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A Review on Process Parameters of Electric Discharge Machining

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ABSTRACT:
Electrical Discharge Machining (EDM) has been widely explored for its capability to process hard-to-machine materials with high precision. This review synthesizes findings from various research studies on optimizing EDM process parameters, improving surface integrity, and adopting advanced machining techniques. Several optimization strategies, including Taguchi, ANOVA, NSGA-II, and TOPSIS, have been employed to enhance Material Removal Rate (MRR), Surface Roughness (SR), and Electrode Wear Rate (EWR). Studies on innovative EDM approaches, such as powder-mixed EDM, vibration-assisted EDM, and Dry EDM, have demonstrated significant improvements in machining efficiency and surface quality. Additionally, novel dielectric fluids, including eco-friendly vegetable oils, have been evaluated for sustainable EDM applications. Research on specialized materials, such as titanium alloys, magnesium metal matrix composites, and shape memory alloys, highlights the role of electrode materials and machining conditions in achieving optimal performance. The integration of advanced methodologies and material-specific EDM approaches contributes to the continued evolution of EDM, paving the way for improved precision, efficiency, and sustainability in manufacturing industries.
Keywords: Electrical Discharge Machining (EDM), Optimization Techniques, Taguchi Method, ANOVA, TOPSIS, Process parameters

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I.

II. INTRODUCTION

Electric Discharge Machining (EDM) is one of the most advanced non-traditional machining processes, widely recognized for its ability to machine complex geometries and extremely hard materials with high precision. Developed in the mid-20th century, EDM has become an indispensable technology in industries such as aerospace, automotive, medical, and tool and die manufacturing. Unlike conventional machining techniques, which remove material through direct mechanical contact between the tool and workpiece, EDM relies on electrical discharges to erode material from a conductive workpiece. This unique method enables the fabrication of intricate shapes that would be difficult or impossible to achieve using traditional subtractive manufacturing methods.

The EDM process operates on the principle of controlled spark erosion, where a series of rapid electrical discharges occur between a tool electrode and the workpiece, both of which are submerged in a dielectric fluid. A voltage is applied, creating a spark gap between the electrode and the workpiece. When the voltage exceeds the dielectric breakdown strength, a plasma channel forms, generating extremely high temperatures (ranging from 8,000°C to 12,000°C). This intense localized heating melts and vaporizes the workpiece material, which is subsequently flushed away by the dielectric fluid. Because EDM does not involve direct tool-workpiece contact, it eliminates mechanical stresses, tool wear, and deformation, making it particularly effective for machining fragile or thin-walled components.

EDM can be categorized into three primary types, each tailored for specific applications. Die-Sinking EDM, also known as ram EDM, employs a pre-shaped electrode to form intricate cavities in the workpiece, making it ideal for mold and die manufacturing. Wire EDM (WEDM) utilizes a continuously moving, thin wire electrode to cut precise two-dimensional and three-dimensional profiles, commonly used in aerospace and medical applications. Hole-Drilling EDM is specifically designed for creating deep, narrow holes with high aspect ratios, often used in turbine blades and fuel injectors. Each variant of EDM offers unique advantages depending on the desired machining requirements.

One of the key benefits of EDM is its capability to machine ultra-hard materials such as tungsten carbide, Inconel, and titanium alloys—materials that pose significant challenges to conventional machining methods. Additionally, EDM allows for high-precision manufacturing with superior surface finishes, eliminating the need for extensive post-processing. However, the effectiveness of EDM is highly dependent on various process parameters, including discharge current, pulse duration, pulse-off time, and dielectric fluid properties. These parameters significantly influence material removal rate (MRR), electrode wear rate (EWR), and surface roughness (SR), ultimately affecting the overall performance of the machined components.

Discharge current, for instance, plays a crucial role in determining the rate of material removal, where higher current values lead to increased MRR but may also cause excessive surface roughness and thermal damage. Pulse duration affects the energy delivered per spark, impacting surface integrity and machining accuracy. Pulse-off time dictates the cooling period between discharges, influencing the efficiency of debris removal and preventing secondary discharges. The choice of dielectric fluid, whether hydrocarbon-based or deionized water, affects spark stability, flushing efficiency, and electrode wear. Proper optimization of these parameters is essential to achieve the desired balance between machining speed, precision, and surface quality.

Despite its numerous advantages, EDM has inherent limitations, including relatively slow material removal rates, high energy consumption, and the requirement for electrically conductive materials. Additionally, the formation of a recast layer— a thin layer of resolidified material on the machined surface—can impact mechanical properties such as fatigue resistance and corrosion susceptibility. To address these challenges, researchers and engineers are continually exploring optimization strategies, including the application of statistical methods such as Taguchi analysis, Analysis of Variance (ANOVA).

This review aims to provide a comprehensive analysis of the various process parameters on EDM. By examining recent studies and experimental findings, this paper highlights the relationships between process parameters and key performance attributes, offering insights into best practices and future research directions in EDM technology. Understanding these factors is crucial for optimizing machining process, reducing defects, and expanding the capabilities of EDM in industrial and commercial applications.

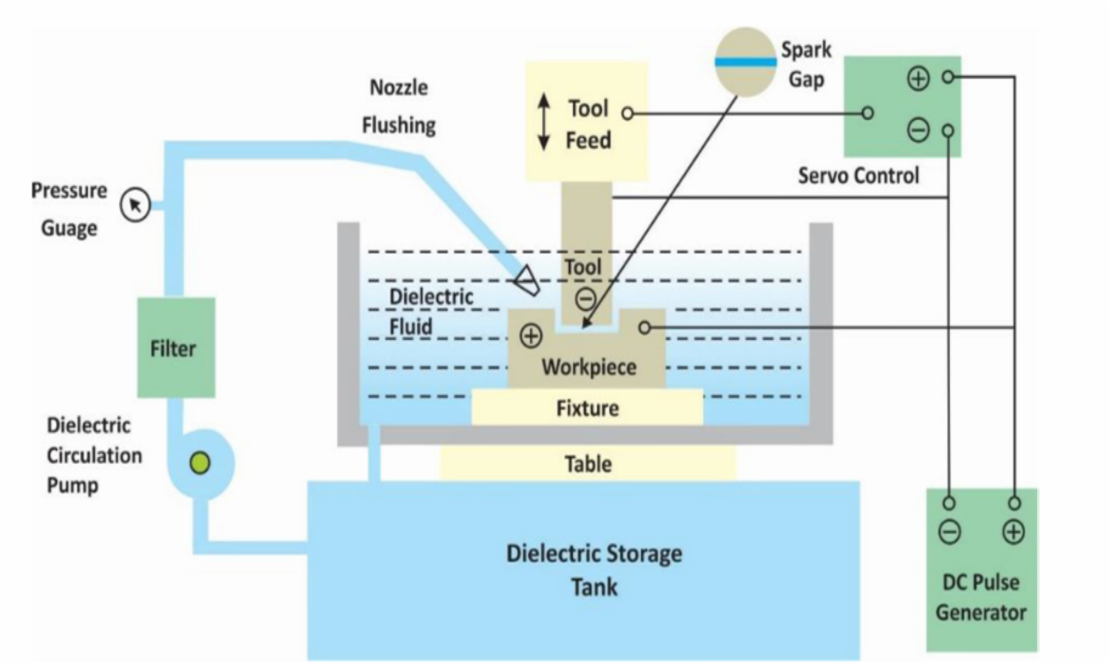

Fig .1 Schematic Diagram of EDM process [6]

III.

IV. LITERATURE REVIEW

1) Van Tron Tran et al. optimized die-sinking EDM parameters for machining AISI P20 steel using copper electrodes. They employed the Taguchi method and ANOVA to analyse Material Removal Rate (MRR), Electrode Wear Rate (EWR), and Surface Roughness (SR), varying current (I), pulse-on time (Ton), and pulse-off time (Toff) in an L9 orthogonal array. The optimal MRR was achieved at I = 6A, Ton = 120 µs, Toff = 30 µs, while the lowest EWR and SR were observed at I = 2A with varying Ton and Toff. ANOVA identified current as the most influential factor, contributing 92–96%. Grey Relational Analysis determined I = 6A, Ton = 120 µs, and Toff = 60 µs as the best overall combination. Higher current and longer Ton increased surface roughness and recast layer thickness. While the study effectively optimized EDM performance, it was limited to copper electrodes and AISI P20 steel, with minimal focus on dielectric fluid properties.

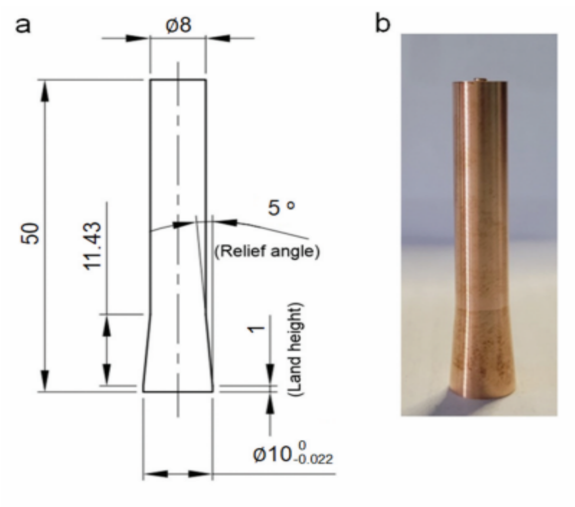

Fig 2 (a) The design of copper electrode for the EDM process. (b) the fabricated copper electrode. [1]

2) Chitrasen Samatra et al conducted a study on optimizing the die-sinking EDM process for machining Ti6Al4V alloy using the hybrid Taguchi-RAMS-RATMI methodology. The research aimed to improve machining efficiency and surface integrity by optimizing key parameters, including pulse-on time (Ton), duty cycle, peak current, and voltage. The results indicated that peak current was the most influential factor, contributing 51.77% to machining performance. The optimal parameter combination for maximizing material removal rate (MRR) and depth of cut while minimizing tool wear rate (TWR) and surface roughness was identified as Ton = 500 µs, Duty Cycle = 8%, Peak Current = 40A, and Voltage = 20V. Surface morphology analysis revealed that optimized EDM settings resulted in a thinner recast layer, fewer microcracks, and reduced heat-affected zones, enhancing surface integrity. The study effectively demonstrated that high peak currents improve MRR but may also lead to increased tool wear and rougher surfaces. ANOVA validation confirmed the reliability of the results. While the research successfully optimized EDM parameters, it focused primarily on Ti6Al4V and copper electrodes, limiting its applicability to other materials.

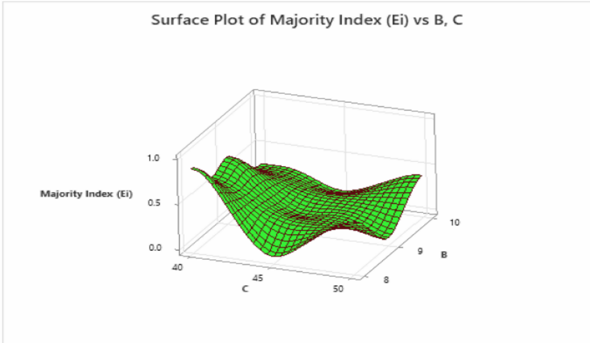

Fig 3 The surface plot of the RATMI majority index (Ei) vs. duty cycle and peak current [2]

3) Shoaib Mohammad et al studied the performance of multi-material cladded electrodes in EDM for machining D2 tool steel, analysing Material Removal Rate (MRR), Surface Roughness (SR), Tool Wear Ratio (TWR), and Overcut (OC). Discharge current was the most significant factor, contributing 43.77% and 65.80% to MRR for the Copper-in-Graphite-out (Cuin-Grout) and Graphite-in-Copper-out(Grin-Cuout) configurations, respectively. Graphite provided a smoother finish but had higher wear, while Cuin-Grout exhibited lower TWR and OC. Multi-material electrodes enabled controlled pattern generation, with a maximum depth difference of 0.08 mm for Cuin-Grout and 0.04 mm for Grin-Cuout. While electrode configuration significantly impacted EDM performance, interfacial gaps between materials could affect machining precision. The study concluded that Grin-Cuout is preferable for smoother surfaces and lower MRR, while Cuin-Grout is better for minimizing TWR and OC.

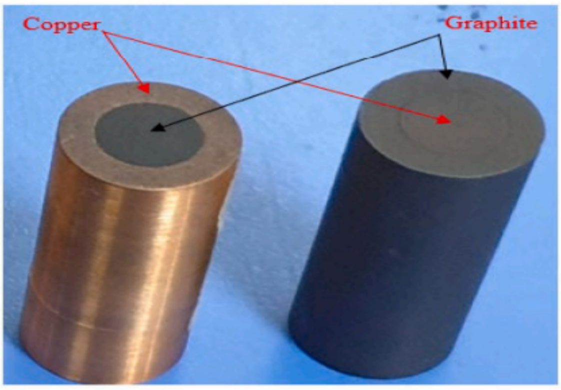

Fig4 Multi-material electrodes after machining. [3]

4) Yuhong Ding et al conducted a study on surface strengthening of Ti–6Al–4V alloy using near-dry multi-flow channel electrode EDM, aiming to enhance hardness, wear resistance, and corrosion resistance. The study analyzed the effects of pulse-on time (Ton), pulse-off time (Toff), peak current, and electrode speed on material removal rate (MRR) and surface roughness (Sa). Results showed that MRR and Sa increased with Ton and peak current but decreased with Toff and RPM. The optimized parameters were identified as Ton = 120 µs, Toff = 50 µs, peak current = 6 A, and RPM = 600 r/min. The strengthened surface exhibited a droplet-stacking morphology with improved bonding to the substrate, achieving a maximum layer thickness of 68 µm. X-ray diffraction (XRD) analysis confirmed the presence of Ti_2N, Ti_2AlN, and TiN, leading to a significant increase in surface microhardness (3–5 times that of the substrate). Wear resistance improved by over 40%, with abrasive and spalling wear identified as dominant mechanisms, while corrosion resistance increased by 72%. The study concluded that near-dry multi-flow channel EDM is an effective method for enhancing Ti–6Al–4V alloy properties, making it suitable for aerospace, biomedical, and other high-performance applications.

5) Jay Vora et al, investigated the machining characteristics of Nitinol shape memory alloys (SMAs) using nano-graphene mixed Electrical Discharge Machining (EDM) with a focus on optimizing machining parameters for improved performance. The study employed Taguchi's L9 design and ANOVA to analyse the effects of pulse-on time (Ton), pulse-off time (Toff), nano-graphene powder concentration (PC), and discharge current on material removal rate (MRR), surface roughness (SR), and dimensional deviation (DD). Results indicated that nano-graphene addition significantly enhanced MRR while reducing SR and DD, with ANOVA identifying PC, Ton, and Toff as the most influential parameters. The Heat Transfer Search (HTS) algorithm was used for optimization, achieving a maximum MRR of 62.66 mg/min, minimum SR of 2.64 µm, and minimum DD of 86.07 µm. multi-objective optimization yielded a balanced configuration with minimal deviation from predicted values, confirming the effectiveness of the HTS technique. Morphological analysis using Field Emission Scanning Electron Microscopy (FESEM) revealed that nano-graphene at 2 g/L improved surface quality by reducing resolidified debris, micro-pores, and micro-cracks. The study concluded that nano-graphene mixed EDM enhances machining performance and surface integrity, making it highly applicable for aerospace and biomedical industries.

6) Abdul Faheem et al. investigated the machinability of Ni 55.65Ti shape memory alloys (SMAs) using electric discharge machining (EDM), focusing on optimizing process parameters for improved surface roughness (SR) and maximum material removal rate (MRR). The study analyzed the effects of pulse-on time (Ton), duty factor, and peak current, revealing that the lowest SR achieved was 6.828 µm, while the highest MRR was 4.552 mm^3/sec. ANOVA identified pulse-on time and peak current as the most influential factors, contributing 49.78% and 43.81%, respectively. The study utilized the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) for multi-objective optimization, generating Pareto-optimal solutions, which were further ranked using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The highest-ranked solution was obtained at a pulse-on time of 262 ms, peak current of 20 A, and duty factor of 9.99, optimizing SR at 9.127 µm and MRR at 4.209 mm^3/sec. Scanning Electron Microscopy (SEM) analysis showed that higher discharge energy led to micro-cracks, globule formations, and recast layers, increasing surface roughness, while lower peak current and pulse-on time resulted in smoother surfaces. The study concluded that NSGA-II and TOPSIS effectively optimize EDM parameters for Ni 55.65Ti SMA, ensuring a balance between machining efficiency and surface integrity, with applications in aerospace and biomedical industries.

7) Huu-Phan Nguyena et al investigated the effect of low-frequency vibration on Electrical Discharge Machining (EDM) performance, focusing on optimizing process parameters to enhance material removal rate (MRR) and surface roughness (SR). The study employed the Taguchi method and the Technique for Order Preference by

Similarity to Ideal Solution (TOPSIS) for optimization, analyzing the influence of pulse current (I), pulse-on time (Ton), pulse-off time (Toff), and vibration frequency (F). Results showed that low-frequency vibration improved chip evacuation, leading to a 33% increase in MRR and a 32% reduction in SR. The optimal parameters were identified as I = 8A, Ton = 50 ms, Toff = 5.5 ms, and F = 512 Hz, with process accuracy validated at 86.6% using the Ci value in TOPSIS. Surface analysis revealed a significant reduction in recast layer thickness, fewer micro-cracks, and better spark distribution, resulting in improved machining stability. Morphological examination indicated that vibration-assisted EDM produced smaller, more uniform craters and reduced adhered debris due to enhanced dielectric fluid flow. The study concluded that integrating low-frequency vibration into EDM improves machining efficiency, surface integrity, and overall performance, making it beneficial for aerospace and precision tooling applications.

8) Hassan Farooq et al conducted a study on Dry Electrical Discharge Machining (DEDM) of Siliconized Silicon Carbide (SiSiC), focusing on optimizing material removal rate (MRR) and surface roughness (Ra) by varying dielectric gases and electrode shapes. The study analysed the effects of peak current (Ip), pulse-on time (Ton), and gap voltage (V), revealing that oxygen gas produced the highest MRR, approximately 3.1 times greater than air and significantly higher than nitrogen, due to its strong oxidizing properties. The highest MRR (0.9001 mm^3/min) was achieved using oxygen at 9A, 10µs, and 150V, whereas nitrogen resulted in the lowest MRR (0.0116 mm^3/min). Surface roughness analysis showed that nitrogen provided the best finish (Ra = 1.022 µm) by forming a protective nitride layer, while oxygen led to higher roughness (~6.423 µm) due to crater formation. Tubular electrodes improved debris removal, reducing Ra compared to plane electrodes. The study identified peak current (53.3%) and pulse-on time (27%) as the dominant factors influencing MRR, with lower values enhancing surface smoothness. A confirmation test validated the accuracy of the developed mathematical model, with errors under 10%. The study introduced Swirl Assisted Flushing (SAF), which increased MRR by 21.38% compared to conventional direct impingement, and confirmed DEDM as an environmentally friendly alternative with no toxic emissions. The research concluded that oxygen maximizes MRR, nitrogen provides the best surface finish, and tubular electrodes enhance machining efficiency.

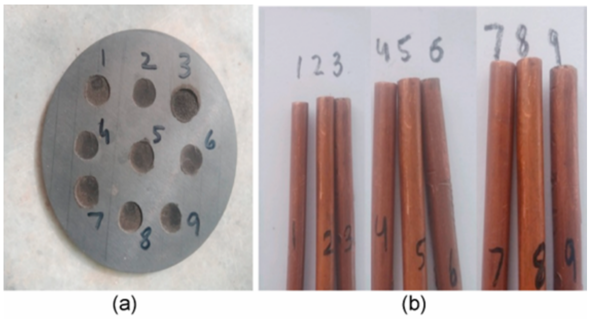

Fig 5 a) Holes on work piece (b) Plane copper electrodes.[8]

9) Karthik S et al investigated the mechanical properties and EDM machinability of WE43(T6) magnesium metal matrix composites (MMCs) reinforced with silicon carbide (SiC) and aluminium oxide (Al O). The study analysed material removal rate (MRR), tool wear rate (TWR), and surface roughness (SR) using copper, brass, and tungsten carbide electrodes while evaluating the effects of pulse-on time (Ton), discharge current (Ip), and spindle speed (S). Results showed that adding 5% reinforcement improved hardness, tensile strength, and wear resistance while reducing composite weight by 1%, though porosity increased by 19.5%. Copper electrodes achieved the highest MRR (4.51 mg/s) at Ton = 6 µs, Ip = 9 A, while tungsten carbide exhibited the lowest TWR due to its high melting point. The best surface finish was also obtained with tungsten carbide, while brass had the highest SR (~2.1 µm). The study concluded that SiC and Al O reinforcement enhanced WE43(T6) composites for aerospace and biomedical applications, with copper electrodes optimizing MRR, tungsten carbide minimizing TWR, and brass increasing surface roughness.

10) B Singaravel investigated the feasibility of using vegetable oil as a dielectric fluid in Electric Discharge Machining (EDM) of Ti-6Al-4V, aiming to provide a sustainable alternative to conventional kerosene-based dielectrics. The study compared the dielectric properties of sunflower, canola, and jatropha oils with kerosene while evaluating surface roughness (Ra) under varying energy settings using copper, brass, and tungsten copper electrodes. Results showed that vegetable oils exhibited similar dielectric properties and erosion mechanisms to kerosene, though surface roughness was slightly higher, with sunflower oil producing the roughest surfaces, followed by jatropha and canola. Higher pulse-on time increased crater depth and roughness. Despite this, vegetable oils offer significant environmental benefits due to their biodegradability and reduced toxicity. The study concluded that vegetable oil-based dielectrics could effectively

replace conventional fluids in EDM, aligning with sustainable manufacturing practices.

Fig 6 Machined samples with copper electrode.[10]

TYPES OF MATERIALS USED

Workpiece Materials: AISI P20 tool steel, Ti-6Al-4V, D2 tool steel, Siliconized Silicon Carbide (SiSiC), Ni 55.65Ti shape memory alloy, WE43(T6) magnesium metal matrix composite, Nitinol shape memory alloy
Electrode Materials: Copper, Brass, Tungsten carbide, Graphite, Copper-Graphite cladded electrodes (Copper-in-Graphite-out and Graphite-in-Copper-out)
Dielectric Fluids: Kerosene, Deionized Water, Oxygen (O), Nitrogen (N), Air, Sunflower Oil, Canola Oil, Jatropha Oil.

V. RESULTS TABLE

TABLE 1: Process parameters and their effects in EDM

Process Parameter	Effect on EDM Performance	Optimized Values (from different studies)
Discharge Current (I)	Increases MRR [2] but also increases surface roughness and tool wear.[7]	6A for Ti-6Al-4V [2]; 8A for low-frequency vibration-assisted EDM.[7]
Pulse-on Time (Ton)	Higher Ton increases MRR [2] but also increases surface roughness [4] and recast layer thickness [6].	500 µs for Ti-6Al-4V [2]; 120 µs for Ti-6Al-4V surface strengthening [4]; 262 ms for Ni-55.65Ti [6]
Pulse-off Time (Toff)	Longer Toff improves surface quality [4] and flushing efficiency but reduces MRR [1].	50 µs for Ti-6Al-4V [4] 60 µs for AISI P20 steel [1]
Peak Current	Dominates MRR and surface roughness [2]; higher values increase tool wear [6].	40A for Ti-6Al-4V [2] 20A for Ni-55.65Ti [6]
Duty Cycle	Higher values increase MRR but can lead to overheating and microcracks [2]	8% for Ti-6Al-4V [2]
Electrode Speed (RPM)	Higher RPM improves surface hardness and wear resistance [4]	600 rpm for Ti-6Al-4V. [4]
Nano-particle Concentration (PC)	Adding nano-particles like nano-graphene enhances MRR and	2 g/L of nano-graphene for Nitinol. [5]

	reduces SR. [5]	
Dielectric Fluid Type	Affects spark stability, debris removal, and surface finish [8][10]	Oxygen (max MRR); Nitrogen (best surface finish) [8]; Vegetable oil (eco-friendly alternative) [10].
Electrode Material	Copper provides high MRR [3]; Tungsten carbide offers best surface finish; Brass increases roughness. [9]	Copper for MRR [3]; Tungsten carbide for best surface finish [9]
Vibration Frequency (F)	Low-frequency vibration improves MRR and reduces SR by enhancing chip evacuation [7]	512 Hz (33% MRR increase, 32% SR reduction). [7]

VI.

VII. EDM PROCESS PARAMETERS

4.1 Discharge Current (I):

Discharge current refers to the amount of electrical current applied during each spark in the EDM process. It is a key parameter affecting Material Removal Rate (MRR), Surface Roughness (SR), and Electrode Wear Rate (EWR). Increasing the discharge current enhances MRR by providing higher energy per discharge, but it also leads to increased surface roughness and tool wear. For example, in the machining of Ti-6Al-4V, a peak current of 40A resulted in high MRR but also increased electrode wear.[2] However, for Ni-55.65Ti SMA, an optimized peak current of 20A was found to achieve a balance between material removal and surface quality.[6] In low-frequency vibration-assisted EDM, a discharge current of 8A was effective in improving chip evacuation and machining stability [7]

4.2 Pulse-on Time (Ton):

Pulse-on time refers to the duration for which the discharge remains active in a single cycle. It significantly affects MRR, surface integrity, and the formation of the recast layer. A longer Ton increases MRR, as more material is removed per pulse, but it can also lead to a thicker recast layer, microcracks, and poor surface integrity. In Ti-6Al-4V surface strengthening, a Ton of 120 µs resulted in optimal surface properties with improved hardness and wear resistance.[4] For Ni-55.65Ti SMA, a Ton of 262 ms provided a balance between high MRR and controlled surface roughness [6], whereas, for AISI P20 steel, 120 µs was found to be ideal for minimizing defects and improving the surface finish [1].

4.3 Pulse-off Time (Toff):

Pulse-off time is the interval between two consecutive discharges, allowing the molten material and debris to be flushed away. A longer Toff helps in improving surface quality and reducing secondary discharges, which minimizes unwanted defects like microcracks and debris deposition. However, an excessively high Toff can lower MRR since the machine spends more time idle between discharges. For Ti-6Al-4V surface strengthening, a Toff of 50 µs was effective in enhancing wear resistance [4], while for AISI P20 steel, a Toff of 60 µs led to a better surface finish by reducing the recast layer and improving debris removal [1]

4.4 Peak Current:

Peak current represents the maximum current value reached during a discharge cycle. It is one of the most significant factors influencing MRR and surface roughness. Higher peak current leads to an increase in MRR, but it also results in greater surface roughness and heat-affected zones. For instance, Ti-6Al-4V machining showed that a peak current of 40A led to improved material removal but required careful optimization to control surface roughness.[2] In contrast, for Ni-55.65Ti SMA, an optimized peak current of 20A was found to provide a balance between machining efficiency and surface integrity[6].

4.5 Duty Cycle:

Duty cycle is the ratio of pulse-on time to the total cycle time and directly affects machining speed and energy efficiency. A higher duty cycle increases MRR, but it can also lead to excessive thermal loading, causing microcracks and structural damage in the workpiece. For Ti-6Al-4V, a duty cycle of 8% was found to be optimal for achieving a good balance between high MRR and minimal tool wear [2]

4.6 Dielectric Fluid Type:

Dielectric fluid plays a crucial role in spark stabilization, debris flushing, and cooling during EDM. Different dielectric fluids exhibit varying effects on MRR, surface roughness, and electrode wear. Studies showed that oxygen-based dielectric fluids provided the highest MRR, while nitrogen resulted in the best surface finish.[8] Additionally, vegetable oils such as sunflower and canola oil were found to be environmentally friendly alternatives to conventional kerosene, though they resulted in slightly rougher surfaces [10]

4.7 Electrode Material:

The choice of electrode material significantly affects machining efficiency and surface quality. Copper electrodes provided high MRR, while tungsten carbide resulted in the best surface finish due to its high melting point and wear resistance. In contrast, brass electrodes tended to increase surface roughness.[9] For multi-material cladded electrodes, it was observed that a Copper-in-Graphite-out (Cuin-Grout) configuration minimized tool wear, whereas a Graphite-in-Copper-out (Grin-Cuout) configuration produced smoother surfaces [3]

4.8 Vibration Frequency:

Low-frequency vibration assists in chip evacuation, reducing the chance of debris accumulation and secondary discharges. This results in a 33% increase in MRR and a 32% reduction in surface roughness when optimized at 512 Hz. The improved dielectric fluid movement due to vibration also helps in achieving more uniform crater formation and reduced adhered debris [7]

VIII. CONCLUSIONS

- Higher discharge current (I) increases Material Removal Rate (MRR) but leads to higher surface roughness and tool wear. [2][6]
- Increasing pulse-on time (Ton) enhances MRR but also results in a thicker recast layer and more microcracks. [4][6]
- Pulse-off time (Toff) affects surface quality and machining efficiency. A longer Toff improves flushing and debris removal, leading to better surface finishes..[4][1]
- Peak current significantly influences MRR and surface roughness. While a higher peak current increases material removal, it also raises the risk of microcracks and rougher surfaces.[2][6]
- Duty cycle affects machining speed and thermal damage. [2]
- Dielectric fluid choice impacts MRR, surface finish, and environmental impact.[8][10]
- Electrode material selection influences machining performance. [9][3]
- Optimized process parameters using statistical methods like Taguchi, ANOVA, and NSGA-II improved EDM machining for materials like titanium alloys, shape memory alloys, and SiSiC ceramics.[1][6]
- For SiSiC, oxygen as a dielectric maximized MRR, while nitrogen improved surface smoothness. Tubular electrodes enhanced debris removal, improving machining efficiency.[8]
- Surface strengthening techniques like near-dry multi-flow channel EDM for Ti-6Al-4V improved hardness, wear resistance, and corrosion resistance, making it suitable for aerospace and biomedical applications.[4]
- Nano-graphene mixed EDM enhanced Nitinol SMA machining by reducing micro-pores and micro-cracks, leading to better surface integrity.[5]

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