

# AN INTEGRATED GRA-RSM METHOD TO EDM PARAMETER PERFORMANCE STUDY ON SILICON NITRIDE-TITANIUM NITRIDE COMPOSITE FOR INCREASING GEOMETRICAL TOLERANCES

Dineshkumar P<sup>1</sup>, Krishnan K<sup>2</sup>, Sathish A<sup>3</sup>

<sup>1</sup>Assistant Professor, Department of Mechanical Engineering, Mahendra Engineering College, Namakkal, Tamilnadu, India.

<sup>2,3,4</sup>UG Students, Department of Mechanical Engineering, Mahendra Engineering College, Namakkal, Tamilnadu, India.

## ABSTRACT

In today's world, ceramic composites are being refined for more than just their enhanced hardness and strength. They may also be used to create geometries that are notoriously tough to process, making them suitable for Electrical Discharge Machining. With multi-response elements like material removal rate, electrode wear rate, and geometrical errors, sparking parameters like current (I), pulse on time (Tonne), pulse off time (Toff), and dielectric flushing pressure (P) are upgraded. Machine time was reduced from 12.517 to 10.121 minutes, material removal rate was increased from 0.0183 to 0.0215 g/min, electrode wear rate was decreased from 0.0024 to 0.0002 g/min, circularity was decreased from 0.175 mm to 0.098 mm, cylindricality was decreased from 0.761 to 0.541 mm, and perpendicularity was decreased from 1.071 to 0.085 mm, according to the outcome of the confirmation experiments. After the data was optimised to its maximum potential, the grey relational grade was raised to 0.16464. As a result, using grey relational analysis to optimise Spark Electrical Discharge Machining settings for different performance factors appears to be a successful use of experimental results.

**Keywords:** EDM; pulse on time; pulse off time; GRA; ANOVA; SEM

## 1. INTRODUCTION

The challenge of reducing the size of mechanical components with complicated forms is of paramount importance in emerging applications. Ceramics have a substantial and established market in industrial settings, particularly for metal forming, machining, and wear applications (Philip, Mathew, and Kuriachen 2021; Ahmad and Sueyoshi 2010). Traditional powder metallurgy is used to make most ceramics, and post-sintering machining is needed for around 60% of the components. (Lee and Lau 1991; Yan-Cherng Lin et al. 2009). Assuming they have a high enough electrical conductivity, these hard materials can be milled by EDM (Lin et al. 2009). The capacity to machine precisely and the ease with which EDM can carve complicated patterns are its main selling points. (Rajavel et al. 2021; Selvarajan et al. 2020). If you're looking for a ceramic composite with outstanding mechanical, thermal, and tribological qualities, go no further than silicon nitride (Si<sub>3</sub>N<sub>4</sub>). But regular mechanical machining methods have a hard time making them. It might be possible to utilise EDM to make intricate forms out of materials that conduct electricity. "Petrovic" from 1995. A number of difficulties and restrictions may arise while machining conductive ceramic composites. Cutting tools crafted from diamond or CBN, which are very hard, are frequently required, which can drive up expenses (Selvarajan, Narayanan, and JeyaPaul 2016; Selvarajan, and Venkatramanan 2023a). Additionally, conductive ceramic composites are more likely to shatter during machining processes due to their brittleness. They can be difficult to cut with consistently because to their high heat conductivity (Selvarajan, Narayanan, and Jeyapaul 2014a; Alfattani et al. 2023). Their characteristics can be changed by chemical processes that occur during machining. Additionally, their hardness and brittleness make it difficult to achieve very precise machining. According to Selvarajan et al. (2023a) and Selvarajan, Narayanan, and Jeyapaul (2014b), these constraints can restrict the complexity and precision of the components that can be manufactured, which in turn increases manufacturing costs. In order to conquer these obstacles, producers might employ cutting-edge machining processes, specialised tools, and CAD/CAM software to optimise tool paths (Selvarajan et al. 2023a).

Ideal for electrical discharge machining are ceramic composites with high conductivity. Research by Srinivasan et al. (2022) and Srinivasan, Palani, and Balamurugan (2021) has shown that conductive composites may be made using a range of unconventional methods. According to the study, conductive composites are finding more and more uses (Muttamara et al. 2003). Furthermore, EDM parameters are evaluated for significance using Taguchi grey relational analyses (TGRA) (Somani, Tyagi, and Kimar 2021).

Investigated the effect of electrical discharge machining (EDM) settings on a Si<sub>3</sub>N<sub>4</sub>-TiN ceramic composite by use of a tapered copper electrode. Citations: (Murugan, Sathesh Kumar, and Alagarsamy 2022; Nguyen and Pham 2021). An

L9 orthogonal array experimental design is used to manufacture the composite, taking three input factors into account: pulse current, pulse on-time, and pulse off-time (Chiabert, Lombardi, and Orlando 1998). The material removal rate (MRR), overcut (OC), and taper ratio (TR) are three metrics that are thought of as machining performance parameters. The best EDM factor combinations for multiple replies are found using Taguchi and grey relational analysis (GRA) (Sheth et al., 2021; Ferreira, Carvalho, and Guedes-Silva 2019).

Micro- and nano-applications are on the rise, making EDM an increasingly important technique in manufacturing engineering (Gotoh, Tani, and Mohri 2016; Selvarajan et al. 2023c). (Selvarajan et al. 2023b). As a result, components made using EDM must have exacting dimensions and close form tolerances. Various form and orientation tolerances, including cylindricity, circularity, perpendicularity, and others, are examined in this experimental study (Selvarajan et al. 2023d) for silicon nitride composites during the EDM process. Despite their importance in manufacturing owing to their outstanding mechanical and thermal characteristics, conventional machining poses a significant challenge to Si<sub>3</sub>N<sub>4</sub>-TiN composites, which are the subject of this study's investigation (Selvarajan et al. 2023f). The machinability of MoSi<sub>2</sub>-SiC composites using die-sinking EDM and rotary EDM are compared in the study (Selvarajan et al. 2023g). Because of its extreme hardness and lack of toughness, the material can develop surface imperfections such as microcracks, pores, recast layers, craters, and unmelted spherical particles. The geometrical tolerance of Si<sub>3</sub>N<sub>4</sub>-TiN composites is investigated in this work using Spark Erosion Machining. These composites are difficult to process because of their high hardness. In their study published in 2023, Selvarajan et al.

A survey of the relevant literature uncovered a dearth of substantial experimental work in this area. And in non-traditional machining methods like EDM, geometrical tolerances are crucial considerations.

Research into electrical discharge machining (EDM) on Si<sub>3</sub>N<sub>4</sub>-TiN ceramic composites has been limited, according to the reviewed literature.

- ✓ EDM has been used in a small number of experiments to determine the geometric tolerances, MRR, and EWR of Si<sub>3</sub>N<sub>4</sub>-TiN composites.
- ✓ The impact of the EDM technique on the geometrical tolerance of Si<sub>3</sub>N<sub>4</sub>-TiN composites has received very little attention.
- ✓ Why There hasn't been enough research on ceramic composites using GRA to find the best EDM process parameters.
- ✓ Optimising the EDM input process parameters for Si<sub>3</sub>N<sub>4</sub>-TiN ceramic composites has been the subject of few research that have utilised ANOVA analysis.
- ✓ Despite being grounded on an extensive literature research on EDM of composites, the Si<sub>3</sub>N<sub>4</sub>-TiN conductive ceramic composite has received less attention in topographical analysis.

Consequently, the geometrical tolerances were assessed after subjecting Si<sub>3</sub>N<sub>4</sub>-TiN composites to the EDM method. Next, the best parameters for enhanced geometrical tolerances in Si<sub>3</sub>N<sub>4</sub>-TiN composites are estimated using the GRA approach and the ANOVA technique. Experiments are carried out utilising the DOE approach to assess the output responses of Si<sub>3</sub>N<sub>4</sub>-TiN composites. Although there have been many research on electrical discharge machining (EDM), using scanning electron microscopy (SEM) to study the machined surface topography has only been done in a small number of experimental works.

## 2. METHODS AND MATERIALS

According to Selvarajan et al. (2023e), Taguchi came up with a DOE approach that reduces the amount of trials and analysis needed to get the desired outcomes. The research in this study relied on specimens made of titanium nitride. For every possible combination of parameters, the machining experiments were carried out. The work piece's weight was measured before and after machining using electronic balances with a 300-gramme capacity and a precision of 0.001 grammes. These balances, produced in Mumbai by Citizen Scale (I) Pvt. Ltd. (Model CG 203). We also used a stopwatch to keep track of how long the experiment lasted. Because electrode wear impacts the accuracy of machined features, measuring and controlling it is crucial. When it comes to tool wear, the melting points of the electrode materials are crucial. We can observe the work piece and electrode held in place during the machining of conductive ceramic composites using advanced die sinking EDM.

A rod of 20 mm in length and 5 mm in diameter was utilised in a copper-based electrode to attain a high MRR with little tool wear. Circularity, cylindricity, and perpendicularity were measured with a precision of 4.5 microns using CMM. This study utilised a CNC Coordinate Measuring Machine (CMM) from HELMEL Engineering, which has an accuracy of 4.5µm. Geomet, a universal CNC CMM programme, was used. The GEOMET measurement software of the CMM machine was configured to calculate the values of circularity, cylindricity, and perpendicularity.

### 3. Results and discussions

#### 3.1. MRR AND EWR

The experiment was ended by carefully wiping the parts with acetone and then calculating the final weight of each electrode. Using the following formula, we were able to calculate the material removal rate:

$$MRR = (W_1 - W_2) / t, \quad (1)$$

Where,

W<sub>1</sub> - Workpiece mass prior to milling,

W<sub>2</sub> - The finished product's mass following machining,

t - Machining Time (minute).

$$EWR = W_{tb} - W_{ta} / t, \quad (2)$$

Where,

W<sub>tb</sub> - Weight of the tool before machining,

W<sub>ta</sub> - Weight of the tool after machining,

t - Machining Time (minute).

**Table 1.** MRR and EWR for cylindrical electrode.

Exp. No	Input parameters				Machining Time (min)	Output responses		Geometrical Tolerances		
	Current (amp)	Pulse on time (μs)	Pulse off time (μs)	Dielectric pressure (kg/cm)		MRR (g/min)	EWR (g/min)	Circularity (mm)	Cylindricity (mm)	Perpendicularity (mm)
1	4	25	5	23	26.367	0.0179	0.0021	0.090	0.545	1.067
2	4	27	6	25	31.268	0.0172	0.0043	0.105	0.579	0.938
3	6	30	5	25	20.167	0.0212	0.0010	0.789	1.122	0.827
4	4	30	7	27	34.167	0.0364	0.0008	0.312	1.026	1.467
5	6	25	6	27	12.517	0.0183	0.0024	0.175	0.761	1.071
6	8	27	5	27	13.483	0.0262	0.0031	0.872	0.771	1.327
7	8	25	7	25	11.210	0.0184	0.0022	0.982	1.316	1.327
8	6	27	7	23	21.133	0.0106	0.0006	0.119	1.113	0.970
9	8	30	6	23	12.017	0.0374	0.0015	0.129	1.219	1.420

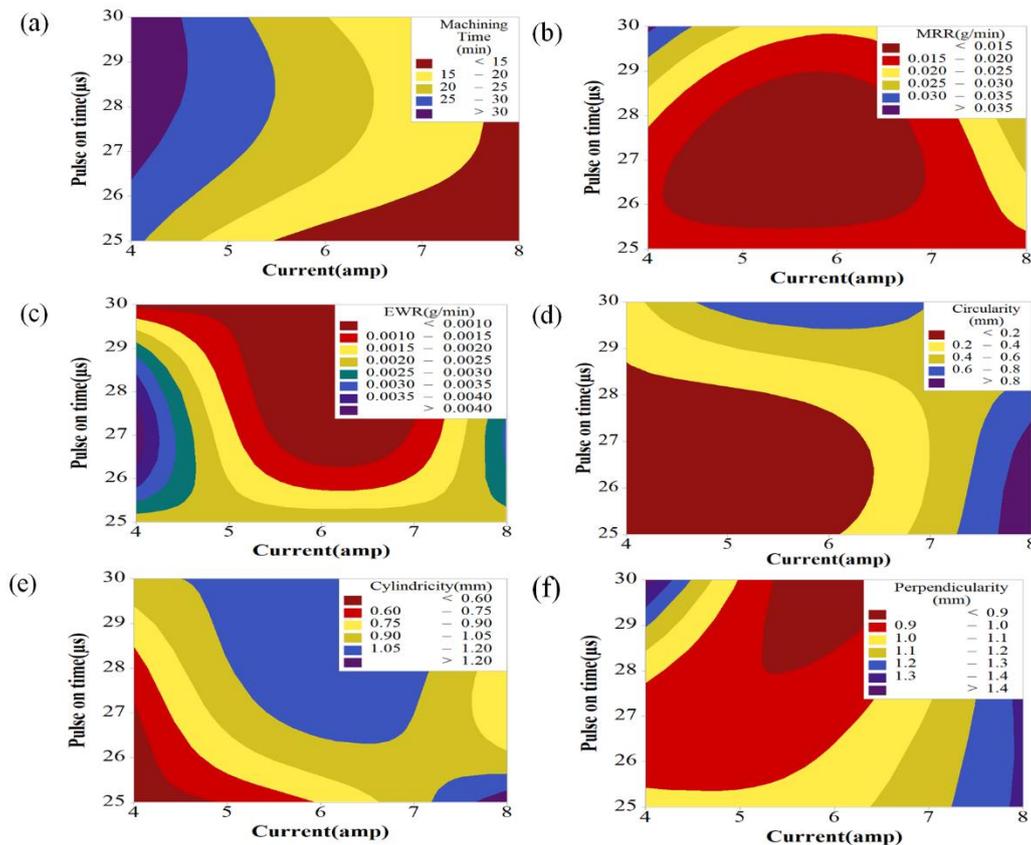
According to the results, the MRR reaches its maximum of 0.0374 gm/min with an 8-amp current and a 30-second pulse-on duration. However, with a current of 6 amps and a pulse on duration of 27 seconds, the lowest possible MRR was a meagre 0.0106 gm/min. Alternate pulse-on-time and current configurations provide the MRR between the two extremes.

It is possible that the spark produced by an electrical discharge between the work piece and the electrode during EDM is responsible for the observed rise in MRR. The spark creates extremely high temperatures and pressures, which force the molten material out of the work piece. The maximum allowable ratio is dependent on a number of inputs, including; current, pulse on time, electrode material, work piece material, and dielectric fluid.

The results of this study make it very evident that the MRR levels are proportional to the current and pulse on time. The reason behind this is that increasing the current and pulse duration causes the spark's temperature and pressure to rise, leading to more material removal. As a thicker recast layer accumulates and thermal damage sets in, MRR values may be reduced by increases in current and pulse on time beyond a specific limit. To sum up, the current study demonstrates that the maximum RMS return to milling (MRM) in electrical discharge machining (EDM) is affected by a number of input factors, and that the optimal current-to-pulse-on-time ratio for maximum RMS differs between applications and materials. You can see that the EWR values vary depending on the input parameters in the table below. By adjusting the current to 4 amps and the pulse on time to 27 seconds, the maximum EWR value of 0.0043 gm/min was attained. A 6 A current with a pulse on time of 27 sec was used to measure an EWR of 0.0006 gm/min. Electrode machining (EDM)

involves eroding or cutting a metal work piece with an electrical discharge. This process involves removing material from a work piece by generating a spark between an electrode and the work piece. This spark causes the metal to melt and vaporise at a high temperature. More material will be removed in the same amount of time if the EDM process is efficient, as demonstrated by the EWR value.

The EWR values vary depending on the input parameters since the strength and length of the spark discharge are affected by current and pulse on time. To enhance the rate of material removal, one can raise the spark's energy by gradually increasing the current and the pulse duration. Too high of a current or pulse rate, however, could harm the electrode or work piece, reducing the process's effectiveness. Thus, it is essential to adjust the input parameters such that the necessary quantity of material is removed without damaging the electrode or work piece in any way.



**Figure 1.** Contour plots for (a) machining time; (b) MRR; (c) EWR; (d) circularity; (e) cylindricity; (f) perpendicularity : current vs. pulse on time.

By creating set geometric tolerance strips, a contour layer allows one to see a 3D surface. The geometrical tolerance is affected by the x and y axis input values, and the z axis slide's ability to attain certain edge positions is described here. With these parameters set: current 6 amps, pulse on time 26 s, as shown in Figure 1 (a), the least perpendicularity is obtained. This combination of parameters yields the minimum cylinder, as shown in Figure 1 (b): current 5 amps, pulse on time 25 s. With these parameters set: current 6 amps, pulse on time 28 s, the minimal circularity is shown in Figure 1 (c). Figure 1 (d) demonstrates that the EWR was decreased when the maximum TMR was obtained from the combination of these parameters (current 4-8 amps) and the pulse on time 29  $\mu$ s simultaneously.

The greatest maximum return ratio (MRR) obtained from this specification of pulse on time (30  $\mu$ s) and current (8 amps) is displayed in Figure 1(e). Picture 1 In general, the results indicate that a current of 8 amps and a pulse on time of 28-30  $\mu$ s provide the best performance for these parameter combinations. The values of MRR have grown in tandem with the present rate and pulse on time.

Last but not least, it found that the current, which controls the strength of the electrical discharges, is a crucial EDM parameter. Rougher geometrical tolerances may be the consequence of increasing the current, which can increase material removal rates. The rate of material removal and surface finish can also be influenced by the pulse on and pulse off times.

Pulse durations that are too long raise the possibility of electrode wear while simultaneously increasing the rate of material loss. Longer pulse-off periods, on the other hand, may slow down the pace of material removal yet provide a smoother surface finish. Another critical component that might affect EDM is dielectric pressure. The dielectric fluid is

employed to flush out the eroded material and cool the work piece. You may increase the material removal rate by increasing the dielectric pressure, which improves the cooling effect and makes it easier to remove the eroded material. But, electrode degradation and surface roughness are both worsened by increased dielectric pressure. Accordingly, in optimising EDM settings for ceramic composites, it is necessary to strike a compromise between the required material removal rate, surface quality, and the danger of electrode wear and other problems. To do this, one must employ specialised EDM software to optimise the settings, closely observe and experiment with the EDM process, and so on.

### 3. CONCLUSIONS

In order to enhance the EDM machining performance and the geometrical tolerances of the machined hole, the GR-RSM method has been employed. Here is a brief overview of the work's conclusion:

1. EDM machining of Si<sub>3</sub>N<sub>4</sub> based ceramic composites has shown significant improvements in performance metrics including geometrical tolerances, MRR, and EWR when cylindrical-profile copper electrodes are used.
2. As shown, the Si<sub>3</sub>N<sub>4</sub> ceramic composite material's performance in EDM is significantly improved in a number of areas. In order to machine Si<sub>3</sub>N<sub>4</sub> ceramic composites using cylindrical electrodes, the optimal parameter is A3B1C2D
3. Using cylindrical electrodes to machine Si<sub>3</sub>N<sub>4</sub>, the best EDM settings for a variety of performance metrics are 8 A current, 20 sec pulse on, 5 sec pulse off, and 28 kg/cm<sup>2</sup> dielectric pressure. 0.0214 g/min is the maximum resistance loss and 0.002 g/min is the electrical work rate in the cylindrical electrode. The plasma energy generation and machined hole circularity were both enhanced at high pulse current.

### 4. REFERENCES

- [1] Ahmad, N., and H. Sueyoshi. 2010. "Properties of Si<sub>3</sub>N<sub>4</sub>-TiN Composites Fabricated by Spark Plasma Sintering by Using a Mixture of Si<sub>3</sub>N<sub>4</sub> and Ti Powders." *Ceramics International* 36 (2): 491-496. doi:10.1016/j.ceramint.2009.09.029.
- [2] Alfattani, R., M. Yunus, L. Selvarajan, and K. Venkataramanan. 2023. "Spark Erosion Behavior in the Machining of MoSi<sub>2</sub>-SiC Ceramic Composites for Improving Dimensional Accuracy." *Journal of the Mechanical Behavior of Biomedical Materials* 148 (December): 106166. doi:10.1016/j.jmbbm.2023.106166.
- [3] Chiabert, P., F. Lombardi, and M. Orlando. 1998. "Benefits of Geometric Dimensioning and Tolerancing." *Journal of Materials Processing Technology* 78 (1-3): 29-35. doi:10.1016/S0924-0136(97)00459-7.
- [4] Dikshit, M.K., S. Singh, V.K. Pathak, K.K. Saxena, M.K. Agrawal, V. Malik, K. hazim Salem, and M.I. Khan. 2023. "Surface Characteristics Optimization of Biocompatible Ti6Al4V with RCCD and NSGA II Using Die Sinking EDM." *Journal of Materials Research and Technology* 24: 223-235. doi:10.1016/j.jmrt.2023.03.005.
- [5] Ferreira, T.S., F.M.S. Carvalho, and C.C. Guedes-Silva. 2019. "Densification and Microstructure of Si<sub>3</sub>N<sub>4</sub>-TiN Ceramic Composites." *Cerâmica* 65: 87-91. doi:10.1590/0366-6913201965s12605.
- [6] Gotoh, H., T. Tani, and N. Mohri. 2016. "EDM of Insulating Ceramics by Electrical Conductive Surface Layer Control." *Procedia CIRP* 42: 201-205. doi:10.1016/j.procir.2016.02.271.
- [7] Lee, T.C., and W.S. Lau. 1991. "Some Characteristics of Electrical Discharge Machining of Conductive Ceramics." *Materials and Manufacturing Processes* 6 (4): 635-648. doi:10.1080/10426919108934794.
- [8] Lin, Y.-C., A.-C. Wang, D.-A. Wang, and C.-C. Chen. 2009. "Machining Performance and Optimizing Machining Parameters of Al<sub>2</sub>O<sub>3</sub>-TiC Ceramics Using EDM Based on the Taguchi Method." *Materials and Manufacturing Processes* 24 (6): 667-674. doi:10.1080/10426910902769285.
- [9] Murugan, C., R.M.S. Kumar, and S. V. Alagarsamy. 2022. "Investigations on Electric Discharge Machining Behaviour of Si<sub>3</sub>N<sub>4</sub> -TiN Ceramic Composite." *Silicon* 14 (2): 547-555. doi:10.1007/s12633-020-00848-w.
- [10] Muttamara, A., Y. Fukuzawa, N. Mohri, and T. Tani. 2003. "Probability of Precision Micro-Machining of Insulating Si<sub>3</sub>N<sub>4</sub> Ceramics by EDM." *Journal of Materials Processing Technology* 140 (1-3): 243-247. doi:10.1016/S0924-0136(03)00745-3.
- [11] Nguyen, H.-P., and V.-D. Pham. 2021. "Single Objective Optimization of Die- Sinking Electrical Discharge Machining with Low Frequency Vibration Assigned on Workpiece by Taguchi Method." *Journal of King Saud University - Engineering Sciences* 33 (1): 37-42. doi:10.1016/j.jksues.2019.11.001.
- [12] Oßwald, K., S. Schneider, A. Klink, and T. Bergs. 2022. "White Layer Thickness Variation in Die Sinking EDM." *Procedia CIRP* 113: 5-9. doi:10.1016/j.procir.2022.09.111.
- [13] Petrovic, J.J. 1995. "Mechanical Behavior of MoSi<sub>2</sub> and MoSi<sub>2</sub> Composites." *Materials Science and Engineering: A* 192-193: 31-37. doi:10.1016/0921-5093(94)03246-7.

- [14] Philip, J.T., J. Mathew, and B. Kuriachen. 2021. "Transition from EDM to PMEDM – Impact of Suspended Particulates in the Dielectric on Ti6Al4V and Other Distinct Material Surfaces: A Review." *Journal of Manufacturing Processes* 64: 1105–1142. doi:10.1016/j.jmapro.2021.01.056.
- [15] Rajavel, R., L. Selvarajan, G. Rajkumar, R. Raja, and A. Rakshna. 2021. "Investigation on Machinability of Al 2024&#amp; 7.5% Si3N4 Metal Matrix Composite with PMEDM Using Taguchi Based GRA." *Materials Today: Proceedings* 46: 9449–9453. doi:10.1016/j.matpr.2020.03.234.
- [16] Rajkumar, G., M. Saravanan, A.B.H. Bejaxhin, S. Sharma, S.P. Dwivedi, R. Kumar, and S. Singh. 2023. "Parametric Optimization of Powder-Mixed EDM of AA2014/Si3N4/Mg/Cenosphere Hybrid Composites Using Fuzzy Logic: Analysis of Mechanical, Machining, Microstructural, and Morphological Characterizations." *Journal of Composites Science* 7 (9): 380. doi:10.3390/jcs7090380.
- [17] Rehman, A. ur, W. Arif, M.I. Hussain, S. Miran, S. Hussain, and G.H. Lee. 2022. "Analysis of Particle Size and Concentration in Die Sinking Electric Discharge Machining." *Materials* 15 (14): 4932. doi:10.3390/ma15144932.
- [18] Sarma, P., D.J. Borah, P.K. Patowari, and A. Likhite. 2022. "Machinability Study of Austempered Ductile Iron Using Die-Sinking EDM." *International Journal of Machining and Machinability of Materials* 24 (3-4): 314. doi:10.1504/IJMMM.2022.125201.
- [19] Selvarajan, L., C.S. Narayanan, and R. JeyaPaul. 2016. "Optimization of EDM Parameters on Machining Si<sub>3</sub>N<sub>4</sub>–TiN Composite for Improving Circularity, Cylindricity, and Perpendicularity." *Materials and Manufacturing Processes* 31 (4): 405–412. doi:10.1080/10426914.2015.1058947.
- [20] Selvarajan, L., R. Rajavel, B. Prakash, D.G. Mohan, and S. Gopi. 2020. "Investigation on Spark Electrical Discharge Machining of Si3N4 Based Advanced Conductive Ceramic Composites." *Materials Today: Proceedings* 27: 2174–2178. doi:10.1016/j.matpr.2019.09.090.
- [21] Selvarajan, L., C. Sathiya Narayanan, and R. Jeyapaul. 2014a. "Multi-Objective Optimization on Electric Discharge Machining Using by Grey Relational Analysis." *Applied Mechanics and Materials* 592–594: 550–554. doi:10.4028/www.scientific.net/AMM.592-594.550.
- [22] Selvarajan, L., C. Sathiya Narayanan, and R. Jeyapaul. 2014b. "Optimization of Machining Characteristics in EDM of Si<sub>3</sub>N<sub>4</sub>-TiN Composites by Taguchi Grey Relational Analysis." *Applied Mechanics and Materials* 592–594: 600–604. doi:10.4028/www.scientific.net/AMM.592-594.600.
- [23] Selvarajan, L., and K. Venkataramanan. 2023a. "Si<sub>3</sub>N<sub>4</sub>–TiN Conductive Ceramic Composites: Topography on EDMed Surfaces and Precise Drilled Holes." *Materials Science and Technology* 39 (15): 2006–2017. doi:10.1080/02670836.2023.2187156.
- [24] Selvarajan, L., and K. Venkataramanan. 2023b. "Surface Morphology and Drilled Hole Accuracy of Conductive Ceramic Composites Si3N4–TiN and MoSi2–SiC on EDMed Surfaces." *Wear* 530–531: 204973. doi:10.1016/j.wear.2023.204973.
- [25] Selvarajan, L., R. Rajavel, C. Arun, and C. Raju. 2023a. "Experimental Analysis and Surface Morphology of Holes Made by Electrical Discharge Machining on MoSi2–SiC Composite." *Journal of Materials Engineering and Performance*. doi:10.1007/s11665-023-09000-2.
- [26] Selvarajan, L., K. Venkataramanan, A. Nair, and T.S. Senthilkumar. 2023b. "Enhanced Jaya Optimization in Electrical Discharge Hole Making of MoSi2–SiC Composite with Surface Morphology Analysis." *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 45 (10): 555. doi:10.1007/s40430-023-04493-3.
- [27] Selvarajan, L., K. Venkataramanan, K.P.S. Perumal, M. Yunus, R. Alfattani, and A. Aravindhan. 2023c. "A Review of Spark Erosion Machining Efficiency, Characterization and Optimization Techniques for Ceramic Composites." *Composite Interfaces*: 1–52. doi:10.1080/09276440.2023.2268967.
- [28] Selvarajan, L., K. Venkataramanan, R. Rajavel, and T.S. Senthilkumar. 2023d. "Fuzzy Logic Optimization with Regression Analysis on EDM Machining Parameters of Si3N4–TiN Ceramic Composites." *Journal of Intelligent & Fuzzy Systems* 44 (6): 8869–8888. doi:10.3233/JIFS-223650.
- [29] Selvarajan, L., R. Rajavel, K. Venkataramanan, and V.P. Srinivasan. 2023e. "Experimental Investigation on Surface Morphology and Recasting Layer of Si3N4–TiN Composites Machined by Die-Sinking and Rotary EDM." *Ceramics International* 49 (5): 8487–8501. doi:10.1016/j.ceramint.2022.11.011.

- [30] Selvarajan, L., K. Venkataramanan, A. Nair, and V.P. Srinivasan. 2023f. "Simultaneous Multi-Response Jaya Optimization and Pareto Front Visualization in EDM Drilling of MoSi<sub>2</sub>-SiC Composites." *Expert Systems with Applications* 230: 120669. doi:10.1016/j.eswa.2023.120669.
- [31] Selvarajan, L., R. Rajavel, M. Yunus, and R. Alfattani. 2023g. "Die-Sinking and Rotary EDM Surface and Subsurface Analysis of MoSi<sub>2</sub>-SiC Ceramic Composites." *Materials Science and Technology* 39 (18): 3150–3166. doi:10.1080/02670836.2023.2240103.
- [32] Selvarajan, L., Rajavel Rajendran, Senthil Kumar Shanmugakani, and K. Venkataramanan. 2023h. "Analyzing the Geometrical Errors of Silicon Nitride-Titanium Nitride on Performing Electric Discharge Machining Using Response Surface Methodology." *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*. doi:10.1177/09544089231166303.
- [33] Sharma, S., U. K. Vates, and A. Bansal. 2022. "Influence of Die-Sinking EDM Parameters on Machining Characteristics of Alloy 625 and Alloy 718: A Comparative Analysis." *Materials Today: Proceedings* 50: 2493–2499. doi:10.1016/j.matpr.2021.10.450.
- [34] Sheth, M., K. Gajjar, A. Jain, V. Shah, H. Patel, R. Chaudhari, and J. Vora. 2021. "Multi-Objective Optimization of Inconel 718 Using Combined Approach of Taguchi—Grey Relational Analysis." In *Advances in Mechanical Engineering* 229–235. Singapore: Springer.
- [35] Singh, R., R.P. Singh, and R. Trehan. 2022a. "Parametric Investigation of Tool Wear Rate in EDM of Fe-Based Shape Memory Alloy: Microstructural Analysis and Optimization Using Genetic Algorithm." *World Journal of Engineering* 19 (3): 418–428. doi:10.1108/WJE-04-2021-0203.
- [36] Singh, R., R.P. Singh, and R. Trehan. 2022b. "Surface Integrity and Accuracy Based Aspects in EDM of Cu-Based SMA: An Experimental Investigation with Microstructural Analysis." *Advances in Materials and Processing Technologies*: 1–14. doi:10.1080/2374068X.2022.2099655.
- [37] Somani, N., Y.K. Tyagi, and P. Kumar. 2021. "Review on Alternative Approaches to Fabricate the Copper Based Electric Discharge Machining (EDM) Electrodes." *IOP Conference Series: Materials Science and Engineering* 1116 (1): 012105. doi:10.1088/1757-899X/1116/1/012105.
- [38] Srinivasan, V.P., P.K. Palani, and S. Balamurugan. 2021. "Experimental Investigation on EDM of Si<sub>3</sub>N<sub>4</sub>-TiN Using Grey Relational Analysis Coupled with Teaching-Learning-Based Optimization Algorithm." *Ceramics International* 47 (13): 19153–19168. doi:10.1016/j.ceramint.2021.03.262.
- [39] Srinivasan, V.P., Ch. Sandeep, C. Shanthi, A.B.H. Bejaxhin, R. Anandan, and M. Abisha Meji. 2022. "Comparative Study on EDM Parameter Optimization for Adsorbed Si<sub>3</sub>N<sub>4</sub>-TiN Using TOPSIS and GRA Coupled with TLBO Algorithm." *Adsorption Science & Technology* 2022: 1–19. doi:10.1155/2022/4112448.
- [40] Vidya, S., R. Wattal, and P.V. Rao. 2022. "Experimental Investigation on Machinability and Geometric Tolerance in Die-Sinking EDM of Microholes and Channels." *MAPAN* 37 (2): 399–407. doi:10.1007/s12647-022-00532-x.