimum value of } X_i \]

(b) For higher the better
\[ X_i(k) = \frac{X_i(k) - \text{min}X_i(k)}{\text{max}X_i(k) - \text{min}X_i(k)} \]  \hspace{1cm} \text{(3)}

Deviation Sequence

Deviation sequence is defined as amount of each response which gains from reference.

\[ \Delta_{0i}(k) = X_0(k) - X_i(k) \]  \hspace{1cm} \text{(4)}

\[ \Delta_{0i}(k) = \text{deviation sequence} \]
\[ X_0(k) = \text{reference sequence } = 1 \]

Grey relational coefficient (GRC)

The grey relation coefficient is computed to reveal the relation between ideal and actual normalized experimental result.

\[ E_i(k) = \frac{\Delta_{\text{min}}(k) + \varepsilon \Delta_{\text{max}}(k)}{\Delta_{0i}(k) + \varepsilon \Delta_{\text{max}}(k)} \]  \hspace{1cm} \text{(5)}

Where

\[ \varepsilon = \text{distinguish coefficient } = 0.5 \text{ to give equal importance to all value.} \]
\[ \Delta_{\text{min}} = \text{the lower value of } \Delta_{0i}(k) \]
\[ \Delta_{\text{max}} = \text{the highest value of } \Delta_{0i}(k) \]

Grey relational grade (GRG)

\[ \gamma_i = \frac{1}{n} \sum_{k=1}^{n} E_i(k) \]  \hspace{1cm} \text{(6)}

Where

\[ n = \text{no. of response} \]
\[ k = \text{suggestion for response} \]

**Table 5. Normalization of MRR and SR**

| S.No. | MRR   | Ra    |
|-------|-------|-------|
| 1     | 0.080 | 0.761 |
| 2     | 0.719 | 0.985 |
| 3     | 0.070 | 0.642 |
| 4     | 0.547 | 0.925 |
| 5     | 0.490 | 0.627 |
| 6     | 0.246 | 1.000 |
| S.No. | MRR  | Ra   |
|------|------|------|
| 1    | 0.920| 0.239|
| 2    | 0.281| 0.015|
| 3    | 0.930| 0.358|
| 4    | 0.453| 0.075|
| 5    | 0.510| 0.373|
| 6    | 0.754| 0.000|
| 7    | 0.564| 0.448|
| 8    | 0.708| 0.463|
| 9    | 0.907| 0.433|
| 10   | 0.176| 0.104|
| 11   | 0.920| 0.358|
| 12   | 0.280| 0.672|
| 13   | 0.580| 0.478|

**Table 6. Deviation sequence for responses**
| S.No. | MRR  | Ra   |
|------|------|------|
| 14   | 0.582| 0.403|
| 15   | 0.779| 0.537|
| 16   | 0.853| 0.597|
| 17   | 0.740| 0.254|
| 18   | 0.000| 0.582|
| 19   | 1.000| 0.194|
| 20   | 0.509| 1.000|
| 21   | 0.611| 0.567|
| 22   | 0.730| 0.910|
| 23   | 0.554| 0.493|
| 24   | 0.620| 0.701|
| 25   | 0.571| 0.433|
| 26   | 0.492| 0.672|
| 27   | 0.627| 0.970|

Table 7. Grey Relational Coefficient (GRC) for response
| S.No. | Grey Relational Grade | Rank |
|-------|-----------------------|------|
| 1     | 0.514                 | 10   |
| 2     | 0.806                 | 1    |
| 3     | 0.466                 | 18   |
| 4     | 0.697                 | 5    |
| 5     | 0.534                 | 6    |
| 6     | 0.699                 | 4    |
| 7     | 0.499                 | 13   |
| 8     | 0.467                 | 17   |
| 9     | 0.446                 | 21   |
| 10    | 0.783                 | 2    |
| 11    | 0.467                 | 16   |
| 12    | 0.534                 | 7    |
| 13    | 0.487                 | 15   |
| 14    | 0.508                 | 11   |
| 15    | 0.437                 | 22   |
| 16    | 0.413                 | 25   |
| 17    | 0.533                 | 8    |
| 18    | 0.731                 | 3    |
| 19    | 0.527                 | 9    |
| 20    | 0.414                 | 24   |
| 21    | 0.459                 | 20   |
| 22    | 0.381                 | 27   |
| 23    | 0.489                 | 14   |
| 24    | 0.431                 | 23   |
| 25    | 0.501                 | 12   |
| 26    | 0.465                 | 19   |
| 27    | 0.392                 | 26   |

From above, Grey Relational Grade using L27 experiment shows that the maximum Grade presents the compatible experimental result is nearer to the ideal normalized value. So in this L27, experiment run no. 2 has the better multi performance feature because it has larger Grade.
3. Result and Discussion

Main Effect Plot for MRR

![Main Effects Plot for MRR](image)

**Figure 2.** Variation in MRR

From the above main effect plot graph for material removal rate are analyzes in respect of input parameter. At the initial stage for current 4Ip, the lower value of current shows the less quantity of material removed but in case of medium value of current at 6 Ip, the quantity of material removal increases as compare to the current 4. The higher value of current shows the higher material removal as comparison of current 4 and 6. From the above analysis of main effect plot graph the result shows that the, when the value of current increases then material removal rate is also increased and also decreased when current decreased. From the analysis of voltage, the result shows that the material removal rate increases between the 40V to 60V but after that the material removal rate decreases between the 60V to 80V, due to the formation of recast layer.

The above analysis is shows that maximum MRR is obtained at the value of 100µs. With the increases in pulse duration from the 100-300µs, the material removal decreased. The decrement in material removal take place may be due to higher pulse duration more material gets melt between tool and work material, so there is need proper flushing time for debris between tool and work material so arcing happen, this cause of decrement in material removal. The above analysis shows that maximum MRR is obtained at value 6 with increases of duty cycle MRR increases slightly from value at 7-8.

Main Effect plot for Surface Roughness

![Main Effects Plot for Ra](image)
From the above analysis, the surface roughness decreases when current decreases. But surface roughness increases from current value at 4-6Ip, and decreases when current increases from current value 6-8Ip. When the voltage decreases surface roughness also decreases, but slightly increases when voltage increases, minimum surface roughness obtained when pulse on time decreases but increasing in pulse on time the result shows slightly decrement in surface roughness from value 200-300µs. The effect of duty cycle shows that surface roughness is minimum when duty cycle decreases but surface roughness increases with increasing of duty cycle from value at 7-8

Mean calculation for grey relational grade (GRG)

From the table 9, it defines the information about mean of grey relational grade and it shows the difference between the higher and lower value which decided the rank of each level of machining parameter. The ranking of the process parameter gave the current is most influence parameter on output response and after that duty factor, pulse on time, voltage influence respectively.

| Parameter      | Level 1 | Level 2 | Level 3 | Max-Min | Rank |
|----------------|---------|---------|---------|---------|------|
| Current(Ip)    | 0.496   | 0.477   | 0.661   | 0.183   | 1    |
| Voltage (V)    | 0.532   | 0.533   | 0.499   | 0.033   | 4    |
| Duty Factor (t) | 0.550   | 0.526   | 0.481   | 0.069   | 2    |
| Ton (µs)       | 0.549   | 0.522   | 0.493   | 0.056   | 3    |

4. Conclusion

The stir casting method is very efficient and easy fabrication process to fabricate the hybrid metal matrix composite. In this work the experiment was performed by design of experiment L27 Box-Behnken method. Grey Relational Analysis is used to optimize the EDM process parameter for aluminium based hybrid metal matrix composite. According analysis of response table the current is most influence parameter as compared to other parameter and the combination of other. In this
In the present study, the main optimal input parameter was $I_p = 8$, voltage = 40, $T_{on} = 200$, and duty cycle = 7. Using a copper tool during the machining of aluminium-based hybrid metal matrix composite. The optimization of EDM parameters will save time in machining and improve surface roughness.

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