Optimization of EDM Process Parameters on Machining Characteristics of SiC and Graphene Reinforced Al 6061-T6nano-Composites

Saikiran Ammisetty1, *, Dhanunjaykumar Ammisetti2, K. Satyanarayana3, Suresh Chitturi4, N. Sunil Naik5
1JNTUA College of Engineering, Anantapur, INDIA
2, 5Lakireddy Bali Reddy College of Engineering, INDIA
3Vasireddy Venkatadri Institute of Technology, INDIA
4Vignan’s Institute of Engineering for Women
*Corresponding Author
‘dhanaammisetti@gmail.com

Abstract. Aluminum composites play an important role in various applications due to their low weight to strength ratio, high corrosive resistance, etc. As reinforcement materials, Graphene and SiC nano particles were used. Since, they have a high melting point, young modules, strong electrical and thermal properties etc. Electrical Discharge Machining (EDM) is one of the non-conventional machining techniques widely used for the machining of hard materials such as composites. The aim of current work is to evaluate the influence of EDM process parameters such as peak current, pulse on-time, voltage and flushing pressure on machining of Aluminium 6061 reinforced with 0.5 wt% SiC and 0.5 wt% Graphene nanoparticles. Al-based Metal Matrix Composite was casted by using liquid processing technique i.e. Stir Casting. Taguchi’s Design of Experiments was used to evaluate the effect of process parameters on machining characteristics i.e. Material Removal Rate (MRR) and Tool Wear Rate (TWR) of developed composite. From the results it was observed that peak current is the most influencing factor on MRR and TWR followed by other parameters.

Keywords: Electrical Discharge Machining, Metal Matrix Composite, Design of Experiments, Material Removal Rate, Tool Wear Rate

1. Introduction

Metal matrix composites are used in many fields due to their high specific strength, strong corrosion resistance and improved mechanical properties. Currently, industries are looking for light weight material with improved properties such as defence, automotive, sports, electronic, aerospace etc. For that AMMCs plays a major role due to its improved physical and mechanical properties. This improvement in properties was done because of reinforcement addition to the base material. Various types of reinforcements are available such as SiC, TiC, Al2O3, MoS2, B4C, TiB2, ZrO2, Graphite, Graphene, Carbon Nano Tubes, etc. Machining of this newly developed composite material viz. metal matrix composites, nano composites, and ceramic composites, found difficult by existing manufacturing industries / conventional machining processes [1]. Because it is hard and difficult to machine, reduces surface finish and accuracy and increased machining cost. To machine these outlandish composites non-conventional methods are preferable such as Electric Discharge Machining (EDM), Electro Chemical Machining (ECM) etc.[2,3]. In this, no direct contact between cathode and anode, no external pressure on work piece and dielectric fluid is used to dissipate the generated heat at sparking zone and to flush out the debris from the machining surfaces. Many authors reported their work on EDM of composites. N. Radhika et.al [5] developed the Aluminium hybrid metal matrix composite. They reported the impact of process parameters on MRR, TWR and SR by using Taguchi’s Design of Experiments. It states that SR was influenced by peak current, MRR was
influenced by flushing pressure and TWR was influenced by pulse on-time mostly. Sarivastava et al. [6] studied the machinability behavior of developed Al6063/SiC MMC using EDM. Developed composite shows improved mechanical properties. Machinability was enhanced by 37.5% at optimum condition of process parameters. B.C. Kandpal et al. [7] reported the optimization of process parameter of EDM of AMMCs. Optimization was done using Taguchi method in combination with S/N ration and ANOVA test. They found the MRR increase with increasing peak current and pulse on time but decreases with increasing duty factor. Optimum parameters for getting higher MRR are 14A, 200μs and 50%. K. G. Maniyaret al. [8] described the effect of process parameters, weight percentage of reinforcement on MRR, TWR and SR with the help of L27 orthogonal array and its significance on output responses was studied by ANOVA. The process parameters were designed to get maximum MRR and minimum TWR and SR. Contribution current for MRR was 83.5%, for SR was 70.22% when compared to other parameters. C. Karet al. [9] fabricated the aluminium - red mud reinforced MMCs by stir casting method and machined using EDM.

From the literature survey, it can be concluded that so much of research work was done on fabrication and machining of MMCs. However, there is a gap in the development of AMMCs with SiC/GNPs as reinforcement. In this work, influence of EDM process parameters such as flushing pressure, pulse on-time and peak current on MRR, TWR and Surface Roughness of SiC/GNPs reinforced AMMCs by DOE.

2. Materials and Method

Any composite material contains two different phases. One is called as matrix phase which acts as supporting material and the other is reinforcement phase which gives strength to the composite. In the present work Silicon Carbide (SiC) and Graphenemano particles were mixed with aluminium 6061 alloy.

2.1 Methodology

Initially AA6061 ingots were loaded in the electrical furnace assisted graphite crucible and melted at 800°C. After melting, to extract the trapped gases from the melt, 3 grams of C₂Cl₆ was added to the melt. Reinforcement in the respective proportions was mixed with 2 grams of Potassium hexaFluoroTitanate (K₂TiF₆) and then preheated in preheater die for 2 hours so that it is free from foreign particles, moisture content and also increases the wettability. K₂TiF₆ is called as flux powder or molten salts used for improving wettability between matrix and reinforcement materials. Later preheated reinforcement has mixed with the AA6061 melt in 4 steps while rotating the stirrer at 400 rpm. Addition of reinforcement in steps improves the distribution in the matrix and it leads to better properties. The stirrer has rotated for 10 min in the melt to get uniform distribution of reinforcement in the melt. After stirring the molten mixture was held in the furnace for 5 minutes to settle down the particles then it has poured into the preheated die. The developed casting was shown fig 1. From the developed casting 40*10*10(mm³) billets were prepared for EDM machining and shown in fig 2.
2.2 Design of Experiments

In any industry, high quality and high productivity is a challenging task. For that, Design of experiments (DOE) mainly used for generating effective combination of process parameters by reducing number of experiments. In this study, Taguchi based mathematical model with 27 experiments was developed to study the process parameter influence on machining characteristics. This is one of the best methods to create the mathematical model. From the literature, it was observed that the most effective parameters on machining characteristics are pulse on–time ($T_{on}$), flushing pressure ($P$), peak current ($I_p$) and voltage ($V$). The other parameters such as pulse off–time, duty factor, polarity and spark gap also influence EDM performance with less effect. $T_{on}$, $P$, $I_p$ and $V$ are taken as input variables. MRR and TWR are taken as output variables. The input variables and their levels are shown in Table 1. Based on machine capacity the level values are taken into consideration. In this work, $L_{29}$ orthogonal array is considered with 27 rows and 9 columns. In any optimization process number of experiments should be more to get accurate results.
Table 1: Machining parameters and Levels

| S.No | Parameters          | Symbol | Units | Level A | Level B | Level C |
|------|---------------------|--------|-------|---------|---------|---------|
| 1    | Pulse on-time       | $T_{on}$ | $\mu$s | 100     | 200     | 300     |
| 2    | Peak Current        | $I_p$   | A     | 10      | 20      | 30      |
| 3    | Voltage             | V       | V     | 40      | 50      | 60      |
| 4    | Flushing Pressure   | $P$     | kg/cm$^2$ | 0.3       | 0.5       | 0.7       |

For each parameter three levels of values are selected based on the minimum and maximum values of the parameters. MINITAB18 has used for generating the relation between parameters. This is specifically used for DOE applications. The interactions of input variables on output variables also investigated. After finding the MRR and TWR for each experiment, the entire data is converted to signal-to-noise (S/N) ratio. It is the ratio of the mean of the signal to the standard deviation of noise. Rank of input variables to be determined with this ratio. It contains 3 different quality characteristics, known as smaller the better, larger the better and nominal the best [10]. For TWR, smaller the better characteristic is suitable because tool life should be high in any machining process. But it is quite opposite in case of MRR where larger the better is considered.

Larger the better characteristics-

$$z = \frac{su(1)}{n} \times Log_{10}(\frac{n^2}{v^2}) .................. \text{Eq (1)}$$

Smaller the better characteristics-

$$s = \frac{su(1)}{n} \times Log_{10}(\frac{n^2}{v^2}) .................. \text{Eq (2)}$$

Analysis of Variance (ANOVA) is used to find the relative effect of one parameter on the other. To analyse the experimental data this statistical tool was used. The mean square of the result with deviation from sample mean was compared and given the optimized results i.e. minimum TWR and maximum MRR.

3. Experimental Setup:

ELECTRONICA-SMART ZNC kick the bucket sink EDM machine was utilized for experimentation on created Aluminium nano composite. Aluminium composite examples as appeared in fig. 2 were utilized as work-pieces with length, width and thickness being 10mm, 40mm, and 10 mm individually. Copper anode with 8 mm distance across is utilized as instrument material to make pockets on the aluminium billets. A few materials can be utilized as device materials however the vast majority of the scientists selected copper as apparatus material since it has high electrical conductivity and financially accessible. Dielectric liquid utilized in this examination is EDM Oil. The reason this oil is to chill off the created heat among apparatus and work-piece and to flush out the eliminated chips during machining. Morphology of machining zone and test arrangement was appeared in fig.3. The parametric arrangement with 4 components (input factors) and 3 levels (Level 1, 2 & 3) and their reactions are appeared in Table 2. Most importantly, step in EDM in the wake of turning on the force flexibly is setting the boundaries in the control board. The instrument will perform as indicated by the qualities entered in the control board. In the current work, 8 mm pockets with 3 mm profundity were made on the work piece surface.

The instrument moved opposite to the work surface for example in Z-heading. The device is empowered with servo instrument so it can keep up appropriate hole between the apparatus and work surface and return to the first situation after finish of machining. The machined work pieces are
indicated fig 4. To figure MRR and TWR both apparatus work-piece loads are estimated when machining then determined utilizing condition (3) and (4). This was rehashed for all examinations.

For experiments on the produced Aluminium matrix nano composite, the diesink EDM machine was used. Composite aluminium specimens, as shown in Fig. 2 were used as workpieces of 10 mm, 40 mm, and 10 mm in length, width and thickness. The copper electrode was used to manufacture pockets on the aluminium billets as a tool material. Many materials may be used as tool materials, but most researchers have chosen copper as a tool material because it has high electrical and economic conductivity. EDM Oil is the dielectric fluid used in this experiment. The purpose of this oil is to cool down the heat produced between the instrument and the work-piece and flush out the chips removed during machining. The parametric configuration with 4 factors (input variables) and 3 levels (Level A, B & C) and their responses are shown in Table 2. The parameters in the control panel are first and foremost set in EDM after switching on the power supply. The tool will work in compliance with the values entered on the control panel. 10 mm pockets with a depth of 5mm were formed on the work-piece surface in the present work.

The instrument shifted in the Z-direction perpendicular to the work surface. The tool is fitted with a servo mechanism so that it can maintain a correct distance between the tool and the work surface and return to the original location after machining is done. The machined work-pieces are shown in Figure 4. Both work-piece weights are measured before and after machining and then determined using equations (3) and (4) to calculate MRR and TWR. For all tests, this was replicated.

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MRR = \frac{I.W.W - F.W.W}{I.W.T - F.W.T} \left( \frac{gm}{hr} \right) \quad \text{Eq. (3)}
\]

\[
TWR = \frac{I.W.T - F.W.T}{I.W.W} \left( \frac{gm}{hr} \right) \quad \text{Eq. (4)}
\]

I.W.W - Initial Weight of Work-piece
F.W.W - Final Weight of Work-piece
I.W.T - Initial Weight of Tool
F.W.T - Final Weight of Tool

![Experimental setup of EDM machining](image_url)
4. Results and Discussions:
The influence of input variables on response was found out from the data generated by S/N ratio and ANOVA tools. All the responses for respective experimental conditions were shown in the table below:

| S. No | I  | T<sub>on</sub> | V  | P  | MRR | S/N for MRR | TWR  | S/N for TWR |
|-------|----|-------------|----|----|-----|-------------|------|-------------|
| 1     | 10 | 100        | 40 | 0.3| 5.9550 | 13.9008 | 0.1011 | 19.9050     |
| 2     | 10 | 100        | 50 | 0.5| 9.8301 | 18.9193 | 0.0949 | 21.4218     |
| 3     | 10 | 100        | 60 | 0.7| 9.7326 | 18.8228 | 0.2338 | 13.3998     |
| 4     | 10 | 200        | 50 | 0.3| 12.0117 | 20.8370 | 0.2652 | 11.2070     |
| 5     | 10 | 200        | 60 | 0.5| 10.8526 | 19.8710 | 0.1794 | 14.4524     |
| 6     | 10 | 200        | 40 | 0.7| 12.475 | 21.1950 | 0.1225 | 18.9769     |
| 7     | 10 | 300        | 60 | 0.3| 9.3835 | 18.4685 | 0.0986 | 20.1225     |
| 8     | 10 | 300        | 40 | 0.5| 9.3601 | 18.4442 | 0.1806 | 15.3604     |
| 9     | 10 | 300        | 50 | 0.7| 10.16 | 18.2338 | 0.09 | 21.9382     |
| 10    | 20 | 100        | 40 | 0.7| 12.6821 | 21.3504 | 0.0953 | 20.4181     |
| 11    | 20 | 100        | 50 | 0.3| 22.1204 | 26.8959 | 0.1301 | 17.7145     |
| 12    | 20 | 100        | 60 | 0.5| 19.4157 | 25.7631 | 0.2831 | 10.9612     |
| 13    | 20 | 200        | 50 | 0.7| 27.0869 | 28.3284 | 0.2086 | 13.6137     |
| 14    | 20 | 200        | 60 | 0.3| 23.95 | 27.2157 | 0.135 | 17.3933     |
| 15    | 20 | 200        | 40 | 0.5| 21.2 | 26.5267 | 0.24 | 12.3958     |
| 16    | 20 | 300        | 60 | 0.7| 23.6712 | 27.4844 | 0.2958 | 10.5800     |
| 17    | 20 | 300        | 40 | 0.3| 26.4705 | 28.4552 | 0.4294 | 5.5243      |
| 18    | 20 | 300        | 50 | 0.5| 27.44 | 28.1103 | 0.524 | 4.0963      |
| 19    | 30 | 100        | 40 | 0.5| 10.54 | 20 | 0.424 | 7.1309      |
| 20    | 30 | 100        | 50 | 0.7| 32.124 | 21.7556 | 0.212 | 10.1169     |
| 21    | 30 | 100        | 60 | 0.3| 29.5522 | 29.4118 | 1.3032 | -2.5628     |
| 22    | 30 | 200        | 50 | 0.5| 46.2857 | 33.3089 | 1.0142 | -0.9393     |
| 23    | 30 | 200        | 60 | 0.7| 40.1276 | 32.4913 | 0.4829 | 8.3383      |

Fig. 4: Work piece after machining
Effect of Machine Parameters on MRR

From the S/N ratios response table of MRR shown in Table 3, it is observed that peak current (I) is influencing more on MRR, followed by $T_{on}$, V and P.

Table 3: Response Table for S/Noise Ratios- MRR (Larger is better)

| Level | I (A) | P (kg/cm$^2$) | $T_{on}$ (μs) | V (V) |
|-------|-------|---------------|---------------|-------|
| 1     | 18.74 | 24.98         | 21.87         | 23.24 |
| 2     | 26.68 | 24.61         | 26.46         | 25.30 |
| 3     | 28.68 | 24.51         | 25.77         | 25.56 |
| Delta | 9.93  | 0.47          | 4.59          | 2.31  |
| Rank  | 1     | 4             | 2             | 3     |

From the MRR main effects plot shown in fig.5, it was observed that, MRR increases with improved current and voltage values. So, enhancement in I value causes the improvement in intensity of electric discharge. Whenever this high electric discharge pulses impinges on the work piece surface, the K.E. of pulses converts to heat energy. Owing to this, temperature increases at both tool and work piece surfaces and erosion of metal will happen by melting and evaporation and increases MRR. But increasing of flushing pressure reduces MRR. As at high pressure velocity is low. So, it will not flush out the debris from the tool and work surfaces. Clustering of debris takes place in the gap and reduces the MRR. MRR is directly proportional to $T_{on}$ in that sense MRR should increase with increased $T_{on}$. But in fig.5($T_{on}$) MRR increases and then decreases. From this it can be observed that MRR not only depends on $T_{on}$ but also requires certain I value to remove material on work surface. So, from the main effects plot for S/N ratios we can found the optimal machining conditions and those are I= 30 A, $P = 0.3$ kg/cm2, $T_{on} = 200$ μs and $V = 60$ V.
Main effects plot for MRR

4.2 Effect of Machine Parameters on TWR
Table 4 shows the rankings of process parameters on TWR. It is concluded that I is the most effecting factor followed by P, T\textsubscript{on} and V.

Table 4: Response Table for S/Noise Ratios-TWR (Smaller is better)

| Level | I (A)  | P (kg/cm\textsuperscript{2}) | T\textsubscript{on} (μs) | V (V)  |
|-------|--------|-------------------------------|--------------------------|--------|
| 1     | 17.419 | 10.127                        | 13.166                   | 12.639 |
| 2     | 12.520 | 10.235                        | 10.251                   | 11.251 |
| 3     | 5.052  | 14.629                        | 11.250                   | 11.101 |
| Delta | 12.367 | 4.502                         | 2.590                    | 1.538  |
| Rank  | 1      | 2                             | 3                        | 4      |

Main effects plot for TWR was shown in Fig.6, it can be noticed that TWR decreases linearly with the enhancement in I. Similarly, TWR decreases linearly by increasing voltage factor. Whereas by increasing flushing pressure TWR also increases. But in case of Ton, TWR decreases up to level 2 then it increases TWR. Optimum machining conditions were found from the main effects plot and those are I=30 A, T\textsubscript{on}=200 μs, P=0.3 kg/cm\textsuperscript{2} and V=60 V.

4.3 Analysis of Variance
The most significant factor which affects the output response was found by using ANOVA tool.

ANOVA for TWR

| Source | DF | Seq SS | Adj SS | Adj MS | F        | P       | Contribution |
|--------|----|--------|--------|--------|----------|---------|--------------|
| I      | 2  | 9.2543 | 9.2543 | 4.62715| 58.92    | 0.000   | 52.87%       |
### 4. Conclusion

Aluminium MMCs are fabricated successfully by means of stir casting process and machined on Electric Discharge Machine at predefined machining conditions. The main objective of this work is to evaluate the impact of process parameters on MRR and TWR. From this experimental study it is observed that Current (I) and Ton are the most influencing parameters on MRR of fabricated Al composites while in the case of TWR, current (I) and interaction of I and Ton are the most influencing factors. Optimal parameters for maximizing the MRR and minimizing the TWR are found.

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