iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** IV **Month of publication:** April 2025

DOI: https://doi.org/10.22214/ijraset.2025.68300

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

A Comprehensive Review of Optimization Methods for WEDM of AISI D2 Steel

Vishal Rajak
Lecturer (GFL), Department of Mechanical Engineering, Govt. Polytechnic College, Raghogarh, Dist. Guna (M.P.), India

Abstract: ***Wire Electric Discharge Machining (WEDM) is a highly utilized machining technique across various industries, particularly for die-punch fabrication and machining of hard, brittle materials. It is also extensively applied in producing intricate and complex geometries with precision. The efficiency of the WEDM process largely depends on selecting appropriate machining parameters. In the manufacturing industry, optimization methods play a vital role in determining the most effective machining conditions, enabling industries to manufacture high-quality components while minimizing costs. However, identifying the ideal combination of process parameters to maximize the material removal rate in WEDM presents a significant challenge. This paper examines various optimization techniques used to improve material removal rates by refining key machining parameters.***

Keywords: WEDM, AISI D2 Steel, Taguchi, RSM, MRR.

I. INTRODUCTION

Electric Discharge Machining (EDM) is a non-traditional machining process widely used for shaping complex profiles on electrically conductive materials that exhibit high strength and resistance to elevated temperatures. Due to its versatility in the manufacturing industry, EDM has gained significant prominence and is now one of the most widely used machining techniques after conventional methods such as turning, milling, and drilling. Its ability to process hard materials with precision makes it a preferred choice for various industrial applications.

EDM operates on the principle of electro-thermal machining, where electrical energy is used to generate controlled sparks between the tool and the workpiece. These sparks produce intense thermal energy, which facilitates the removal of material from the workpiece. This unique mechanism enables EDM to efficiently machine intricate shapes and hard-to-cut materials that are difficult to process using conventional techniques.

In Electric Discharge Machining (EDM), material removal occurs due to localized melting and vaporization of the workpiece. The EDM process is broadly categorized into three main types, further divided into eight sub-categories, as depicted in Figure1.

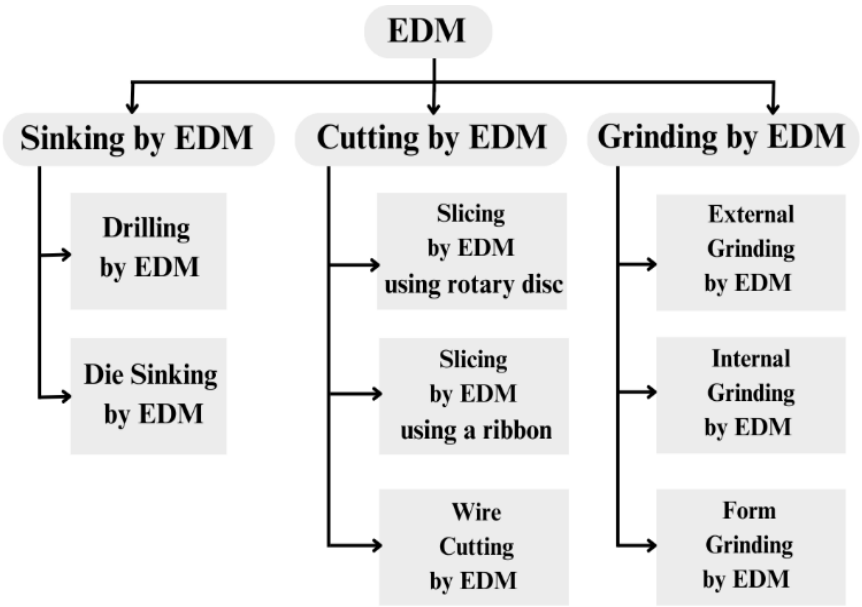


Fig1: Classification of Electric Discharge Machining (EDM).

©IJRASET: All Rights are Reserved

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

Wire Electrical Discharge Machining (WEDM) is a non-contact subtractive manufacturing method that utilizes a thin, electrically charged wire along with a dielectric fluid to shape metal components. Instead of mechanically cutting the material, the process removes it by melting or vaporizing small portions, generating fine chips and precise cut lines. This makes WEDM particularly useful for machining intricate parts that are difficult to manufacture using conventional methods. However, the material must be electrically conductive for the process to work effectively.

During machining, the workpiece is submerged in a dielectric fluid and secured using a machinist vise. The wire, carrying an electric charge, passes through the workpiece, creating sparks that erode the material. Essentially, the wire holds one side of the electrical charge, while the conductive workpiece carries the opposite charge. As they come close, a high-temperature electrical discharge bridges the gap, causing localized melting and material removal.

In the Wire EDM process, the electric spark serves as the cutting tool, shaping the material into the desired form. Additionally, deionized water is used to regulate the machining process and effectively remove the tiny particles generated during material removal, as illustrated in Figure 2.

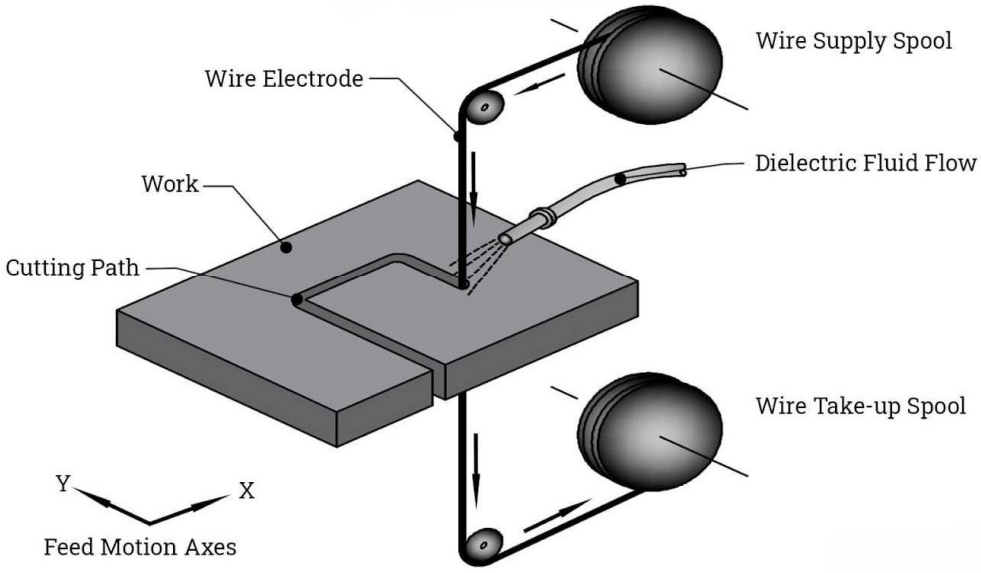


Fig2: Schematic Diagram of Basic Principle of WEDM.

II. LITERATURE REVIEW

A literature review is a structured analysis of a research domain that aids in identifying specific research gaps. It involves gathering, assessing, and synthesizing information from various sources, including scholarly articles, books, professional writings, and web-based materials.

Dhoria, Subbaiah, and Rao et al. (2024) conducted a multi-objective parametric optimization study on Wire Electrical Discharge Machining (WEDM) of hybrid Al6351/SiC/Gr composites using the Non-dominated Sorting Genetic Algorithm II (NSGA-II). Their research focused on optimizing process parameters to enhance machining performance, including material removal rate, surface roughness, and dimensional accuracy. The study demonstrated that NSGA-II effectively identified optimal trade-offs between conflicting machining objectives, leading to improved efficiency and precision. The findings contribute to the advancement of WEDM for hybrid composites, offering valuable insights into parameter selection and multi objective optimization techniques for achieving superior machining outcomes [1].

A.Thillaivanan et al. (2023) discussed the complexity of the electrical discharge machining (EDM) process, emphasizing the challenge of selecting optimal cutting parameters to enhance machining performance. Optimizing operational parameters is crucial, particularly for unconventional machining methods like EDM. The selection of machining parameters depends significantly on the operator expertise and technological knowledge due to the vast number of influencing factors. Standard parameter tables provided by machine tool manufacturer soften fail to meet specific machining requirements, as they do not offer optimal conditions for

©IJRASET: All Rights are Reserved | SJ Impact Factor 7.538 | ISRA Journal Impact Factor 7.894 |

achieving a predetermined machining time for a particular task. To address this, a systematic approach for determining suitable parameter settings is proposed. Using the Taguchi parameter design method combined with analysis of variance (ANOVA), key factors influencing machining performance-such as total machining time, oversize, and taper in an EDM-drilled hole are identified. Artificial neural networks, known for their adaptability, serve as effective modeling tools capable of learning complex relationships between input parameters and output characteristics [2].

Ashish Srivastava et al. (2023) highlight that surface finish and metal removal rate (MRR) are crucial factors for customers, as they play a key role in minimizing machine cycle time and overall production costs. In recent years, the demand for high-quality products has increased, leading to the adoption of advanced and rapid manufacturing technologies. This study presents an experimental investigation on Al2024 composite reinforced with SiC, analyzing the impact of electric discharge machining (EDM). The research examines the influence of three different levels of parameters, including current, pulse-on time, and reinforcement percentage, on both surface finish and MRR [3].

A.K.M Asif Iqbal et al. (2023) discussed the evolution of Electrical Discharge Machining (EDM) from a novel technique to a widely used manufacturing process over the past few decades. Despite its growing application, EDM remains a complex process that is not yet fully understood. Establishing a precise model to predict its performance by linking process parameters is challenging. Optimizing machining parameters is crucial for enhancing production efficiency and minimizing machining time, as both the process and the materials used in EDM are highly expensive.

This study develops empirical relationships between machining parameters and performance measures to assess the machinability of stainless steel. The research considers voltage, electrode rotational speed, and feed rate as key machining factors, evaluating their effects on material removal rate (MRR), electrode wear rate (EWR), and surface roughness (Ra). Response Surface Methodology (RSM) is employed to analyze interactions between these variables and their influence on responses. A Central Composite Design (CCD) is used to determine model coefficients for the three factors. The responses are formulated using a response surface model derived from experimental data, and Analysis of Variance (ANOVA) at a 95% confidence level is conducted to identify significant coefficients [4].

B. Bhattacharyya et al. (2022) stated that electrochemical machining (ECM) holds significant promise in the field of non-traditional machining due to its wide range of applications. It is anticipated that ECM will be effectively and commercially adopted in modern industries. However, to fully harness its potential, a systematic approach is necessary to address key machining challenges. This is primarily due to the intricate interplay of physico-chemical and hydrodynamic phenomena occurring within the machining gap [5].

Bikash Choudhuri et al. (2022) studied H21 steel, a hot work tool steel known for its excellent red hardness, high mechanical strength, and machining challenges. Wire Electrical Discharge Machining (WEDM) is preferred for such materials due to its ability to achieve high-speed and high-precision machining, ensuring both productivity and accuracy. Cutting speed directly influences machining efficiency, while kerf width determines the final product's tolerance. In this study, Response Surface Methodology (RSM) and Artificial Neural Network (ANN) were employed for modeling, sensitivity analysis, and optimization. The ANN model demonstrated superior predictive capability compared to RSM, highlighting its effectiveness in capturing the nonlinear characteristics of the machining process [6].

Datta et al. (2021) developed quadratic mathematical models to describe the behavior of the WEDM process. Experiments were carried out using six process parameters—discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow rate—each varied at three levels. The study demonstrated the effectiveness of the grey-Taguchi method as a multi-objective optimization tool for WEDM applications [7].

S. Gopalakannan et al. (2020) conducted experiments using a face-centered central composite design within the framework of response surface methodology. The study employed analysis of variance (ANOVA) to examine the effects of various process parameters—pulse current, gap voltage, pulse on time, and pulse off time—on key machining responses, namely material removal rate (MRR), electrode wear ratio (EWR), and surface roughness (SR). The primary goal was to determine the most influential parameters affecting these output characteristics and to develop models for predicting MRR, EWR, and SR [8].

J. Udaya Prakash et al. (2020) aimed to analyze the impact of machining parameters such as gap voltage, pulse on time, pulse off time, wire feed rate, and percentage of reinforcement on material removal rate and surface roughness during the Wire Electrical Discharge Machining (WEDM) of Aluminium alloy (A413), reinforced with fly ash and boron carbide. The experiments were structured based on Taguchi's L27 orthogonal array, considering various parameter combinations. ANOVA was utilized to identify the parameters that significantly influence the machining performance [9].

III. METHODOLOGY

A. Workpiece Material

AISI D2 steel is a high-carbon, high-chromium tool steel known for its excellent hardness, wear resistance, and toughness. It belongs to the cold work tool steel category and is widely used for applications requiring high resistance to abrasion and deformation.

1) Composition of AISI D2 steel

The elemental chemical composition of AISI D2 steel is listed below.

S.No.	Elements	Percentage (%)
1	Carbon (C)	1.40-1.60
2	Chromium (Cr)	11.00- 13.00
3	Molybdenum (Mo)	0.70-1.20
4	Sulphur (S)	≤0.30
5	Vanadium (V)	0.50-1.10
6	Manganese (Mn)	0.20-0.60
7	Silicon (Si)	0.10-0.60
8	Nickel (Ni)	≤0.30
9	Phosphorus(P)	≤0.03
10	Iron (Fe)	Balance

Table I: Composition of AISI D2 Steel.

2) Key Properties of AISI D2 Steel:

- Hardness: Can be hardened to HRC 55-62, providing excellent durability.
- Toughness: Moderate toughness, but higher than other high-carbon steels.
- Wear Resistance: Outstanding wear resistance due to its high carbide content.
- Corrosion Resistance: Moderate corrosion resistance, better than plain carbon steels but lower than stainless steels.
- Machinability: Poor machinability in annealed condition due to its hardness.

B. Machine Tool Used

The experiments will be conducted using a Wire-Cut EDM machine (Electronica Ultracut S2) from Electronica Machine Tools Ltd., as shown in Figure 3 [10]. This machine enables high-precision machining through electrical discharge, ensuring accurate material removal. Various process parameters will be analyzed to evaluate their impact on machining performance and surface characteristics.



Fig3: Electronica Ultracut S2 WEDM Machine.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

IV. OPTIMIZATION TECHNIQUES

Optimizing Wire Electrical Discharge Machining (WEDM) for AISI D2 steel requires a systematic approach to selecting the most suitable machining parameters. The goal is to achieve improved Material Removal Rate (MRR), Surface Roughness (SR), and Electrode Wear Rate (EWR) etc. while maintaining precision and efficiency.

Various optimization techniques are employed to determine the ideal parameter settings that enhance productivity, improve surface quality, and reduce electrode wear. These methods help in analyzing the influence of factors such as pulse on time (Ton), pulse off time (Toff), wire feed rate, gap voltage, and wire tension on the overall machining performance.

The following sections discuss the most effective optimization techniques used in WEDM for AISI D2 steel.

1) Taguchi Method

The Taguchi method is a robust design approach used in WEDM for AISI D2 steel to determine the optimal machining parameters with minimal experimental trials. It uses orthogonal arrays (OA) to systematically organize experiments and analyze how factors like pulse on-time, pulse off-time, and wire tension affect responses such as material removal rate (MRR), surface roughness (SR), and electrode wear ratio (EWR).The signal to noise (S/N) ratio is used to evaluate performance by minimizing variability and maximizing desired outcomes. This method is particularly useful for improving dimensional accuracy and reducing experimental costs while achieving an optimized WEDM process.

2) Response Surface Methodology (RSM)

RSM is a statistical optimization technique that helps in modeling the relationship between WEDM input parameters and machining performance when working with AISI D2 tool steel. It generates a mathematical model based on experimental data to optimize MRR, SR, and EWR. By using a central composite design (CCD) or Box-Behnken design (BBD), it systematically varies process parameters such as pulse duration, gap voltage, and wire feed rate to predict and optimize machining performance. RSM is widely used for fine-tuning process conditions and identifying interactions between variables to enhance precision machining of hard materials like AISI D2.

3) Grey Relational Analysis (GRA)

GRA is a multi-response optimization technique that transforms multiple machining performance parameters into a single optimized value. In WEDM of AISI D2 steel, multiple responses such as MRR, SR, and EWR are converted into grey relational coefficients (GRCs), which are then ranked to determine the optimal parameter settings. This method is highly effective when optimizing conflicting machining parameters, such as increasing MRR while minimizing SR. It helps in identifying the best wire feed rate, pulse time, and flushing pressure settings to achieve a balance between productivity and surface quality in WEDM operations.

4) Genetic Algorithm (GA)

The Genetic Algorithm (GA) is an evolutionary optimization technique inspired by natural selection. It is used in WEDM for AISI D2 steel to find the best machining parameters by simulating evolution through mutation and crossover. GA works by generating multiple possible solutions (chromosomes) and evaluating them using a fitness function based on machining performance metrics like MRR, SR, and tool wear.

Over multiple generations, GA refines the solutions to find the best combination of pulse on-time, pulse off-time, and wire tension. This technique is particularly useful for nonlinear and complex machining problems where traditional optimization methods may fail.

5) Artificial Neural Networks (ANN) &Machine Learning

ANNs and machine learning algorithms are increasingly used in WEDM to predict and optimize machining conditions for AISID2 steel. ANN models are trained using experimental data to learn the relationship between process parameters (wire tension, gap voltage, pulse duration) and performance metrics (MRR, SR, and kerf width). Once trained, the ANN model can accurately predict the optimal settings without additional experiments. When combined with Genetic Algorithms (GA) or Particle Swarm Optimization (PSO), ANN can intelligently select machining parameters in real-time, improving efficiency and precision in WEDM operations.

©IJRASET: All Rights are Reserved | SJ Impact Factor 7.538 | ISRA Journal Impact Factor 7.894 |

6) Particle Swarm Optimization (PSO)

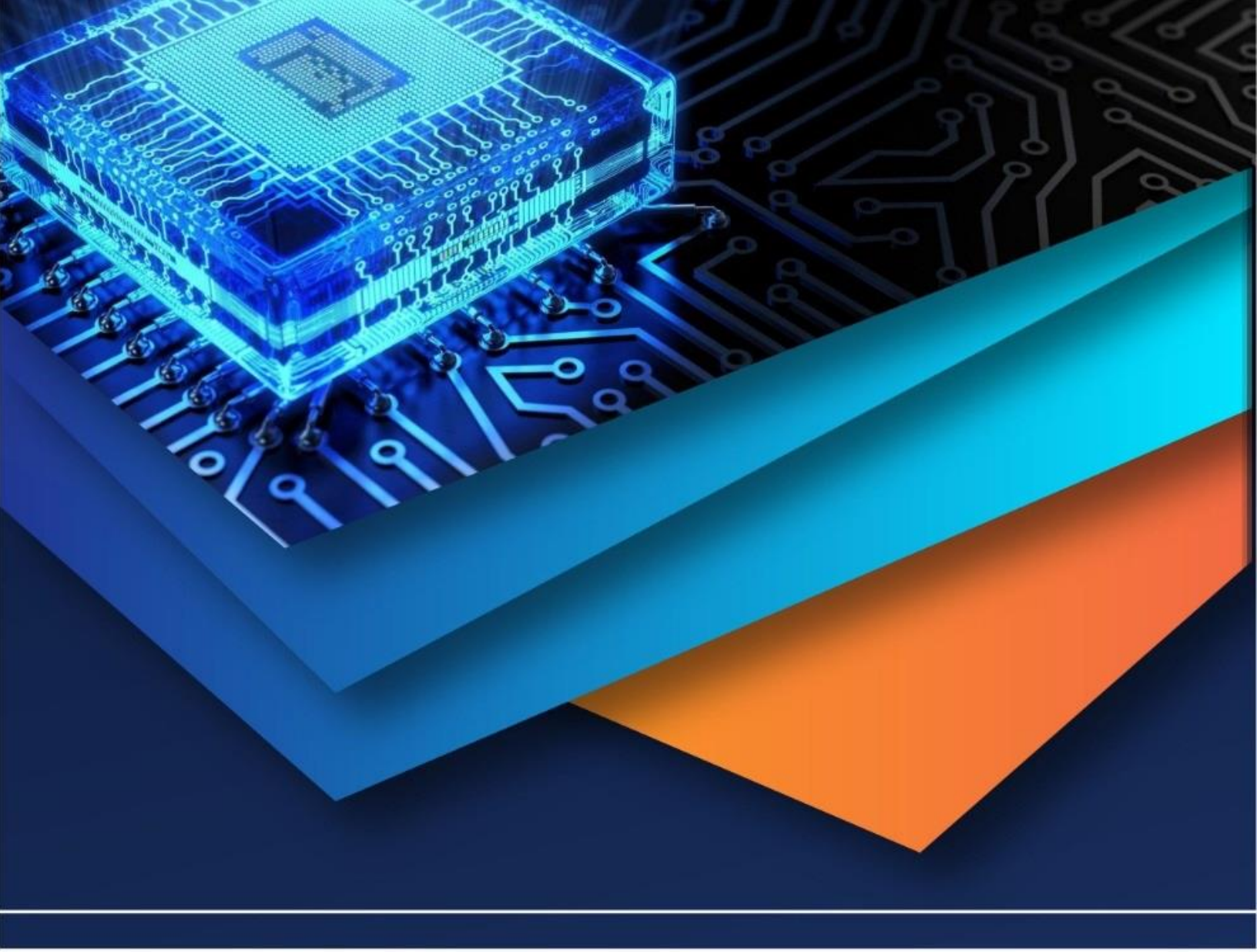
PSO is a swarm-based optimization algorithm inspired by the behaviour of flocks of birds or fish. In WEDM for AISI D2 steel, PSO is used to optimize multiple process parameters simultaneously by treating each machining parameter set as a "particle" that moves in a search space. These particles update their positions based on their own best experience and the experience of neighbouring particles. This method efficiently finds the best combination of wire feed, pulse on/off time, and spark gap to maximize MRR while minimizing SR and tool wear. PSO is particularly effective in solving complex, multi-objective optimization problems in machining.

V. CONCLUSION

Different optimization techniques are used depending on the complexity of the WEDM process, number of parameters, and required accuracy. Traditional techniques like Taguchi and RSM are extensively used for experimental process optimization, whereas GA, ANN, and PSO are preferred for real-time and complex problem-solving. The Taguchi method is a practical and efficient approach for WEDM in AISI D2 steel, offering an organized method to identify optimal machining conditions. By employing orthogonal arrays (OA) and signal-to-noise (S/N) ratio analysis, this method improves material removal rate (MRR), surface quality, and dimensional accuracy while reducing inconsistencies. It minimizes experimental costs and ensures efficient parameter selection with fewer trials. As a result, the Taguchi method is widely utilized for enhancing process stability, increasing machining efficiency, and ensuring high-quality output, making it a key tool in WEDM process optimization.

REFERENCES

[1] Sneha H. Dhoria, K.Venkata Subbaiah and V. Durga Prasada Rao, Multi-Objective Parametric Optimization on WEDM of Hybrid Al6351/SiC/Gr Composites Using NSGA-II, Journal of The Institution of Engineers (India),Series D,January2024.
[2] A. Thillaivanan, P Asokan, K.N.Srinivasan, R.Saravanan,2023,"Optimization Of Operating Parameters for EDM Process Based on the Taguchi Method and Artificial Neural Network ", International Journal of Engineering Science and Technology, Vol.2(12),pp:6880-6888
[3] Ashish Srivastava, Amit Rai Dixit, Sandeep Tiwari,2023, "Experimental Investigation of Wire EDM Process Parameters on Aluminium Metal Matrix Composite Al2024/SiC", International Journal of Advance Research and Innovation, Volume2-2, pp:511-515.
[4] Asif Iqbal, A.K.M., Khan, AhsanAli,2023, "Modeling and Analysis of MRR, EWR and Surface Roughness in EDM Milling through Response Surface Methodology", American Journal of Engineering and Applied Sciences, Vol.3(4), pp:611-619.
[5] Bhattacharyya,2022, "Investigation for controlling electrochemical machining through response surface Methodology-based approach", Journal of Material Processing Technology, Vol.86, pp:200-207
[6] Bikash Choudhuri, Ruma Sen, Subrata Kumar Ghosh, S.C. Saha,2022, "A Comparative Modeling and Multi-Objective Optimization in Wire EDM Process on H21 Tool Steel Using Intelligent Hybrid Approach", International Journal of Engineering and Technology (IJET), Vol8-6, pp:3102-3112.
[7] Datta, Saurav, Mahapatra, SibaSankar,2021, "Modeling, Simulation and Parametric Optimization of Wire EDM Process using Response Surface Methodology coupled with Grey-Taguchi Technique", International Journal of Engineering, Science and Technology, Vol.2(5), pp:162-183
[8] Gopalakannan, S., Senthilvelan, T., Ranganathan, S., 2020, "Modeling and Optimization of EDM Process Parameters on Machining of Al 7075-B4C MMC using RSM", International Conference on Modeling, Optimization and Computing,38:685-690.
[9] J. Udaya Prakash, S. Ananth, S. Jebarose Juliyana &P. John Paul, "Effect of Wire EDM Process Parameters on Machining of Aluminium Matrix Composites (356/Fly Ash)", Lecture Notes in Mechanical Engineering, Proceedings of ICDMC 2019 ,02 June 2020.
[10] Arun Pahade, Yogesh Mishra, Ramnarayan Sahu, "Modeling and Optimization of WEDM Process Parameters on Machining of AISI D2 using RSM and Taguchi method", International Journal of Scientific Engineering and Technology, Volume No.12, Special IssueNo.1,29 Dec.2023.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089 (24*7 Support on Whatsapp)