Optimization of Al-SiC-MW CNT metal composite by W-EDM using Taguchi method

Dr. C. Parswajinan*1, Dr. B. Vijaya Ramnath2, Aiswarya V3, Aswini Subhatra M5, S. Rajesh5, J. Sriram6

*1 Asst. Prof., Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai – 600 044.
2 Asst. Prof., Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai – 600 044.
3,4,5,6 Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai – 600 044.

*parswajinan@gmail.com

Abstract. EDM process is primarily used in machining of Al6061 metal matrix composite reinforced with silicon carbide (SiC) and carbon nano-tube (CNT). This process can be used to measure the Metal Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) of the work piece material. Using Taguchi’s parameter design, significant machining parameters affecting the performance of the process such as discharge current, pulse ON time and duty cycle are the input parameters. The performance measure for each combination of the parameters has been taken. In this work, the MRR, TWR and SR for each combination have been estimated. The results obtained are tabulated. The study demonstrates that the EDM process parameters can be adjusted to do better MRR, TWR and SR by optimizing the parameters using grey relational analysis (GRA).

1. Introduction

Nowadays, Electrical Discharge Machining (EDM) has been tremendously improving to meet the requirements in various manufacturing fields. It is a thermo electrical process in which the material is eroded from the workpiece by electric sparks between the workpiece and the electrode separated by a thin film of dielectric fluid, which is continuously fed to the machining zone to flush away the eroded particles. Several theories are proposed to explain the principle of EDM. The thermo-mechanical theory suggests that material removal in EDM operation is attributed to melting of material caused by flame jets that are formed as a result of various electrical effects of discharge. Thermo-electric theory suggests that the material removal in EDM operations take place as a result of generation of extremely high temperature due to the high intensity of discharge current. In EDM, it is mandatory to select machining parameters for achieving optimal machining performance. Usually, they are determined based on experience or handbook values. However, this does not ensure that this will result in optimal machining parameters due to the environment of machining or other parameters. To solve this issue, Taguchi method is used to determine the optimal machining parameters in the electrical discharge machining process. The Taguchi method optimizes the performance characteristics through the setting of process parameters.
parameters and reducing the sensitivity of the system performance to sources of variation. As a result, the Taguchi method has become a powerful tool in the design of experiment methods. However, most published Taguchi applications to date have been concerned with the optimization of a single performance characteristic.

Jeykrishnan et al. [1 and 2] have done experiments on machining EN24 tool steel and D2 die steel by varying the parameters such as applied current, pulse on time and pulse off time in optimizing the MRR and TWR by employing Taguchi techniques and have concluded that the applied current plays a significant role in obtaining the best output characteristics. Vijaya Ramnath et al. [3] have done trials on drilling the fibre hybrid composites and have optimized the parameters using grey relational analysis (GRA) in obtaining the best output parameters. It is observed that composites reinforced with CNT showed improved mechanical properties [4] like strength and can be used as a better reinforcement for iron [5]. Vijaya Ramnath et al. inferred that increase in aluminium content increases the tensile strength [6]. Addition of CNT increases the compressive strength [7] but not hardness [8]. Mechanical properties are improved in reinforced iron compared to unreinforced iron [9]. Suresh rajan et al. [10] have employed EDM for machining inconel 825 alloys and have optimized the process parameters by using Taguchi techniques in-order to obtain the better surface roughness and have concluded that the pulse on time plays a significant role in getting the best output response. Akilesh et al. [11 and 12] have done electro-chemical machining on SKD-12 tool steel and D3 die steels and have optimized the process parameters using Taguchi techniques and have concluded that MRR and SR can be increased by varying the applied current, voltage and electrolyte concentration.

2. EDM PROCESS

This is the process used to remove metal from workpiece due to spark erosion. The input parameters such as pulse-on time, polarity, discharge current, dielectric fluid etc., which influences mostly the performance of machining process. Hence better machining performance in the EDM process can be achieved by proper selection of the machining parameters.

2.1 Selection of machining parameters

In this process, EDM machine (KT-200) was used for experimental purpose. In this method, the electrode is used as pure copper electrode with cylindrical cross section of diameter 14 mm is used for metal removal from workpiece. Here kerosene is used as dielectric medium. In this experiments, additive (aluminium powder or aluminium oxide powder) to the dielectric fluid (kerosene) is incorporated to mobilize the machining characteristics. The following machining parameters are taken into consideration such as pulse-on Current (A), time (T), and Duty Factor (DF).

2.2 Machining performance evaluation

Machining performance evaluation parameters can be calculated by using the following expression. EWR is defined as the ratio of Electrode Wear Weight (EWW) to Workpiece Removal Weight (WRW). It is usually expressed in percentage,

\[
\text{EWR (g/min)} = (\text{EWW} / \text{WRW}) \times 100
\]

MRR is the ratio of WRW to a period of machining time in minutes (T),

\[
\text{MRR (g/min)} = \text{WRW} / T
\]

By observing from the readings, the machining time for each workpiece can be optimized for 5 minutes. It is observed that, lower the TWR, better the machining performance. Higher the MRR, better the machining performance. Hence, EWR is lower the-better performance characteristic and MRR is higher-the-better performance characteristic.

2.3 Grey Relational Analysis (GRA)

The steps followed in Grey relational analysis were:
i. The input characteristics have been normalized for all the experimental trials;
ii. The Grey relational coefficient (GRC) have been generated;
iii. Upon taking the average of GRC, Grey relational grade (GRG) have been found out;
iv. To determine the significance of each parameter, Analysis of variance (ANOVA) has been incorporated along with GRG.
v. Optimum process parameters have been selected.

3. RESULTS AND DISCUSSION

The experimental layout for L16 orthogonal array (OA) has been given in Table- 3. 1 a and b.

Table - 3. 1 a. Experimental layout for L16 OA

| MRR   | S/N Ratio | TWR  | S/N Ratio | SR |
|-------|-----------|------|-----------|----|
| 0.226 | 12.9178   | 0.08 | 41.9382   | 3.91|
| 0.244 | 12.2522   | 0.009| 40.91515  | 3.94|
| 0.302 | -10.4     | 0.002| 53.9794   | 4.02|
| 0.192 | -14.334   | 0.002| 53.9794   | 4.06|
| 0.2   | -13.9794  | 0.003| 50.45757  | 4.15|
| 0.226 | -12.9178  | 0.004| 47.9588   | 4.16|
| 0.245 | -12.2167  | 0.042| 27.53501  | 4.25|
| 0.215 | -13.3512  | 0.051| 25.8486   | 4.06|
| 0.226 | -12.9178  | 0.052| 25.67993  | 4.08|
| 0.236 | -12.5418  | 0.052| 25.67993  | 3.95|
| 0.249 | -12.076   | 0.054| 25.35212  | 3.84|
| 0.236 | -12.5418  | 0.055| 25.19275  | 3.74|
| 0.246 | -12.1813  | 0.056| 25.03624  | 3.64|
| 0.251 | -12.0065  | 0.058| 24.73144  | 3.85|
| 0.259 | -11.734   | 0.059| 24.58296  | 3.95|

Table - 3. 1 b. Experimental layout for L16 OA

| S/N Ratio | GRC | GRG | Dev Seq | GRG | GRG | Rank |
|-----------|-----|-----|---------|-----|-----|------|
| -11.7092  | 0.00| 0.79| 0.66    | 0.00| 0.79| 0.66 | 1.00| 0.21| 0.34| 0.33| 0.70| 0.59| 0.52| 9    |
| -11.8455  | 0.58| 0.89| 0.56    | 0.58| 0.89| 0.56 | 0.42| 0.11| 0.44| 0.54| 0.83| 0.53| 0.62| 3    |
| -11.9099  | 0.68| 0.88| 0.51    | 0.68| 0.88| 0.51 | 0.32| 0.12| 0.49| 0.61| 0.80| 0.50| 0.62| 4    |
| -12.0845  | 1.00| 1.00| 0.38    | 1.00| 1.00| 0.38 | 0.00| 0.00| 0.62| 1.00| 1.00| 0.45| 0.81| 1    |
| -12.1705  | 0.39| 1.00| 0.31    | 0.39| 1.00| 0.31 | 0.61| 0.00| 0.69| 0.45| 1.00| 0.42| 0.61| 5    |
| -12.361   | 0.43| 0.98| 0.16    | 0.43| 0.98| 0.16 | 0.57| 0.02| 0.84| 0.47| 0.97| 0.37| 0.60| 6    |
| -12.3819  | 0.58| 0.96| 0.15    | 0.58| 0.96| 0.15 | 0.42| 0.04| 0.85| 0.54| 0.93| 0.37| 0.60| 7    |
| -12.5678  | 0.68| 0.80| 0.00    | 0.68| 0.80| 0.00 | 0.32| 0.70| 1.00| 0.61| 0.42| 0.33| 0.48| 13   |
| -12.705   | 0.52| 0.14| 0.31    | 0.52| 0.14| 0.31 | 0.48| 0.86| 0.69| 0.51| 0.37| 0.42| 0.43| 15   |
| -12.2132  | 0.58| 0.12| 0.28    | 0.58| 0.12| 0.28 | 0.42| 0.88| 0.72| 0.54| 0.36| 0.41| 0.47| 14   |
| -11.9319  | 0.63| 0.12| 0.49    | 0.63| 0.12| 0.49 | 0.37| 0.88| 0.51| 0.58| 0.36| 0.50| 0.51| 11   |
| -11.6866  | 0.71| 0.09| 0.67    | 0.71| 0.09| 0.67 | 0.29| 0.91| 0.33| 0.63| 0.35| 0.60| 0.58| 8    |
| -11.4754  | 0.63| 0.07| 0.84    | 0.63| 0.07| 0.84 | 0.37| 0.93| 0.16| 0.58| 0.35| 0.75| 0.64| 2    |
| -11.222   | 0.69| 0.05| 1.00    | 0.69| 0.05| 1.00 | 0.31| 0.95| 0.00| 0.62| 0.35| 1.00| 0.52| 10   |
| -11.7092  | 0.72| 0.02| 0.66    | 0.72| 0.02| 0.66 | 0.28| 0.98| 0.34| 0.64| 0.34| 0.59| 0.49| 12   |
| -11.9319  | 0.76| 0.00| 0.49    | 0.76| 0.00| 0.49 | 0.24| 1.00| 0.51| 0.68| 0.33| 0.50| 0.34| 16   |

3.1 Effects of process parameters on MRR

The MRR increases, when the parameters such as Ton, current and the duty factor increases. This is mainly due to the fact that the more pulse on time and current results in increased machining exposure time, thereby more material gets removed. The Di-electric Current plays a vital role in MRR followed by duty factor and pulse on time. The response table and the ANOVA table for MRR have been given in Table 3.2 and 3.3. The S/N ratio graph for MRR has been given in Fig. 3.1.
### Table 3.2. Response table for MRR

| Level | Ton  | Curr  | DF  |
|-------|------|-------|-----|
| 1     | -11.89 | -11.88 | -11.98 |
| 2     | -12.37 | -11.91 | -11.85 |
| 3     | -12.00 | -11.98 | -11.97 |
| 4     | -11.58 | -12.07 | -12.03 |

Delta | 0.79 | 0.19 | 0.18 |

Rank | 1 | 2 | 3 |

### Table 3.3. ANOVA Table for MRR

| Ton  | Curr  | DF  | MRR  | SNRA1  |
|------|-------|-----|------|--------|
| 100  | 15    | 5   | 0.122 | -18.2728 |
| 100  | 18    | 6   | 0.226 | -12.9178 |
| 100  | 21    | 7   | 0.244 | -12.2522 |
| 100  | 24    | 8   | 0.302 | -10.3999 |
| 200  | 15    | 6   | 0.192 | -14.334 |
| 200  | 18    | 5   | 0.2   | -13.9794 |
| 200  | 21    | 8   | 0.226 | -12.9178 |
| 200  | 24    | 7   | 0.245 | -12.2167 |
| 300  | 15    | 7   | 0.215 | -13.3512 |
| 300  | 21    | 5   | 0.236 | -12.5418 |
| 300  | 24    | 6   | 0.249 | -12.076 |
| 400  | 15    | 8   | 0.236 | -12.5418 |
| 400  | 18    | 7   | 0.246 | -12.1813 |
| 400  | 21    | 6   | 0.251 | -12.0065 |
| 400  | 24    | 5   | 0.259 | -11.734 |

### 3.2 Effects of process parameters on TWR

![Fig. 2. S/N Ratio graph for TWR](image_url)

**Fig. 2. S/N Ratio graph for TWR**
The TWR decreases when the Ton, current and SR increases, as this happens due to the fact that the drop-in pressure makes the molecules to move towards the positively charged material, instead of cathode.

Pulse on Time plays an important role in determining the TWR followed by duty factor and current. The ANOVA table for TWR and Response Table for SR has been given in Table 3.4. The S/N ratio graph for TWR is given in Fig. 2.

Table -3.4. ANOVA for TWR and Response table for SR

| T<sub>n</sub> | Cur | DOF | TWR | S/N Ratio | SR | S/N Ratio |
|----------|-----|-----|-----|-----------|----|-----------|
| 100      | 15  | 5   | 0.014 | 37.0774  | 3.85 | -11.7092 |
| 100      | 18  | 6   | 0.008 | 41.9382  | 3.91 | -11.8435 |
| 100      | 21  | 7   | 0.009 | 40.9151  | 3.94 | -11.9099 |
| 100      | 24  | 8   | 0.002 | 53.9794  | 4.02 | -12.0845 |
| 200      | 15  | 6   | 0.002 | 53.9794  | 4.06 | -12.1705 |
| 200      | 18  | 5   | 0.003 | 50.4576  | 4.15 | -12.361 |
| 200      | 21  | 8   | 0.004 | 47.9588  | 4.16 | -12.3819 |
| 200      | 24  | 7   | 0.024 | 72.5355  | 4.25 | -12.5678 |
| 300      | 15  | 7   | 0.051 | 25.8486  | 4.06 | -12.1705 |
| 300      | 18  | 8   | 0.052 | 25.6799  | 4.08 | -12.2132 |
| 300      | 21  | 5   | 0.052 | 25.6799  | 3.95 | -11.9319 |
| 300      | 24  | 6   | 0.054 | 25.3521  | 3.84 | -11.6866 |
| 400      | 15  | 8   | 0.055 | 25.1927  | 3.74 | -11.4574 |
| 400      | 18  | 7   | 0.056 | 25.0362  | 3.64 | -11.222 |
| 400      | 21  | 6   | 0.058 | 24.7314  | 3.85 | -11.7092 |
| 400      | 24  | 5   | 0.059 | 24.583   | 3.95 | -11.9319 |

3.3 Effects of process parameters on SR

The surface roughness (SR) decreases, when the process parameters such as Ton, current and SR increases. This is due to the fact that the electrons emerge in the gap between the tool and the workpiece, thereby making the pressure to drop; as a result, the energy gathered between the tool and the workpiece increases. This helps in getting better SR.

![Fig. 3. S/N ratio Graph for SR](image)

The pulse on time plays an important role in obtaining better SR, followed by the current and the DF. The response table and the ANOVA table for SR have been given in Table 3.5. The S/N ratio graph for SR has been given in Fig. 3.

Table- 3.5 ANOVA table for SR

| MRR | TWR | SR | GRG | Dev Seq | GRG | GRG | Rank |
|-----|-----|----|-----|---------|-----|-----|------|
| 0.122 | 0.014 | 3.85 | 0.79 | 0.66 | 1.00 | 0.21 | 0.34 | 0.33 | 0.70 | 0.59 | 0.52 | 9 |
| 0.226 | 0.008 | 3.91 | 0.58 | 0.89 | 0.56 | 0.42 | 0.11 | 0.44 | 0.54 | 0.83 | 0.53 | 0.62 | 3 |
| 0.244 | 0.009 | 3.94 | 0.68 | 0.88 | 0.51 | 0.32 | 0.12 | 0.49 | 0.61 | 0.80 | 0.50 | 0.62 | 4 |
| 0.302 | 0.002 | 4.02 | 1.00 | 1.00 | 0.38 | 0.00 | 0.00 | 0.62 | 1.00 | 1.00 | 0.45 | 0.81 | 1 |
| 0.192 | 0.002 | 4.06 | 0.39 | 1.00 | 0.31 | 0.61 | 0.00 | 0.69 | 0.45 | 1.00 | 0.42 | 0.61 | 5 |
| 0.2   | 0.003 | 4.15 | 0.43 | 0.98 | 0.16 | 0.57 | 0.02 | 0.84 | 0.47 | 0.97 | 0.37 | 0.60 | 6 |
| 0.226 | 0.004 | 4.16 | 0.58 | 0.96 | 0.15 | 0.42 | 0.04 | 0.85 | 0.54 | 0.93 | 0.37 | 0.60 | 7 |
| 0.245 | 0.042 | 4.25 | 0.68 | 0.30 | 0.00 | 0.32 | 0.70 | 1.00 | 0.61 | 0.42 | 0.33 | 0.48 | 13 |
| 0.215 | 0.051 | 4.06 | 0.52 | 0.14 | 0.31 | 0.48 | 0.86 | 0.69 | 0.51 | 0.37 | 0.42 | 0.43 | 15 |
| 0.226 | 0.052 | 4.08 | 0.58 | 0.12 | 0.28 | 0.42 | 0.88 | 0.72 | 0.54 | 0.36 | 0.41 | 0.47 | 14 |
| 0.236 | 0.052 | 3.95 | 0.63 | 0.12 | 0.49 | 0.37 | 0.88 | 0.51 | 0.58 | 0.36 | 0.50 | 0.51 | 11 |
| 0.249 | 0.054 | 3.84 | 0.71 | 0.09 | 0.67 | 0.29 | 0.91 | 0.33 | 0.63 | 0.35 | 0.60 | 0.58 | 8 |
| 0.236 | 0.055 | 3.74 | 0.63 | 0.07 | 0.84 | 0.37 | 0.93 | 0.16 | 0.58 | 0.35 | 0.75 | 0.64 | 2 |
| 0.246 | 0.056 | 3.64 | 0.69 | 0.05 | 1.00 | 0.31 | 0.95 | 0.00 | 0.62 | 0.35 | 1.00 | 0.52 | 10 |
| 0.251 | 0.058 | 3.85 | 0.72 | 0.02 | 0.66 | 0.28 | 0.98 | 0.34 | 0.64 | 0.34 | 0.59 | 0.49 | 12 |
| 0.259 | 0.059 | 3.95 | 0.76 | 0.00 | 0.49 | 0.24 | 1.00 | 0.51 | 0.68 | 0.33 | 0.50 | 0.34 | 16 |
4. CONCLUSION

From various observations from the experiments, the following points can be concluded. The performance characteristics of MRR, TWR and SR is significantly improved through this research work. This research has been studied and optimized the parameters for enhancing the performance machining characteristics of EDM process. From this research work the optimized results are found that MRR, TWR and SR were 0.302 g/mm$^3$, 0.002 g/mm$^3$ and 4.02 µm, respectively.

REFERENCE
1. J. Jeykrishnan, B. Vijaya Ramnath, S. Akilesh, R. P. Pradeep Kumar, “Optimization of process parameters on EN24 tool steel using Taguchi technique in electro-discharge machining”, Materials science and Engineering, 2016, Vol. 149, pp. 01022.
2. J. Jeykrishnan, B. Vijaya Ramnath, A. Jude Felix, C. Rupan Pernesh, S. Kalaiyarasan, “Parameter optimization of electro-discharge machining (EDM) in AISI D2 die steel using Taguchi technique”, Indian journal of science and technology, Vol. 9, Issue: 43, 2016.
3. B. Vijaya Ramnath, S. Sharavanan, J. Jeykrishnan, “Optimization of process parameters in drilling of fibre hybrid composite using Taguchi and grey relational analysis”, Materials science and Engineering, 2017, Vol. 183, pp. 012003.
4. B. Vijaya Ramnath, C. Parswajinan, C. Elanchezhian, S. V. Pragadeesh, P. R. Ramkishore, V. Sabarish, “A Review on CNT Reinforced Aluminium and Magnesium Matrix Composites”, Applied Mechanics and Materials, 2014, Vol. 591, pp. 120-123.
5. C. Parswajinan, B. Vijaya Ramnath, M. Vetrivel, P. Ramanarayanan, S. Bharath, T. Ajay, R. Raghav Chander, “A Review on Composite Materials with Ferrous, CNT and Powder Metallurgy”, Applied Mechanics and Materials, 2015, Vol. 813-814, pp. 9-13.
6. B. Vijaya Ramnath, C. Elanchezhian, M. Jaivignesh, S. Rajesh, C. Parswajinan, A. Siddique Ahmed Ghias, “Evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites”, Materials and Design, 2014, Vol. 58, pp. 332–338.
7. C. Parswajinan, B. Vijaya Ramnath, M. Vetrivel, C. Elanchezhian, K. Loganathan, R. Sarvesh, C. Rohit Prasanna, R. N. Karthik Babu , “Experimental Investigation of Mechanical and Chemical Properties of Aluminium reinforced with MWCNT”, Applied Mechanics and Materials, 2015, Vol. 766-767, pp 287-292.
8. B. Vijaya Ramnath, C. Parswajinan, C. Elanchezhian, S. V. Pragadeesh, C. Kavin, P. R. Ramkishore, V. Sabarish, “Experimental Investigation on Compression and Chemical Properties of Aluminium Nano Composite”, Applied Mechanics and Materials, 2014, Vol. 680, pp. 7-10.
9. C. Parswajinan, B. Vijaya Ramnath, C. Elanchezhian, S. V. Pragadeesh, P. R. Ramkishore, V. Sabarish , “Investigation on Mechanical Properties of Nano Ferrous Composite”, Procedia Engineering, 2014, Vol. 97, PP. 513 – 521.
10. J. Jeykrishnan, B. Vijaya Ramnath, G. Sureshrajan, M. Siva Bharath, X. HervinSavariraj, S. Akilesh, “Effects of die-sinking electro-discharge machining on surface roughness in inconel 825 alloy”, Indian journal of science and technology, Vol. 9, Issue: 41, 2016.
11. J. Jeykrishnan, B. Vijaya Ramnath, C. Elanchezhian, S. Akilesh, “Parametric analysis on Electro-chemical machining of SKD-12 tool steel”, Materials today: Proceedings, 2017, Vol. 4(2(A)), pp. 3760-3766.
12. J. Jeykrishnan, B. Vijaya Ramnath, C. Elanchezhian, S. Akilesh, “Optimization of process parameters in electro-chemical machining (ECM) of D3 die steels using Taguchi technique”, Materials today: Proceedings, 2017, Vol. 4(8), pp. 7844-7891.