

RESEARCH ARTICLE

Optimization of AA7075–SiC Composite Machining by WEDM Using Biosilica Additives

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ABSTRACT – The study herein discusses the wire-cut electrical discharge machining (WEDM) with the addition of biosilica from maize cobs for the precision cutting of AA7075 aluminum and silicon carbide (SiC) metal matrix composites. The new, harmless addition of biosilica as a dielectric agent not only supports the sustainability of the process but also enhances surface quality and cutting speed. A Taguchi L9 design was used to conduct an experiment investigating the effects of peak current, gap voltage, and pulse-on time on material removal rate (MRR) and surface roughness (Ra). The optimal machining parameters were determined using Grey Relational Analysis and an artificial neural network (ANN). These model developments aimed to predict performance outcomes. The findings indicated that the dielectric fluid with biosilica increased MRR by 25% and simultaneously decreased Ra by 15% when compared with the typical dielectric. SEM and AFM analysis confirmed surface uniformity improvement and reduced microcrack formation. The artificial neural network model, trained using the backpropagation method on the experimental data, produced predictions for material removal rate and average roughness with an R^2 of 0.96, indicating that the model is highly reliable. In conclusion, the present research not only reveals a non-conventional machining process but also provides an eco-friendly approach to optimizing wire EDM of metal matrix composites with nano-reinforcement.

ARTICLE HISTORY

Received : 07th July 2025
 Revised : 14th Oct. 2025
 Accepted : 28th Oct. 2025
 Published : 20th Dec. 2025

KEYWORDS

AA7075
 WEDM
 MRR
 Surface Roughness
 Bio silica

1. INTRODUCTION

Metal matrix composites (MMCs) are crucial materials used across industries for their outstanding properties, such as high strength-to-weight ratios, good corrosion resistance, wear resistance, and versatility, all enabled by continuous improvements in their manufacturing processes [1]. Among the main reasons for using metal-matrix composites (MMCs) as a better option than conventional materials in mechanical engineering departments is that they offer superior lightweight and strength, along with the ability to withstand heat and temperature changes. These are the main characteristics that do not make them unacceptably expensive [2]. Besides, unconventional machining techniques such as electrochemical jet machining (ECJM), electrical discharge machining (EDM), electrochemical machining (ECM), abrasive water jet machining (AWJM), and laser beam machining (LBM) have been spotlighted as major replacements for traditional machining methods, yielding high-quality engineering parts with unique attributes [3].

Various tests regarding the mechanical, microstructural, and tribological characteristics of hybrid metal-matrix nanocomposites (HMMCs), Al-0.7Fe-0.6Si-0.375Cr-0.25Zn/10 wt%SiCP/3 wt%GrP-MMC, Al-0.7Fe-0.6Si-0.375Cr-0.25Zn/15 wt%SiCP/5 wt%GrP-MMC, and Al-0.7Fe-0.6Si-0.375Cr-0.25Zn/20 wt%SiCP/8 wt%GrP-MMC [4], required extensive evaluation by the researchers. A combination of alumina, B₄C, and SiC has been used as additives in Al-6061 to produce a composite material that has received a rating of good tensile strength, wear resistance, and thermal expansion [5]. The focus of this research is to analyze the wear and friction of the Aluminum metal matrix composite, specifically an Al 7075-based composite reinforced with fly ash and silicon carbide, using the stir-casting technique [6]. The high hardness and abrasive nature of ceramic reinforcements in metal matrix composites (MMCs), such as silicon carbide (SiC)- reinforced AA7075, make machining them extremely difficult [7]. With a microhardness of about 2700 HV, SiC particles often lead to increased cutting forces, poor surface quality, and rapid tool wear during standard machining operations. MMCs have excellent mechanical qualities and are suitable for automotive and aerospace applications, but these drawbacks prevent their wider industrial adoption [8].

Wire electrical discharge machining [9] is a widely recognized unconventional machining technique frequently employed for the fabrication of intricate shapes. When very intricate constructions must be machined with extreme precision, this process is more suitable. Researchers have recently begun machining hard materials using a powder-activated dielectric medium to remove larger materials and enable eco-friendly, sustainable manufacturing [10]. Non-traditional methods such as Wire-Cut EDM (WEDM) and Electrical Discharge Machining (EDM) have become more popular for overcoming the limitations of traditional machining [11]. By providing longer flames and a wider spacing

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between them, the additional particles improve machinability. This resulted in improved machined surface accuracy. There have been more verified studies regarding this phenomenon in the research community lately. When using deionized water to mill silicon carbide (SiC), the effects of adding biosilica were investigated in [12]. This study used a dielectric medium made of biosilica with weights of 0.25, 0.5, and 1.0. Surface quality and material clearance rate are sufficient up to 1.0 volume % particle addition. The potential biological uses of the powder-mixed EDM method were also investigated by Abdul-Rani et al. [13], who outline the progression of the electro-discharge machining (EDM) process, transitioning from traditional EDM to powder-mixed EDM. It mainly focuses on biomedical applications, the problems associated with the research, and case studies of different materials used in powder-mixed EDM. The same opinion was expressed by Boominathan et al. [14], who stated that Micro-EDM is a very effective technique in micromachining hard and conductive materials. However, the issues of slow machining rates, high tool wear rates, and poor surface quality, all due to the nature of the removal process, remain very challenging to overcome. In this work, the effect of the micro-electrical discharges machining of Inconel 718 alloy with the addition of silicon carbide (SiC) nano powder (25nm–35nm) into the insulator is investigated.

According to previous research, powder-mixed EDMs work well with tougher materials. It is common practice to augment the dielectric in such an array with silicon, tungsten, chromium, or copper particles to generate continuous sparks with a wider tool gap [15]. These procedures reduce mechanical stresses by removing material with controlled sparks that do not come into direct contact with the tool or workpiece. Additionally, powder-mixed EDM (PMEDM), which involves mixing conductive powders with the dielectric fluid, has been shown to improve material removal rate (MRR), improve energy distribution, and produce smoother surfaces. The use of environmentally friendly biosilica, made from agricultural waste such as rice husks and maize cobs, as a sustainable dielectric additive has been investigated in recent studies [16,17]. In addition to being inexpensive and biodegradable, biosilica has superior thermal conductivity and dielectric properties that are comparable to those of traditional powders.

The majority of current research [18,19], however, focuses on metallic or hybrid powders (such as graphite, aluminum, or SiC), and the potential of biosilica in WEDM of aluminum composites remains poorly understood, especially for AA7075-SiC systems. Schubert et al. showed that powder-mixed EDM (PMEDM), with a focus on antibacterial and biocompatible surface qualities, shows great promise for advanced surface modification, particularly for medical devices. Their work demonstrated the importance of powder parameters (size, type, and concentration) and the role of CFD simulation in understanding powder dispersion [20]. A comprehensive state-of-the-art review of PMEDM was provided by Srivastava et al. [21]. They described material-removal methods and reported notable improvements in surface quality when using tailored, environmentally friendly powders. The silicon material is both long-lasting and cheap in these routine upgrades. It is affordable and easy to get. Other particles are produced by electrical discharge machining; however, owing to their shared metallic characteristics, they may react with the base metal. Silicon is highly reactive with oxygen, forming silicon oxide, and is usually found in nature as its oxide. Crushed dirt and agricultural by-products are two potential sources of silica. Biosilica is made from a range of plentiful sources, such as rice husks, maize cobs, wheat husks, and maize fibre, for various uses. Agricultural areas saw an abundance of these biomasses after grain harvests [22].

The application of affordable, renewable, or waste materials to produce engineered silica particles exemplifies a significant approach to sustainability. Rice husks serve as renewable resources, enabling the production of modified silica particles and biofuels [23]. It is also beneficial to add bio-based nanofillers to the dielectric fluid. This makes machining less harmful to the environment and more useful. This is the reason why several academics are looking into green dielectric manufacturing as a potential new field of study. Biosilica extraction from maize cobs has been the subject of many recent research articles. Scientific investigations have demonstrated that the method of silica extraction from corn cobs is effective (Figure 1). Seghir et al. [24] studied Silica (SiO₂), a fundamental element of the earth's crust, which has found extensive application in various nanotechnological fields. The study and analysis of SiO₂ nanoparticles (SiO₂NPs) synthesis derived from different agricultural residues, such as rice husk, rice straw, maize cobs, and bagasse, were conducted in detail. Singh et al. [25], along with others, examined the use of silica extensively across many sectors, including construction, the chemical industry, agriculture, health care, and environmental remediation. The sol-gel method has proven quite successful for producing nanomaterials from various precursors since its initial proposal. [26]. Metal matrix composites (MMCs) are already heavily used in the automotive and aerospace industries because of their great mechanical properties, along with their lightweight and fuel-efficient [27]. Nanocomposites with their nanosized reinforcements can be embedded in polymer, metals, or ceramics to develop structures that are much more intricate than those of micron-sized reinforced composites. Aluminium matrix composites are primarily concerned with enhancing specific strength, as well as providing high temperature and wear resistance for various applications. The precise prediction of the coefficient of friction in aluminum alloy composites, specifically AA7075, is essential for enhancing their performance in tribological applications. Therefore, increasing spark intensity can lead to a larger spark gap, improved surface quality, and a lower rate of tool wear. EDM machining has become popular for unusual aluminium alloys and other conductive materials due to their potential in modern production. Furthermore, utilising environmentally friendly equipment for machining is now being viewed from several angles. Newly developed alloys such as AA7075-TiO₂, AA7075-SiC, and AA7075-TiB₂ are designed for specific industrial uses. The EDM machining of these MMCs has not been the subject of any particular study, and the findings are currently unknown [28-30].

Researchers have conducted numerous studies to create an effective wire-cut EDM process using the most advanced deep learning method based on artificial neural networks (ANNs) [31-34]. Appropriate technologies like ANN not only

offer a great way to unravel the complexities of such predictions but also present an outstanding method. Besides being a nonlinear one, this method is particularly effective for drawing a detailed and intricate picture of nonlinear problems, and that is why it is being used in various areas such as structural engineering, composite materials, and material removal. An artificial neural network is usually built around the concept of a biological neural network in that it consists of a set of interconnected artificial neurons, which are also known as processing units, capable of executing the functions of a neuron. The network is structured in such a way that every input signal is treated as a real number and each neuron produces its output by first summing its inputs and then passing the result through a nonlinear activation function. In addition, neurons usually have a weighting factor associated with them, which determines the amount of signal to be transferred across the synapse. In the case of neural networks, the layers of neurons stacked up permit different ways of analyzing the inputs. The signals are passed on from the first input layer to the last output layer, but may also go around the network several times before getting the final result, which is the most accurate one.

Sakthimurugan et al. [35] discuss the use of silane-treated corn cob biosilica as an additive in deionized water-based green dielectric for WEDM of innovative metal matrix composites. The research by Gostimirović, Rodić, and Sekulić introduces a fuzzy inference system (FIS) for the prediction of electrical discharge machining (EDM) process quality, which addresses the inherent difficulties and nonlinearities in the EDM operations [36]. The proposed method exposes the relevant and unique dimensionless quantities by combining the artificial neural network (ANN) and data-driven dimensional analysis. According to Xu et al. [37], the fully connected neural network is utilized to develop the ridge function for the response surface within a physical system. Rizvi et al. [38] examine how variations in turning process parameters influence the surface roughness and metal removal rate (MRR) of AISI 1040 steel. The Taguchi-based grey relational analysis approach has been identified as an effective structured method for optimizing parameters [39]. Senthilkumar et al. [39] employed a combined Neuro and Genetic approach to enhance the machining process of the WC-Co composite. Similarly, Kumar et al. [40] utilized this approach to address a single objective optimization problem. According to these studies, ANNs have been effectively employed to forecast different aspects of material removal. This approach merges the advantages of experimental methods with the mathematical modelling capabilities of neural networks to estimate unknown values. Ganapathy et al. validated the use of ANN in modern process analytics by demonstrating that ANN models outperform conventional regression techniques for complicated nonlinear interactions in terms of properly predicting and optimizing EDM responses [41]. Kumar et al. [42] demonstrated ANN's versatility across process domains by applying ANN to predict microhardness and other reactions in EDM of titanium alloys. The higher performance of ANN in predictive machining analytics was confirmed by Debnath et al., who compared ANN with gene expression programming for multidimensional EDM process prediction [43].

Although many studies have been conducted on WEDM of metal matrix composites, the incorporation of sustainable dielectric modifiers sourced from agricultural waste is mostly unaddressed. Current research mostly utilizes traditional or synthetic dielectrics, neglecting the potential of biosilica to improve machining performance and surface integrity. A systematic approach that integrates experimental optimization and predictive modeling, especially by the use of ANN, for eco-friendly dielectrics is currently lacking. This work analyzes the impact of biosilica-enriched dielectric fluid on the WEDM performance of AA7075-SiC composites to solve existing gaps. This study seeks to investigate the influence of critical process parameters on the material removal rate (MRR) and roughness of the surface (Ra) through the use of Taguchi designs and grey relationship analysis for optimization techniques in conjunction with the creation of a model using artificial neural networks to forecast machining results. Surface integrity is also evaluated using AFM and SEM studies. This cohesive and sustainable methodology enhances the comprehension of WEDM mechanisms in composite systems while setting the way for environmentally friendly precision production.

2. EXPERIMENTAL WORK

2.1 Materials

The current experiment utilised a modified aluminium metal matrix composite (MMC) known as AA7075-SiC, which was produced based on the research referenced in [44]. The hardness is 121 BHN, the yield strength is 86 MPa, the elongation is 22%, and the tensile strength is 175 MPa for the alloy. The thickness is 10 mm, and the actual density is 2.68 g/cm³ for the cast aluminium alloy plate. The chemical structure of the novel AA7075-SiC used in the machining investigation is shown in Table 1. Whatman filter paper, deionized water, acetic acid, ethanol, and chemicals from MERCK India Ltd. were used as additional reagents.

Table 1. Chemical composition of AA7075-SiC

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al	Others
%	0.3	0.3	1.6	0.2	2.5	0.2	5.6	87.1	Remainder

2.2 Biosilica Preparation

The harvest process involved the collection of maize cobs from surrounding fields, followed by rigorous washing and drying procedures. The muffle furnace was the place where biomass burning was done at a controlled high temperature of 650 degrees Celsius for 3 hours with a heating rate of 10 degrees Celsius per minute. After burning, the furnace was left to cool down by itself. Prempeh et al. [45] suggest a better method of making biogenic silica from corn husk using a

sol-gel polymeric process. Biogenic silica from corn husk through the sol-gel process combines environmental sustainability and excellent material properties, thus making it suitable for various industrial applications, particularly as a catalyst support. The process of silica extraction from maize cob ash (CCA) was done with the help of the sol-gel method. The first step consisted of dissolving CTAB in distilled water, followed by stirring the mixture for five minutes to obtain a clear and homogeneous solution. Subsequently, NH_4OH infusion was slowly introduced over 10 minutes, then the silica extract was added and left at room temperature for about 20 hours. The silicon dioxide extracts were then officially dried in the furnace at 105 degrees Celsius for 24 hours. To eliminate carbonates and other non-reactive materials, particles were subjected to heat treatment in a muffle furnace at 550 °C. Figure 1 show the biosilica extraction process: (a) Raw corn cobs act as a source of biomass, (b) burnt corn cobs are the result of carbonization, (c) acid leaching is the process eliminating metallic impurities, (d) silica is precipitated after alkaline extraction, (e) drying and calcination are done to silica gel, and (f) biosilica powder is produced and it is used as a dielectric additive for WEDM. The particles of silica obtained were of size 100–150 nm as confirmed by particle size analysis.

The XRD pattern of the WEDM-processed AA7075–SiC composite with biosilica-enriched dielectric, displayed in Figure 2, incorporates the detection of numerous distinct phases, which suggest the intricate interplay among the aluminum matrix, SiC reinforcement, and biosilicon-derived additives. The most intense peaks at $2\theta = 38.5^\circ$, 44.7° , and 65.1° represent the (111), (200), and (220) planes of the α -Al (face-centered cubic) phase, thus confirming that the main aluminum matrix keeps its crystal structure even after the discharge machining process. The drastic and sharp peaks are the signs of the codeposition of high crystal and low lattice deformation of the aluminum phase during WEDM, despite the thermal and electrical forces that come from it. In addition to the reflections of aluminum, the distinct peaks of hexagonal SiC are observed at the 2θ values of 35.6° and 60.0° , which correspond to its (111) and (220) planes, respectively. The fact that these SiC peaks still appear after machining suggests that the reinforcing particles retain their structural integrity and do not disintegrate during the transient high-temperature plasma of WEDM. This is consistent with earlier findings in Al–SiC composites, where the SiC phase remains identifiable in XRD after extensive processing.

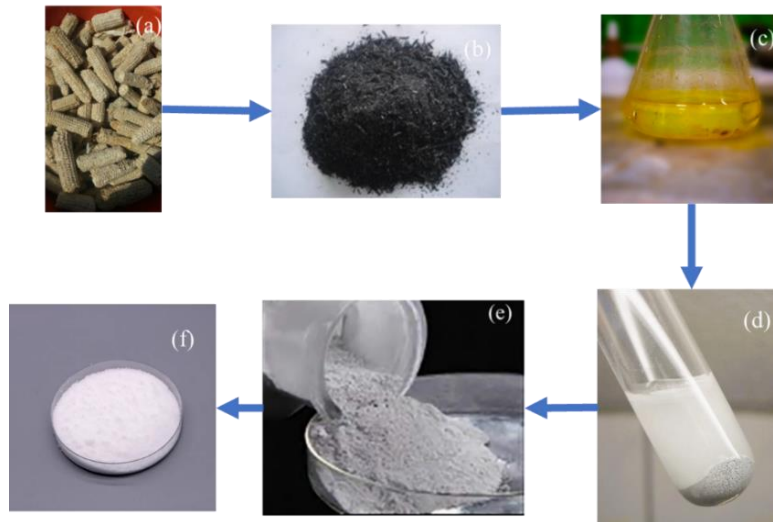


Figure 1. Process of bio-silica extraction

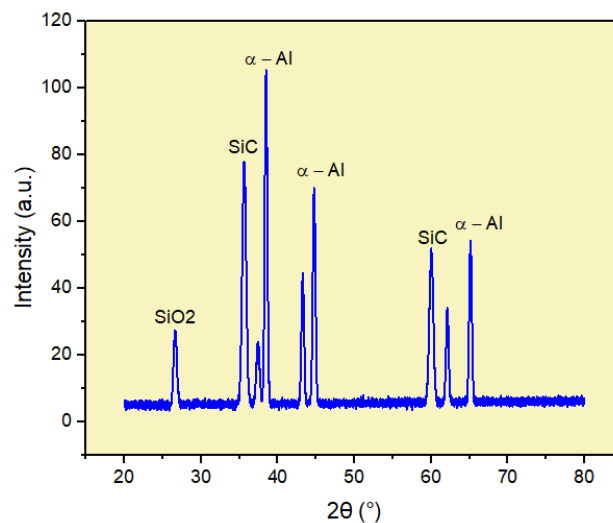


Figure 2. XRD analysis of AA7075–SiC composite with biosilica-enriched dielectric

2.3 Preparation of Biosilica Dielectric

The electrically conducting fluid utilized in the present study was synthesized by combining biosilica particles, corn cob, and deionized water. The procedure entailed meticulously combining deionised water and biosilica nanoparticles for a duration of 10 minutes. The acronym "ABD" denotes an as-received biosilica dielectric. During the mixing process, the fluid was heated to 60 degrees Celsius, and the necessary amount of biosilica nanoparticles was methodically added. The solution of colloidal particles was subjected to ultrasound for 10 minutes to achieve uniform dispersion. Thereafter, the well-blended biosilica-water mixture was permitted to cool to the specified processing temperature. All dielectric fluids formulated in our current experiment are enumerated in Table 2.

Table 2. Classifications of deionized fluid as dielectric materials

Dielectric Classification	Proportion of Biosilica Mass
ABD0/ TBD0	0
ABD1 / TBD1	0.25
ABD2 / TBD2	0.50
ABD3 / TBD3	1
ABD4 / TBD4	2
ABD5 / TBD5	4

2.4 Machining Procedure

AA7075-SiC MMC was produced with a WEDM (Ezeecut Plus CNC Wire-Cut EDM Machine) with specified process variables. The incision was kept at a constant length of 30 mm by applying 8 g of wire tension with a wire that was 0.25 mm thick. Brass was used as the tool material in this case. The specimen size used in this inquiry was a rectangular plate measuring 100 × 50 × 10 millimetres. The process parameters included a constant voltage difference of 15 V, a maximum current of 12 A, a duty factor of 0.4, and a 0.5 mm standoff distance. The AA7075-SiC MMC was produced using a WEDM (Ezeecut Plus CNC Wire-Cut EDM Machine) with specified process variables. The incision was maintained at a constant length of 30 mm by applying 8 g of wire tension with a wire thickness of 0.25 mm. Brass served as the tool material in this instance. The specimen size used for this investigation was a rectangular plate measuring 100 × 50 × 10 millimetres. The process parameters included a constant voltage gap of 15 V, a maximum current of 12 A, a duty cycle of 0.4, and a 0.5 mm standoff distance. The pulse width was set to 114 volts on and 24 volts off.

Biosilica in deionised water activated the dielectric properties of the medium, as indicated in Table 2. The pressure technique was employed for cleaning. While the machine was in operation, the cutting speed was recorded. The wire EDM equipment used in our present investigation is depicted in Figure 3. The Ezeecut Plus WEDM system's control panel and CNC interface are shown on the left, the full WEDM machine layout with the workpiece, wire electrode, and dielectric tanks highlighted in the center, and a close-up of the wire-workpiece interaction zone during milling using biosilica-enriched dielectric fluid is shown on the right. Here, the pressure technique was employed for cleaning. While the machine was running, the cutting speed was recorded.



Figure 3. Image of a wire-cut machining using electrical discharge apparatus

2.5 Characterization

The study evaluated several machining parameters to measure the effectiveness of incorporating biosilica particles in the water dielectric. Comparing the material's original weight with its final weight after machining and dividing the result by the machining time allowed us to establish the MRR. Weighing the tool and the workpiece was done using a computerised balance that has an accuracy of three decimal places. The duration of the machining process was recorded

with a digital timer, facilitating the computation of the Materials Removal Rate (MRR). The surface roughness tester was invented by Mitutoyo, a Japanese company, and it was used to measure the roughness of the machined surfaces. The tester was version 2.0. The microstructure of the machined surfaces was examined through a Japanese HITACHI S1500 scanning electron microscope, applying standard operating protocols.

2.6 ANN Approach

Artificial intelligence models have frequently been adopted by the engineering industry, and the main driving forces behind this shift have been the massive amounts of digital data, the increase in processing power, and the development of more sophisticated algorithms. One of the most popular models has been the neural network. Researchers studied the removal rate of the material along with the surface that was generated through wire-cut electrical milling on the AA7075-SiC material and figured out the right process parameters through model building. The artificial neural networks were the ones that created this model. These models want to explore the hidden physics by using experimental data and approximating the constitutive model without any pre-set structure. The reason is that machine learning techniques are set up to identify and model data relationships. Thus, ML-infused constitutive models are expected to be as good as or even better than the traditional physics-based ones in modeling. By doing this, the neural network gets the ability to learn, and the learning can even come in the form of performing particular tasks like regression. The author utilized MATLAB for the creation of an ANN, where the error signal produced in the ANN was then transmitted through the backpropagation, because adjusting weights and biases is the aim of the method. The input neurons are defined by three variables—ultimate current, gap voltage, and pulse-on-time parameters. The model consists of 10 hidden layers, with the output layers indicating MRR and surface roughness, as illustrated in Figure 4. The process utilized an optimization technique grounded in gradient descent. The artificial neural network (ANN) model was developed using 25 datasets, with 70% designated for training, 15% for verification, and the final 15% for testing. The hidden layer utilized the tansig function, which is the hyperbolic tangent sigmoid, while the output layer made use of a linear activation function known as purelin. To reduce the MSE and prevent overfitting, hyperparameters like the learning rate, number of epochs and network size were adjusted through repeated trials.

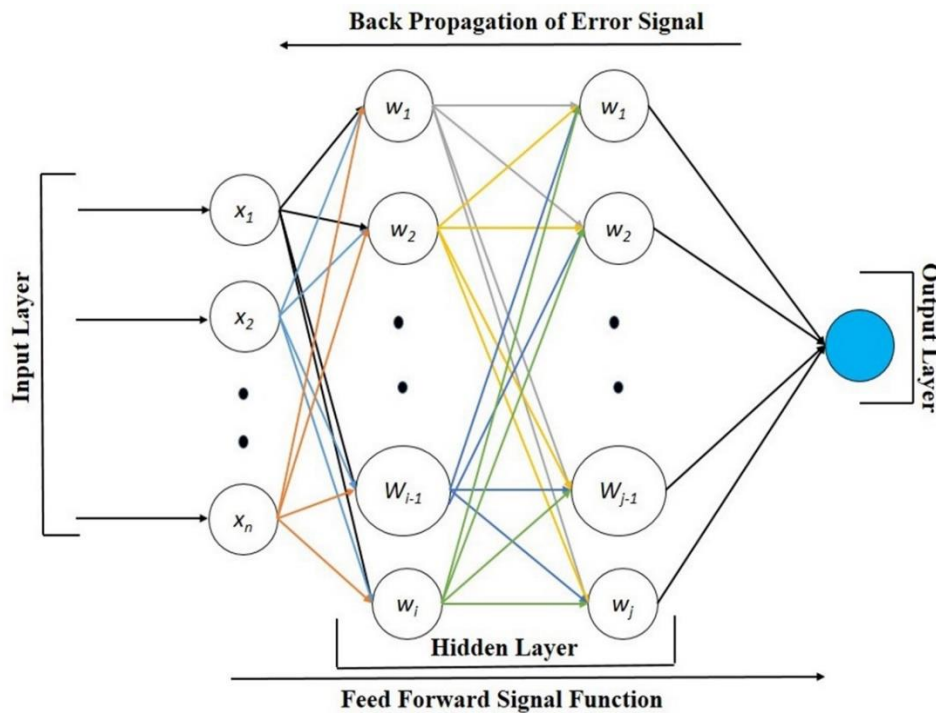


Figure 4. The schematic diagram for ANN

A MATLAB model was created to forecast the substrate rate of removal and surface finish during the wire-cut EDM with the AA7075-SiC. The optimal correlation between the wire-cut EDM procedure variables and either material rate of removal or finished surface was determined by a feed-forward network employing the L-M training method. The arrangement utilized the "tansig" activation function in the hidden layer and "purelin" in the output layer. The smallest mean squared error established the optimum structure on the verification set. The ideal validation occurred at epoch 4, resulting in an MSE = 0.0197, which is the value as depicted in Figure 5.

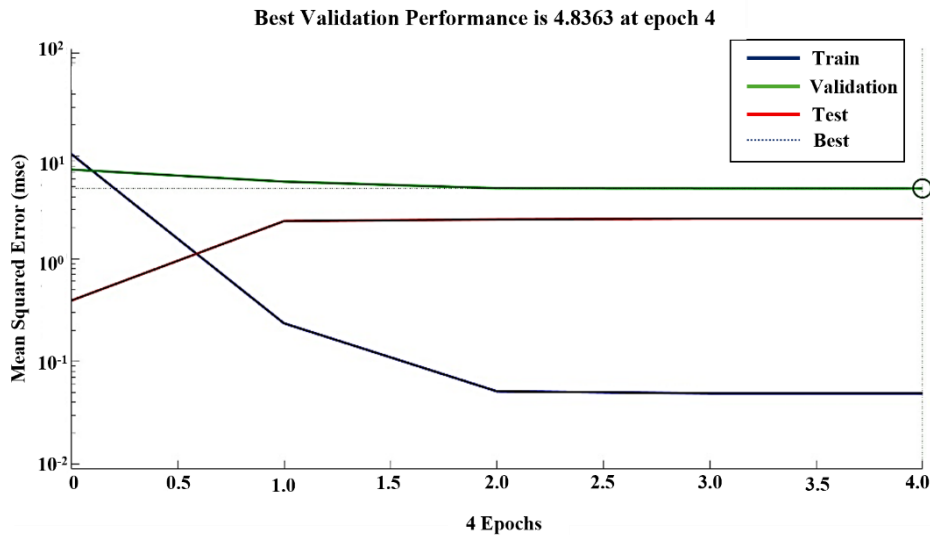


Figure 5. The 4-3-3-1 design of neural networks was utilized to predict the output, resulting in the minimal mean squared error observed during validation

Figure 6 demonstrates the performance of the trained network. The training attained a coefficient of determination of 0.99, signifying a very high degree of accuracy, almost achieving a flawless score of 1. Its correlation coefficients during both validation and testing were 0.945 and 0.942, respectively. The comprehensive prediction model exhibited a correlation coefficient of 0.964. A new study by Paturi et al. investigates the application of neural networks with artificial intelligence (ANN) for modeling and predicting roughness of the surface for wire electrical discharge milling (WEDM) of Inconel 718, a complex superalloy commonly used for aerospace and high-temperature environments [46]. The cascading forward neural network, configured as 5-14-4, efficiently correlates machining parameters—pulse-on duration, pulse-off duration, current peak, regulator voltage, and flushing pressure—with outcomes including removal of material rate, roughness of the surface, speed of cutting, and sparking gap. The anticipated and experimental findings exhibited a robust connection, despite a mean error of 4.3%. The findings of this study illustrate the significant efficacy of artificial neural networks in modeling intricate and unexpected procedures, including the wire-cut electrical discharge machining of AA7075-SiC.

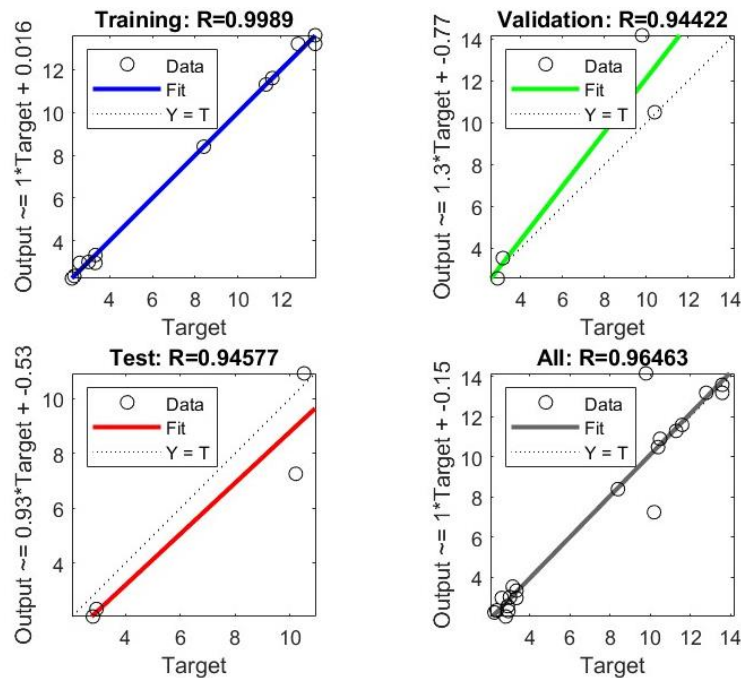


Figure 6. Training, testing, and validation of ANN for the wire-cut EDM process

3. RESULTS AND DISCUSSIONS

3.1 Taguchi Optimization

It is a technique for objectively assessing the impact of modifying one process variable on another. This approach will begin with the identification of several experimental plans, followed by several trials. A spreadsheet was used to lay out

the process's outcomes for additional analysis. This study identified nine different experimental models for executing the process, as there are three inputs. They are often described as an orthogonal array of experiments [47-49]. The signal-to-noise (S/N) ratios and normalized S/N ratios were computed to determine the ideal and most significant process variables according to the output, utilizing various methodologies. The calculations for the signal-to-noise ratio and normalized signal-to-noise ratio typically differ between methodologies. For best results, some outputs should be as low as possible, while other outputs should be as high as possible [50]. This investigation employs an L9 orthogonal array and determines that a greater specified strength for fatigue and a reduced specified wear rate is desirable. The S/N ratio is represented by the following equations: (1) and (2), respectively, while the normalized S to N ratio is delineated in Equations (3) and (4). Table 3 delineates the array of planned experiments utilized in the present investigation to attain optimal results.

Larger the better

$$\frac{S}{N} \text{ ratio} = -10 \log(1/n) + (1|Y_{IJ}^2) \quad (1)$$

Smaller the better

$$\frac{S}{N} \text{ ratio} = -10 \log(1/n) + (Y_{IJ}^2) \quad (2)$$

Larger the better

$$X_{ij} = \frac{(Y_{IJ} - \min(Y_{IJ}))}{\max(Y_{IJ}) - \min(Y_{IJ})} \quad (3)$$

Smaller the better

$$X_{ij} = \frac{(\max(Y_{IJ}) - Y_{IJ})}{\max(Y_{IJ}) - \min(Y_{IJ})} \quad (4)$$

where,

- n Number of replications for each experiment
- Y_{ij} Response values
- X_{ij} Normalized Signal-to-Noise Ratio
- Y_{ij} Signal-to-noise ratio derived from Taguchi experimentation

3.2 Grey Relational Analysis

Ultimately, grey relational analysis was employed to regulate the primary components affecting weld quality. Each trial pattern is assigned a comparable amount of grey relation coefficients; hence, the GRG score is employed to determine the optimal process design. Verification tests were conducted using the optimal ranges of the examined variables to demonstrate the enhancement of a significant attribute, specifically the grey relation grade. The grey relation value for all sequencing and the average grey relation value for all iterations can be calculated using equations (5) and (6). The parameter utilized in the separation procedure is designated with a significance threshold of 0.5 for each conducted experiment.

$$GC_{ij} = \frac{(\delta \min + \phi \delta \max)}{(\delta_{IJ} + \phi \delta \max)} \quad (5)$$

$$Gi = (1|m) \sum GC_{ij} \quad (6)$$

3.3 Verification Assessment

The validation test confirmed the accuracy of the data obtained by the grey relational analysis. The quantities of all influencing elements, as indicated by the method variables, were analyzed in connection to the mean grey relation grade, as outlined in Equation (7).

$$Y = Y_m + \sum (Y_n - Y_m) \quad (7)$$

where,

- Y_m Average grey relationship grade
- Y_n Grey relation grade at an optimal level

3.4 Material Removal Rate

The SEM image of the surface machined by EDM is shown in Figure 6. Reinforcing the metal matrix composites with SiC nanoparticles gives them extremely high strengths. The surface that has been machined using dielectric has an average material removal rate (MRR) of 5.83mm³/min. A weak and moderately strong pulse enhances the strength and hardness of AA70750-Sic MMC, which in turn reduces the material removal rate. On top of that, the conventional dielectric is no match for the biosilica-activated dielectric. The deionized dielectric water provides an improved Material Removal Rate (MRR) of 6.26, 7.72, 7.86, 6.74, and 6.23mm³/min, whereas the biosilica-activated water in its original state yields an MRR of 8.84, 9.62, 10.47, 8.52, and 8.61mm³/min. The incorporation of Al₂O₃ – SiO₂ nanoparticles into an EDM

kerosene dielectric resulted in a notable reduction in EWR and SR, while simultaneously enhancing MRR [51]. Figure 7(a) demonstrates that the surface topography of the EDM-machined surface with a common dielectric is slightly uneven. The variable and uneven topography leads to material removal occurring in distinct ranges, and then the reverse flow of that removed material. Figures 7(b) and (c) show that the machined surface is uniform in dielectrics ABD1 and ABD3. Improved heat evacuation from the machining zone and more consistent machining are two benefits of using biosilica particles. The MRR is increased while biosilica particles treated with silane in deionized water are used instead of biosilica particles in deionized water in their untreated state. The perfect surface polish is achieved by aligning the particle network and increasing the spark length. The biosilica-deionized water dielectrics TBD1, TBD3, and TBD5 are rendered on the machined surface in Figures 7(d)–(f). There are no divots or dents in the extremely level surfaces. On the other hand, a machined surface that was rather uneven was produced by the increased concentration of biosilica in the fluid. The MRR varied between roughly 7.72 and 8.86 mm³/min with regular deionized water. The MRR improved by 25–30% above standard dielectric when biosilica was added, reaching 10.47 mm³/min under ideal conditions and 11.89 mm³/min. The improved heat dissipation and increased spark intensity, made possible by the biosilica particles suspended in the dielectric fluid, are responsible for the performance increase. When biosilica is treated with silane, the surface chemistry of the particles is altered, improving their compatibility and dispersion within the deionized water dielectric. In the spark gap, this results in a uniform distribution of insulating particles and an increase in effective dielectric conductivity, both of which support stable and controlled electrical discharge conditions.

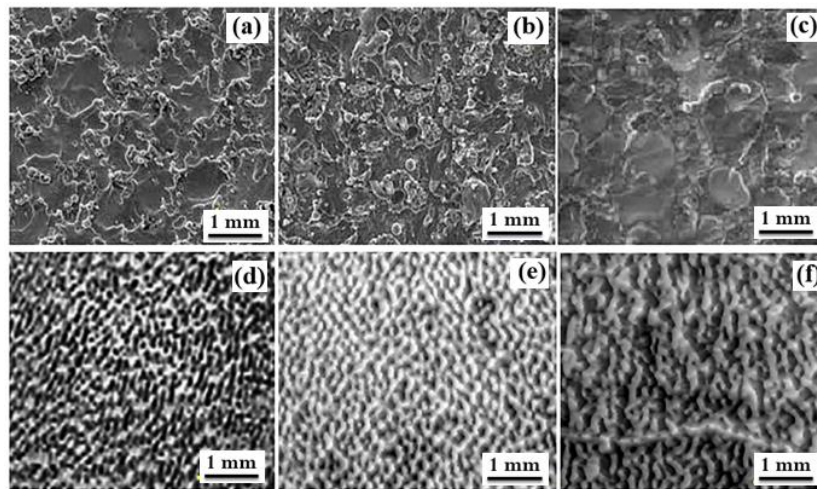


Figure 7. SEM topography of the machined surface (a) ABD0 (b) ABD1 (c) ABD3 (d) TBD1 (e) TBD3 (f) TBD5

3.5 Surface Roughness

The AFM images of a plain dielectric, untreated (ABD3) and treated biosilica (TBD3) from the machined surface are shown in Figures 8(a), (b), and (c), respectively. These clusters affect both electron transit and spark quality. Figure 8(a) indicates that the presence of high spikes increases up to 0.32 μm , the likelihood of a poor finish on the machined surface. Regular tap water lacks the lubricating qualities necessary to preserve a high-quality finish. However, the use of treated and untreated biosilica shows shorter spike lengths of 0.22 μm and 0.18 μm at 8(b) and 8(c). More effective material removal was made possible using biosilica, which has a strong spark intensity and effective temperature control. With plain dielectric, surface roughness values (R_a) were more variable and greater, suggesting lower surface quality. Consistently lowering surface roughness to as low as 2.30 μm , treated biosilica dielectrics showed enhanced surface homogeneity and few flaws, such as microcracks or debris. This is supported by AFM and SEM tests, which visibly verified smoother, more uniform surfaces created with the help of biosilica. Silane coupling agents promote the retention of surface charge in particles by grafting functional groups onto biosilica. These charged particles help to reduce the so-called "breakdown voltage" threshold in the high-voltage environment of WEDM by serving as favorable locations for electron accumulation. Sparking becomes more consistent and intense as a result of this effective improvement in spark-generating frequency and homogeneity over the machining gap. A key factor in increased MRR and improved surface quality is the enhanced charge transfer from the electrode to the workpiece. The creation of plasma channels during discharge events is influenced by the presence of silane-treated, well-dispersed biosilica in the spark gap. The particles stabilize the plasma column and stop weak or unpredictable sparking by facilitating quick changes in local field intensity. Furthermore, biosilica suspensions' improved thermal conductivity makes it possible for heat to dissipate from the spark channel more effectively, which lowers the risk of microcrack development, thermal damage, and local overheating at the freshly machined surface.

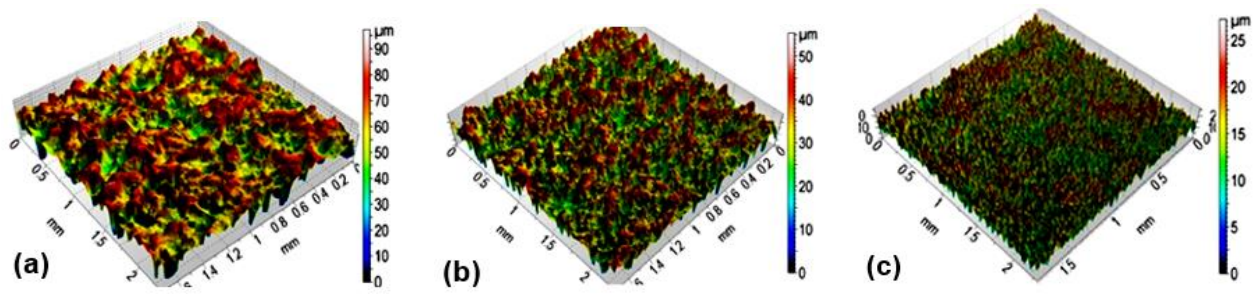


Figure 8. AFM photographs of the machined surface: (a) the Normal dielectric layer, (b) ABD3, (c) TBD3

3.6 Optimization of Machining Variables

The experimental design illustrated in Figure 9 and the appropriate reaction column for the material removal rate (MRR) and surface roughness of various process variables pertinent to the EDM process in Table 3 were employed during the milling technique. The finish of the surface and the material removal rate exhibit variations influenced by the parameters of the operation. This study illustrates that an increase in MRR correlates with enhanced results, whereas a decrease in roughness on the surface is also beneficial.

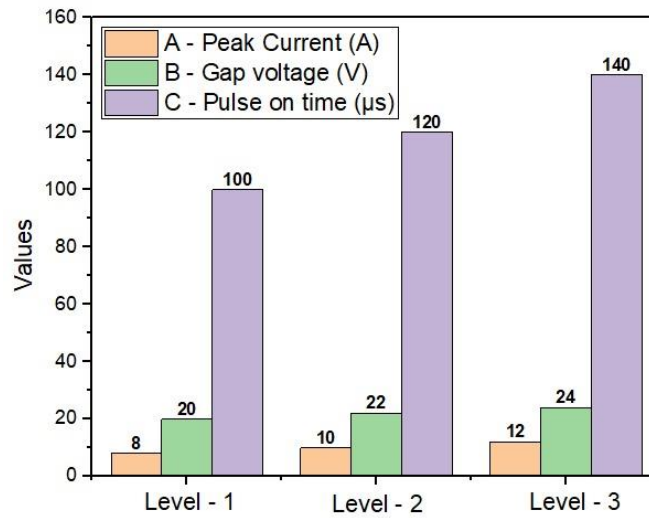


Figure 9. Experiment plan

Table 3. Response table

Trial Runs	A ₁	B ₁	C ₁	MRR (mm ³ /min)	Ra (μm)
1	10	20	140	11.6	2.25
2	8	22	120	10.2	2.81
3	8	24	100	8.4	2.36
4	12	22	140	12.8	2.61
5	10	22	120	10.5	2.94
6	12	22	100	9.8	3.16
7	12	20	140	13.6	3.34
8	10	22	140	10.4	2.91
9	8	24	140	11.3	3.02

The interplay of signal-to-noise ratio, surface roughness (Ra), and the material removal rate (MRR) is depicted in Table 4. Even though the roughness of the surface shows a negative trend, the material's removal rate and signal-to-noise ratio indicate a positive outcome. A better idea produces a more sophisticated result. The obtained S/N ratio is subsequently used to determine the standardized S/N ratio, which is fixed at 1. The computation of the grey relational grades relies on a normalized signal-to-noise ratio. The GRGs create a framework for each experiment.

Table 4. Noise to signal ratio for responses

Trial Runs	MRR (mm ³ /min)		Ra (μm)	
	S/N ratio	Normalized S/N	S/N ratio	Normalized S/N
1	21.28	0.65	-7.04	1.0
2	20.177	0.43	-8.97	0.47
3	18.5	0.0	-7.45	0.94
4	22.14	0.88	-8.33	0.68
5	20.42	0.42	-9.36	0.34
6	19.82	0.37	-9.99	0.17
7	23.01	1.0	-10.47	0.0
8	20.36	0.48	-9.27	0.35
9	21.54	0.74	-9.59	0.37

The primary experimentation, as shown in Table 5, secured a position of 1 (A2B1C3) and received a GRG score of 0.79. The results indicate that during the study, a material removal rate of 11.6 mm/min and a surface roughness of 2.2 μm were accomplished with a maximum current of 10 A, a gap voltage of 20 V, and a pulse duration of 140 μs being applied.

Table 5. Grey relational coefficients and evaluation metrics

Trial Runs	GRC		GRG	Rank
	MRR	Ra		
1	0.57	1.00	0.79	1
2	0.45	0.48	0.47	6
3	0.34	0.82	0.57	4
4	0.73	0.58	0.65	3
5	0.48	0.44	0.45	8
6	0.41	0.37	0.39	9
7	1.01	0.34	0.68	2
8	0.47	0.44	0.47	7
9	0.62	0.41	0.52	5

The analysis of the grey relationship grade (GRG) according to different levels is presented in Figure 10. The study points out that the gap voltage is the most important among the process variables, and it reveals a considerable value in the maximum-minimum level assessment. The polarity level and the distance across the gap are the two factors that determine the creation of pulses. The presence of biosilica is a factor that affects the voltage level in such a way that gap voltage becomes the most important process variable for obtaining high removal of material ratios (MRR) while simultaneously keeping the surface roughness low. The mean values are shown in Figures 11 (a) and (b), and the GRG is plotted accordingly. Experiments 1, 7, 4, 3, and 9 are the ones in which process variables showed the most noteworthy effect, and these contributed to the overall GRG quite a lot compared to the other experiments. New optimized values have been assigned to the variable parameters as per the results given in Table 7.

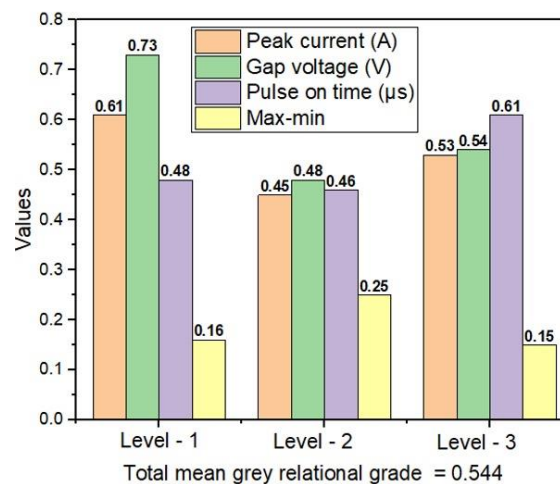


Figure 10. Average of grey relational grades categorized by levels

The optimized amalgamation of process variables labeled A1B1C3 aims to augment the material removal rate while reducing surface roughness. A validation study will be conducted to validate the efficacy of this new set of variables for the process, as specified in Equation 7. Research utilizing the Taguchi method and Grey relational analysis indicated that the ideal process parameters were a maximum power of 10 amps, a gap voltage of approximately 20 volts, with a pulse-on duration of 140 μ s. The dependability of reported improvements was confirmed by the close match between the Artificial Neural Network (ANN) modeling and experimental results ($R^2 = 0.9646$). In addition to its technical advantages, the advent of biosilica promotes environmentally friendly and sustainable manufacturing by using agricultural waste.

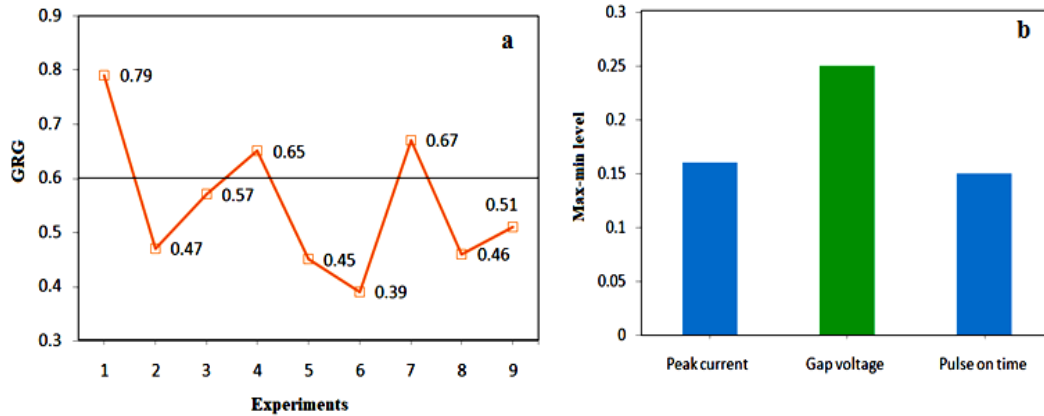


Figure 11. (a) Comparing grey relational grades with experimental trials, (b) Max-min levels vs. variables

3.7 Statistical Analysis Results

Statistical validation was performed using the Analysis of Variance (ANOVA) to evaluate the significance and influence of every control parameter on the results. The ANOVA indicated in Table 6 shows the exceptional model fit for Material Removal Rate (MRR), with $R\text{-Sq} = 99.80\%$. Factor C (Pulse on time) exhibited the most substantial impact (58.31% , $p = 0.004$), followed by factor A (33.48% , $p = 0.008$), and both factors demonstrated significant effects at the 95% confidence level. The analysis of variance (ANOVA) results for the Surface roughness (SR) demonstrated an $R\text{-Sq}$ of 93.79% , $p = 0.01$, signifying that the parameters influence the quality of the surface (Table 7).

Grey relations analysis (GRA) was used to convert the multiple response optimization problem into a single comparable objective function through Grey Relation Grades (GRG). The normalized S/N ratios for both replies were converted into Grey Relational Coefficients with a distinguishing coefficient of $\zeta = 0.5$, and then averaged to derive GRG values. Table 8 specifies the ANOVA conducted on the GRG data, which produced $R\text{-Sq} = 92.84\%$ signifying an adequate model fit for multi-objective optimization. Factor B (50.75% , $p = 0.012$) contributed to the total grey relational grade, while the significance of the result was due to the residual variation (8.65%). The optimum parameter combination ascertained by GRA was $A_1 = 10$, $B_1 = 20$, $C_1 = 140$, leading to a maximum Grey Relational Grade of 0.790. Statistical analysis ratified that the Taguchi-GRA technique has proven to be competent for the optimization of several performance parameters in the process of machining.

Table 6. Variance analysis of the Material Removal Rate (MRR)

Source	DF	Adj SS	Adj MS	F-Value	p-Value	Contribution (%)
A	2	5.231	2.615	130.77	0.008	33.48
B	2	1.243	0.622	31.08	0.031	7.96
C	2	9.111	4.555	227.77	0.004	58.31
Residual	2	0.040	0.020	-	-	0.26
Source	DF	Adj SS	Adj MS	F-Value	p-Value	Contribution (%)

Table 7. Evaluation of variation for Surface Roughness (Ra)

Source	DF	Adj SS	Adj MS	F-Value	p-Value	Contribution (%)
A	2	0.287	0.144	0.42	0.01	51.57
B	2	0.040	0.020	0.06	0.04	13.60
C	2	0.114	0.057	0.17	0.02	27.13
Residual	2	0.681	0.341	-	-	7.70
Total	8	1.123	-	-	-	100.00

Table 8. Evaluation of Variance of Grey Relation Grade (GRG)

Source	DF	Adj SS	Adj MS	F-Value	p-Value	Contribution (%)
A	2	0.000397	0.000199	0.007	0.042	11.25
B	2	0.043460	0.021730	0.761	0.012	50.75
C	2	0.005707	0.002854	0.100	0.024	29.35
Residual	2	0.057089	0.028545	-	-	8.65
Total	8	0.107	-	-	-	100.00

3.8 Potential Industrial Applications

This section will discuss the scalability of biosilica-assisted WEDM and its potential industrial applications. The use of biosilica - a by-product of eco-friendly agriculture - in the form of a dielectric additive will be presented as a revolutionary solution for both surface quality and machining efficiency enhancement in precision manufacturing. Different factors affecting scalability will be reviewed, including cost-effectiveness, biomass availability, and the compatibility of the proposed technology with existing industrial WEDM setups. Furthermore, we will highlight the areas of application in the biomedical, automotive, and aerospace industries where eco-friendly, high-precision, and low-cost machining is essential for high-performance composites. The discussion will explore the approach's broader impact and its flexibility for future adaptation.

The aviation equipment industry frequently uses aluminum matrix composites as lightweight, high-strength materials. The biosilica dielectrics facilitate better machining of those materials directly by providing improved precision and surface integrity. This development entails longer fatigue-resistance lifecycles, greater corrosion resistance, and reduced weight, all of which are vital for both safety and fuel efficiency. Parts of the engine, brake systems, and structures made of SiC-reinforced aluminum composites are less consumed and have their production aligned with WEDM assisted by biosilica. It is also a manufacturing process that is more sustainable, since it not only requires less energy and time, but also produces high-quality products with minimal post-processing. Utilizing biosilica derived from maize cobs creates a circular economy because it not only mitigates environmental impacts in production processes but also increases the value of abundant agricultural waste and reduces dependence on synthetic additives. This green machining approach, friendlier to the environment, can be extended to precision tools, electronics, and medical devices, where the application of intricate composites demands combining superior machining with non-toxic additives.

4. CONCLUSIONS

A novel AA7075-SiC metallic matrix composite (MMC) was created and processed effectively using electric wire-cutting discharge machining (WEDM). The dielectric fluid was also enhanced by adding biosilica derived from maize cobs, which helped in the machining process. The biosilica-decorated dielectric fluid achieved a maximum material removal rate of 11.89 mm³/min and a mean surface roughness of 2.30 μm, thereby improving performance by 25-30% compared to standard deionized water. In the statistical assessment using ANOVA and Grey Relational Analysis, the gap voltage was identified as the most influential factor for material removal rate and surface finish optimization. The SEM and AFM studies indicated that silane-modified biosilica improved spark quality and plasma channel stability, resulting in even smoother machined areas with more uniform material removal. The optimization method was tested using an Artificial Neural Network (ANN) model, which achieved very good predictive accuracy ($R^2 = 0.9646$), thus confirming the process's trustworthiness. The application of biosilica derived from agricultural waste enables eco-friendly machining methods and holds a bright future for composite production in the aerospace and automotive industries. The study results are as follows:

- i) A gap voltage was the main factor affecting machining efficiency in both optimization procedures.
- ii) Dies that contain biosilica work much better in machining and improve surface quality because they keep the plasma stable.
- iii) The ANN model enhances the optimization process, achieving exceptional accuracy in predicting ($R^2 = 0.9646$).

5. FUTURE SCOPE AND LIMITATIONS

New green dielectrics made from agricultural waste biosilica and their use in precision WEDM of metal matrix composites (WEDM) are going to be a major revolution in terms of traditional methods, the ecosystem, quality, and efficiency. The proposed method is not just a significant advance over traditional methods but also a highly viable standard for eco-friendly production in high-tech industries, as it is grounded in the idea of sustainability through the use of surface-engineered nanofillers (biologically sourced materials such as silane-treated biosilica) and the instability of the spark in controlling the process. When these findings are considered, the door is unlocked to introduce bio-based additives into advanced machining, which will benefit not only the precision device, automotive, and aerospace industries but also the environment, as they will gain the dual advantage of performance and reduced ecological footprint [52]. With foresight into future studies, it is expected that the development of multi-objective optimization techniques to further align the sustainability of the process with industrial-scale productivity, as well as the wider use of biosilica and other biogenic

additives in EDM and micromachining, will be the remits of research. Though this investigation demonstrates the potential of biosilica to improve the WEDM performance of AA7075–SiC composites, there are still limitations to consider. Firstly, the ANN model is based on a small set of experiments, which may limit its applicability within the scope of machining conditions. Secondly, the study pertains to only one metal matrix composite (AA7075–SiC), and comparisons with other reinforcements, such as TiB₂, Al₂O₃, or hybrid composites, could further corroborate the universality of the suggested technique. Moreover, tool wear behavior was not included in the current study, which could be an important factor in determining long-term machining efficiency and economic viability. These aspects will be explored in our upcoming work to enhance the understanding of the biosilica-assisted WEDM process.

ACKNOWLEDGEMENTS

Acknowledgements are extended to Dhilipkumar T for taking the SEM images.

FUNDING

This study did not obtain funding from entities within the governmental, commercial, or non-profit sectors.

CONFLICT OF INTEREST

The authors did not provide information regarding any conflicts of interest.

AUTHORS CONTRIBUTION

Sakthimurugan D. (Conceptualization; Formal analysis; Writing - original draft)

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Praveen Kumar A. (Data curation; Writing - original draft; Resources)

Praveenkumar Vijayakumar (Conceptualization; Formal analysis; Visualisation; Supervision)

Barath Kumar M. D. (Methodology; Writing - original draft; Resources)

REFERENCES

- [1] P. Sarmah and K. Gupta, "Recent advancements in fabrication of metal matrix composites: A systematic review," *Materials*, vol. 17, no. 18, p. 4635, 2024.
- [2] P. K. Gupta, A. K. Trivedi, M. K. Gupta, and M. Dixit, "Metal matrix composites for sustainable products: A review on current development," *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 238, no. 10, pp. 1827-1864, 2024.
- [3] Y. Huang, Y. Hu, X. Liu, X. Wang, S. Wu, and H. Shi, "High-quality manufacturing with electrochemical jet machining (ECJM) for processing applications: A comprehensive review, challenges, and future opportunities," *Micromachines*, vol. 16, no. 7, p. 794, 2025.
- [4] H. K. Garg, S. Sharma, R. Kumar, A. Manna, S. P. Dwivedi, M. Abbas, et al., "Mechanical, tribological, and morphological properties of SiC and Gr reinforced Al-0.7Fe-0.6Si-0.375Cr-0.25Zn based stir-casted hybrid metal matrix composites for automotive applications: Fabrication and characterizations," *Journal of Materials Research and Technology*, vol. 28, pp. 3267–3285, 2023.
- [5] V. Jurwall, A. K. Sharma, A. Pandey, and V. K. Pathak, "Mechanical and wear characterization of alumina/B4C/SiC reinforced Al-6061 alloy metal composites," *Composites: Mechanics, Computations, Applications: An International Journal*, vol. 13, no. 3, pp. 55–74, 2022.
- [6] R. K. Mandava, V. V. Reddy, V. R. K. Rao, and K. S. Reddy, "Wear and frictional behaviour of AL 7075/FA/SiC hybrid MMC's using response surface methodology," *Silicon*, vol. 14, no. 10, pp. 5319–5331, 2021.
- [7] R. K. Bhushan, "Effect of tool wear on surface roughness in machining of AA7075/10 wt.% SiC composite," *Composites Part C: Open Access*, vol. 8, p. 100254, 2022.
- [8] H. M. A. Mahmoud, P. Satishkumar, Y. S. Rao, R. Chebolu, R. Y. Capangpangan, A. C. Alguno, et al., "Investigation of mechanical behavior and microstructure analysis of AA7075/SiC/B4C-based aluminium hybrid composites," *Advances in Materials Science and Engineering*, vol. 2022, pp. 1–10, 2022.
- [9] S. J. Juliyana, J. Udaya Prakash, C. S. Rubi, S. Salunkhe, S. R. Gawade, E. S. Abouel Nasr, et al., "Optimization of wire EDM process parameters for machining hybrid composites using grey relational analysis," *Crystals*, vol. 13, no. 11, p. 1549, 2023.
- [10] N. Pragadish, S. Kaliappan, M. Subramanian, L. Natrayan, K. Satish Prakash, R. Subbiah, et al., "Optimization of cardanol oil dielectric-activated EDM process parameters in machining of silicon steel," *Biomass Conversion and Biorefinery*, vol. 13, no. 15, pp. 14087–14096, 2022.
- [11] R. Suresh Babu, B. Jegadeeswaran, S. Srisoorya, S. Tharvin, C. Vasanthakumar, M. Ganesan, et al., "Recent research in wire cut electrical discharge machining process," *Journal on Materials and its Characterization*, vol. 3, no. 1, pp. 41–51, 2024.

- [12] K. Suresh, K. Karuppasamy, S. Palani, S. S. J. Krishnan, and T. Maridurai, "Effect of silane treated wheat husk biosilica (WHB) deionized water dielectric on EDM drilling of Ti-6Al-4V alloy," *Silicon*, vol. 14, no. 14, pp. 9143–9151, 2022.
- [13] M. Abdul-Rani, M. Muhammad, T. V. V. L. N. Rao, S. Rubaiee, A. Ahmed, and M. Danish, "Conventional and powder mixed electro-discharge machining," in *CRC Press eBooks*, 2024.
- [14] E. Boominathan, G. Krishnan, C. Gurijala, and J. Vm, "Studies on the effect of SiC nanopowder concentration and discharge energy on surface roughness and recast layer in micro ED milling of Inconel 718 alloy," *Physica Scripta*, vol. 100, no. 1, p. 015901, 2024.
- [15] K. Sivakumar, J. V. Sai Prasanna Kumar, K. Loganathan, V. Mugendiran, T. Maridurai, and K. Suresh, "Machining characteristics of silane-treated wheat husk biosilica in deionized water dielectric on EDM drilling of Ti-6Al-4V alloy," *Biomass Conversion and Biorefinery*, vol. 14, no. 1, pp. 199–206, 2022.
- [16] Gul, A. M. Abdul-Rani, M. Al-Amin, and E. Garba, "Elucidating powder-mixed electric discharge machining process, applicability, trends and futuristic perspectives," *Machines*, vol. 11, no. 3, p. 381, 2023.
- [17] Abdudeen, J. E. A. Qudeiri, A. Kareem, T. Ahammed, and A. Ziout, "Recent advances and perceptive insights into powder-mixed dielectric fluid of EDM," *Micromachines*, vol. 11, no. 8, p. 754, 2020.
- [18] Samir, F. H. Ashour, A. A. Hakim, and M. Bassyouni, "Recent advances in biodegradable polymers for sustainable applications," *Npj Materials Degradation*, vol. 6, no. 1, p. 68, 2022.
- [19] W. Abd-Elaziem, S. Elkhatny, A. E. Abd-Elaziem, M. Khedr, M. A. Abd El-baky, M. A. Hassan, et al., "On the current research progress of metallic materials fabricated by laser powder bed fusion process: A review," *Journal of Materials Research and Technology*, vol. 20, pp. 681–707, 2022.
- [20] Schubert, V. D. Bui, I. Schaarschmidt, T. Berger, and A. Martin, "Developments in powder mixed EDM and its perspective application for targeted surface modification," *Procedia CIRP*, vol. 113, pp. 100–119, 2022.
- [21] S. Srivastava, M. Vishnoi, M. T. Gangadhar, and V. Kukshal, "An insight on powder mixed electric discharge machining: A state of the art review," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 237, no. 5, pp. 657–690, 2023.
- [22] H. Alshahrani and V. R. A. Prakash, "Effect of silane-grafted orange peel biochar and areca fibre on mechanical, thermal conductivity and dielectric properties of epoxy resin composites," *Biomass Conversion and Biorefinery*, vol. 14, no. 6, pp. 8081-8089, 2022.
- [23] P. Nzereogu, A. Omah, F. Ezema, E. Iwuoha, and A. Nwanya, "Silica extraction from rice husk: Comprehensive review and applications," *Hybrid Advances*, vol. 4, p. 100111, 2023.
- [24] B. Seghir, H. Hemmami, B. M. E. Hocine, Z. Soumeia, M. Sharifi-Rad, C. G. Awuchi, et al., "Methods for the preparation of silica and its nanoparticles from different natural sources," *Biological Trace Element Research*, vol. 201, no. 12, pp. 5871–5883, 2023.
- [25] G. Singh, A. Kumar, A. Kumar, and A. Maity, "Approaches to silica production from agriculture waste biomass," in *Intelligent Systems Reference Library*, 2025, pp. 207–230.
- [26] N. S. Choudhury, "A review of the sol-gel process and its application," *International Education and Research Journal*, vol. 10, no. 7, 2024.
- [27] Aabid, M. A. Murtuza, S. A. Khan, and M. Baig, "Optimization of dry sliding wear behavior of aluminium-based hybrid MMC's using experimental and DOE methods," *Journal of Materials Research and Technology*, vol. 16, pp. 743–763, 2021.
- [28] P. Raj, P. Biju, B. Deepanraj, and N. Menachery, "A systematic review on characterization of hybrid aluminium nanocomposites," *Materials Today: Proceedings*, vol. 72, pp. 2139–2150, 2022.
- [29] U. B. G. Krishna, B. Vasudeva, V. Auradi, and M. Nagaral, "Effect of percentage variation on wear behaviour of tungsten carbide and cobalt reinforced AL7075 matrix composites synthesized by melt stirring method," *Journal of Bio-and Tribo-Corrosion*, vol. 7, no. 3, p. 89, 2021.
- [30] Bhowmik, A. M. Nithin, R. Kumar, K. Venkadeshwaran, A. Alhazaa, H. S. Gill, et al., "Prediction friction forecasting in AA7075 composites through ensemble and probabilistic machine learning," *Journal of Sol-Gel Science and Technology*, pp.1-17, 2025.
- [31] N. Muthuram and F. C. Frank, "Optimization of machining parameters using artificial intelligence techniques," *Materials Today: Proceedings*, vol. 46, pp. 8097–8102, 2021.
- [32] P. Abhilash and D. Chakradhar, "Failure detection and control for wire EDM process using multiple sensors," *CIRP Journal of Manufacturing Science and Technology*, vol. 33, pp. 315–326, 2021.
- [33] Y. S. Sable, H. M. Dharmadhikari, S. A. More, and I. E. Sarris, "Exploring artificial neural network techniques for modeling surface roughness in wire electrical discharge machining of Aluminum/Silicon carbide composites," *Journal of Composites Science*, vol. 9, no. 6, p. 259, 2025.
- [34] U. K. U. Zaman, U. A. Khan, S. Aziz, A. A. Baqai, S. U. Butt, D. Hussain, et al., "Optimization of wire electric discharge machining (WEDM) process parameters for AISI 1045 medium carbon steel using Taguchi design of experiments," *Materials*, vol. 15, no. 21, p. 7846, 2022.
- [35] Sakthimurugan, L. A. M. Raj, V. A. A. Raj, and N. S. Sivakumar, "Wire-cut electrical discharge machining of novel MMCs using silane-treated corn cob biosilica-deionized green dielectric: A cleaner production approach," *Biomass Conversion and Biorefinery*, vol. 13, no. 5, pp. 4373–4383, 2022.
- [36] M. Gostimirović, D. Rodić, and M. Sekulić, "Fuzzy inference system-based prediction of electrical discharge machining quality," *Tehnika*, vol. 76, no. 3, pp. 318–325, 2021.

- [37] Z. Xu, X. Zhang, S. Wang, and G. He, "Artificial neural network-based response surface for data-driven dimensional analysis," *Journal of Computational Physics*, vol. 459, p. 111145, 2022.
- [38] S. A. Rizvi and W. Ali, "Analysis of surface roughness and material removal rate in machining of AISI 1040 steel using CNC turning process," *International Journal of Innovation in Engineering*, vol. 1, no. 3, pp. 8–19, 2021.
- [39] T. Senthilkumar, R. Muralikannan, T. Ramkumar, and S. S. Kumar, "Studies of kerf width and surface roughness using the response surface methodology in AA 4032–TiC composites," *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, vol. 235, no. 6, pp. 2240–2253, 2021.
- [40] V. Kumar and S. C. Mondal, "Experimental investigation and optimization of WEDM process parameters for the development of NI-based hardfaced turning tool insert using hybrid GA-COCOSO technique," *Journal of The Institution of Engineers (India): Series D*, vol. 106, no. 2, pp. 801–816, 2024.
- [41] S. Ganapathy, P. Balasubramanian, B. Vasanth, and S. Thulasiraman, "Comparative investigation of artificial neural network (ANN) and response surface methodology (RSM) expectation in EDM parameters," *Materials Today: Proceedings*, vol. 46, pp. 9592–9596, 2020.
- [42] S. Kumar, S. Kumar, R. Sharma, M. Singh, and R. Singh, "Artificial neural network based modeling to predict micro-hardness during EDM of cryo-treated titanium alloys," *Materials Today: Proceedings*, vol. 56, pp. 2938–2944, 2022.
- [43] S. Debnath, B. Sen, N. Patil, A. Kedia, V. S. Mann, et al., "Predictive modeling of MRR, TWR, and SR in spark-EDM of Al-4.5Cu–SiC using ANN and GEP," *AIP Advances*, vol. 14, no. 9, p. 095225, 2024.
- [44] X. R. Xavier and S. J. Jaisingh, "Synthesis and characterization of AA7050-TiO₂ reinforced aluminium matrix composite," *Journal of Mechanical Science and Technology*, vol. 35, no. 11, pp. 4917–4924, 2021.
- [45] O. Prempeh, S. Formann, I. Hartmann, and M. Nelles, "An improved method for the production of biogenic silica from cornhusk using sol–gel polymeric route," *Biomass Conversion and Biorefinery*, vol. 14, no. 22, pp. 28701–28711, 2022.
- [46] U. M. R. Paturi, H. Devarasetti, N. Reddy, N. Kotkunde, and B. Patle, "Modeling of surface roughness in wire electrical discharge machining of Inconel 718 using artificial neural network," *Materials Today: Proceedings*, vol. 38, pp. 3142–3148, 2020.
- [47] X. Wang, S. Yi, H. Guo, C. Li, and S. Ding, "Erosion characteristics of electrical discharge machining using graphene powder in deionized water as dielectric," *The International Journal of Advanced Manufacturing Technology*, vol. 108, no. 1–2, pp. 357–368, 2020.
- [48] Z. Wu, X. Wu, R. Chen, Y. Yang, M. Wang, L. Xu, L. Meng, and B. Wu, "Working end wear of 3D-laminated microelectrode in reverse-polarity PMEDM with Gr and Cu powders," *The International Journal of Advanced Manufacturing Technology*, vol. 131, no. 7–8, pp. 3555–3564, 2024.
- [49] M. W. Hisam, A. A. Dar, M. O. Elrasheed, M. S. Khan, R. Gera, I. Azad, "The versatility of the Taguchi method: Optimizing experiments across diverse disciplines," *Journal of Statistical Theory and Applications*, 2024.
- [50] Sakthimurugan, L. A. M. Raj, V. A. A. Raj, and K. Thavasilingam, "Taguchi-Grey optimization of surface roughness and material removal rate on electro-discharge machining of novel AA7075-TiO₂ metal matrix composite using waste corncob biosilica dielectrics," *Surface Review and Letters*, vol. 32, no. 1, p. 2450103, 2024.
- [51] Q. A. Sachit and M. A. Tawfiq, "Surface evaluation of EDM 304L stainless steel in a mixed dielectric of Al₂O₃-SiO₂ nanopowder," in *AIP Conference Proceedings*, vol. 3211, no. 1, p. 060013, 2025.
- [52] Ishfaq, N. Ahmad, M. A. Maqsood, M. U. Hameed, L. Lamberti, and C. I. Pruncu, "A systematic study to achieve cleaner and sustainable manufacturing process by using bio-degradable dielectrics," *Sustainable Materials and Technologies*, vol. 37, p. e00685, 2023.