International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 13s,2025
https://theaspd.com/index.php/ijes

Comparative Analysis Of EDM And Micro-EDM Fabricating Titanium By ESDM

Meng-Yun Chung*, Chaur-Yang Chang, and Sheng-Hong Tang
Department of Electrical Engineering, National Taipei University of Technology, Taipei Taiwan
[1]alexmychung@gmail.com

Abstract—*Titanium (Ti) is a widely studied metal oxide material known for its outstanding chemical stability, non-toxicity, and excellent optical and photocatalytic properties. Due to these advantageous characteristics, Ti has found extensive applications in various fields, such as photocatalysis, dye-sensitized solar cells, self-cleaning coatings, air and water purification, and even biomedical devices. In recent years, with the rapid advancement of nanotechnology, nanoscale Ti has demonstrated significantly enhanced photocatalytic efficiency attributed to its high specific surface area and quantum confinement effects. These nanoscale features enable more active surface sites and increased reaction rates, making Ti an ideal candidate for precision applications. This study focuses on investigating the machinability of Ti using two distinct techniques: conventional Electrical Discharge Machining (EDM) and Micro Electrical Discharge Machining (mEDM). By conducting a comparative analysis of these two processes, key machining parameters—such as material removal rate, surface roughness, and electrode wear—were systematically evaluated. Experimental results reveal that micro-EDM offers better control over nanoparticle dispersion, improved processing stability, and enhanced surface quality in micro-scale applications. Conversely, conventional EDM exhibits better scalability, consistent particle morphology, and simplified process setup. The insights gained from this research provide valuable guidance for selecting suitable EDM-based processing methods when fabricating microstructured or nanostructured Ti components, particularly for high-precision or functional surface applications. This comparison contributes to the broader understanding of advanced material processing and highlights the potential of micro-EDM in future nano/micro-fabrication technologies.*
Keywords— *Electric Discharge Machining, Micro-EDM, Titanium, Nanoparticles, Suspensions.*

INTRODUCTION

Nanotechnology is an interdisciplinary field that involves the study and application of materials and systems at the nanoscale (1 to 100 nanometers). When the size of matter is reduced to the nanometer scale, its physical and chemical properties exhibit significant changes compared to those at the macroscopic scale — for example, decreased melting points, enhanced chemical reactivity, and altered electrical properties [1]. These unique characteristics give nanomaterials great potential in a wide range of fields such as energy, medicine, environmental protection, electronics, and optics. Titanium (Ti) is one of the most widely used materials in nanotechnology. At the nanoscale, it exhibits a high specific surface area and excellent photocatalytic properties, making it especially suitable for applications such as the degradation of organic pollutants, inhibition of bacterial growth, and enhancement of energy conversion efficiency. There are various methods for synthesizing nano-Ti, including sol-gel, hydrothermal synthesis, and electrical discharge machining (EDM). These methods allow for the control of particle size, crystal phase, and dispersibility based on specific application requirements.

Through the application of nanotechnology, titanium has evolved from a conventional white pigment into a functional and intelligent material, playing a crucial role in green energy and environmental technologies. Nanotechnology Can Be Broadly Divided into Three Main Areas [2].

A. Nanomaterials

Research and development of materials with nanoscale structures, such as nanoparticles, nanotubes, and nanofilms. These materials exhibit unique properties in terms of strength, conductivity, thermal stability, and more.

B. Nanofabrication / Nanomanufacturing

This area focuses on techniques for creating and manipulating structures at the nanoscale, including self-assembly, photolithography, and electron beam writing. It is widely applied in semiconductor manufacturing, biosensors, and related fields.

C. Nanoscale Devices and Applications

This area emphasizes the practical use of nanotechnology in devices such as nanosensors, nano-medical equipment, and nanoelectronic components, aiming to enhance performance and achieve further miniaturization.

RESEARCH METHODOLOGY

Titanium (Ti) is a metal oxide known for its excellent chemical stability, non-toxicity, and favorable optical properties. It is widely used in photocatalysis, solar cells, self-cleaning coatings, and environmental purification. With the advancement of nanotechnology, nanoscale Ti has demonstrated enhanced reactivity and efficiency in photocatalytic reactions due to its high specific surface area and quantum size effects. The common crystalline forms of nano-Ti include anatase, rutile, and brookite, among which anatase is the most widely used in photocatalytic applications. In recent years, various nanofabrication techniques have enabled precise control over the crystalline phase and particle size distribution of Ti, further improving its optical and catalytic performance [3].This study aims to synthesize titanium (Ti) nanocolloids using the electrical discharge machining (EDM) method through spark discharge. Given the widespread applications of nanoscale Ti in fields such as photocatalysis, solar cells, and environmental materials, developing a high-efficiency, low-cost, and stable method for producing high-quality Ti nanoparticles has become a crucial issue. Compared to conventional chemical synthesis methods, the EDM-based spark discharge process used in this study offers several advantages, including the elimination of chemical additives, uniform particle size distribution, and the direct formation of colloids. Therefore, this study investigates the effects of discharge parameters on nanoparticle formation by controlling processing conditions and observing the outcomes, with the goal of providing a viable technological pathway for green manufacturing of nanomaterials.Under ambient temperature and pressure conditions, titanium (Ti) nanocolloids were synthesized using the Electrical Spark Discharge Method (ESDM). Experimental comparisons were conducted using both a traditional electrical discharge machine (EDM) and a micro-electrical discharge machine (micro-EDM). By adjusting various processing parameters—such as discharge voltage, pulse duration, and frequency—the study analyzes their influence on the yield and characteristics of the resulting nanocolloids. Evaluations were carried out on key outcomes including processing efficiency, particle size distribution, surface quality, and electrode wear under different conditions. This research aims to clarify the differences and potential applications of these two machining technologies in the fabrication of nanomaterials.Electrical discharge machining is a non-traditional machining technique primarily used for processing conductive materials. Its fundamental principle involves generating continuous and controlled electrical spark discharges between a tool electrode and a workpiece, which locally melts and vaporizes the material to achieve material removal. The discharges occur within a very narrow gap—typically a few micrometers—filled with a dielectric fluid such as spark oil or deionized water, which serves to stabilize the electric field, cool the system, and flush away debris. During the machining process, the electrode and the workpiece do not make direct contact; instead, material is gradually eroded through a series of pulsed discharges.A key feature of electrical discharge machining is that it is not limited by the hardness of the material, making it suitable for complex shapes and precision micro-machining. However, it can only be applied to electrically conductive materials. The selected dielectric fluid is either deionized water or a highly insulating liquid, ensuring effective electric field control and stable discharge channels during the EDM process.

(a) Deionized water, due to its extremely low conductivity and environmentally friendly nature, is commonly used in EDM. It effectively reduces electrode wear and enhances the stability of the resulting nanocolloids [4].
(b) Highly insulating liquids help to control the discharge location and suppress abnormal discharge phenomena.

The conductivity of the dielectric fluid plays a critical role in energy control, discharge stability, and the quality of nanocolloid formation during the EDM process. An ideal dielectric fluid should exhibit low electrical conductivity—typically less than 10 μS/cm—to prevent unintended discharges and to maintain a stable pulsed discharge channel. Deionized water, with its extremely low conductivity (less than 1 μS/cm), is particularly suitable for EDM and nanoparticle synthesis. In addition, highly insulating liquids—such as specific synthetic oils or spark oils—also offer low conductivity and are effective in controlling discharge energy and the particle formation process. Selecting a dielectric fluid with an appropriate conductivity enhances the uniformity and stability of Ti nanocolloids [5-6].In electrical discharge machining (EDM), the dielectric fluid initially remains in an insulating state. However, when the electric field intensity applied between the electrode and the workpiece exceeds the dielectric breakdown voltage of the fluid, it is momentarily broken down, transitioning from an insulator to a conductor and forming a discharge channel. Within this channel, a high-temperature arc is generated, which instantly melts or vaporizes localized regions of the electrode and workpiece, thereby removing material. After breakdown, the dielectric fluid also functions to cool the area and flush away debris, while regaining its insulating property before the next discharge pulse. This dynamic cycle of dielectric breakdown and recovery is critical for stable machining of conductive materials [7-9].

During the electrical discharge machining (EDM or micro-EDM) process, the instantaneous temperature at the contact zone between the electrode and the workpiece is extremely high, serving as the primary driving force for the melting and vaporization of the material [10-12].

- According to multiple studies, the local temperature generated during discharge can reach as high as 8000–12,000 K (approximately 7700–11,700°C).
- However, this refers to the instantaneous plasma temperature at the core of the discharge channel, not the overall temperature of the electrode.
- The actual temperature at the heated surface of the electrode, which varies depending on the material and discharge energy, typically ranges from 3000–5000°C—sufficient to cause localized melting, vaporization, or even plasma formation of both the electrode and the workpiece materials. [13-15]

Due to the high-temperature discharge, the localized melting and vaporization of both the workpiece and electrode materials result in the formation of fine metallic particles (at the nano- or microscale). These particles condense and become suspended in the dielectric fluid, forming a stable colloidal suspension. The suspended metallic particles may originate from the workpiece, the electrode, or a combination of both, and their presence in the dielectric fluid constitutes a critical step in the synthesis of nanomaterials [16-18]. Electric Discharge Machining (EDM) is a non-traditional machining technique based on electrical spark discharges, specifically designed for high-precision processing of conductive materials. Its fundamental principle involves generating pulsed voltage between the tool electrode and the workpiece, inducing localized high-temperature arcs that cause the material to melt or vaporize, thereby achieving material removal. This machining process does not require direct contact between the tool and the workpiece, making it particularly suitable for hard materials or intricate geometries in micro-scale fabrication. A schematic representation is shown in Figure 1.

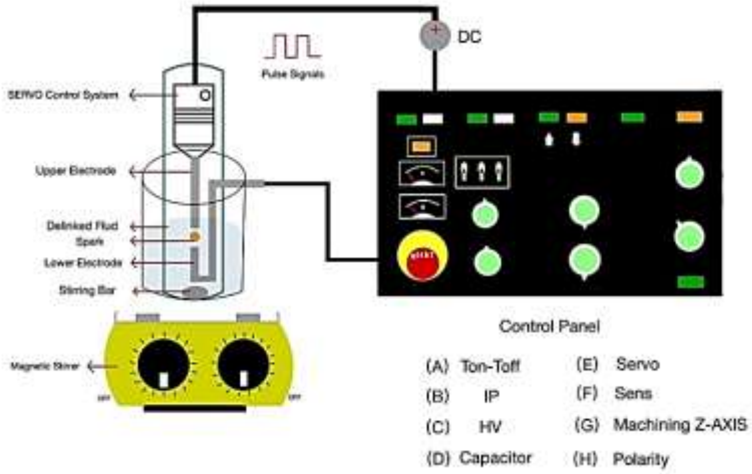


Fig. 1. Schematic Diagram of Electric Discharge Machining (EDM)

The dielectric fluid used in this study has a volume of 150 mL, with conductivity set within the range of 4–10 μS/m. Deionized water was selected as the dielectric fluid. During the experiment, the voltage was fixed at 140 V, and the current was adjusted sequentially from the first to the ninth setting. The total discharge processing time for each experiment was 10 minutes. The raw material used for the preparation of the nanowires was titanium metal wire with a purity of 99.99%. The environmental parameters used in the preparation experiments are shown in Table 1.

TABLE 1.ENVIRONMENTAL PARAMETER

Parameter Item	EDM	mEDM
	Setting conditions	
IP	3	5
Dielectric fluid type	Deionized water	
Volume of the dielectric fluid	150 mL	
conductivity	4–10 μS/m	
voltage	140 V	
Ton-Toff	10-100	
Processing time (per experiment)	10 minutes	
Electrode/workpiece material	Titanium wire (purity 99.99%)	
Wavelength(mv)	192	

UV-Vis spectroscopy was used to analyze the optical properties of titanium (Ti), while a Zetasizer instrument was employed to evaluate its suspension stability and particle size distribution. The six-stage cycle of the electric discharge machining (EDM) process is illustrated in Figure 2.

A. Preparation for Discharge

The conductive materials are placed on the upper and lower electrodes, which are then immersed in the dielectric fluid. Once the electrodes are connected to the power supply, the upper electrode is slowly moved downward, causing the gap voltage (V_gap) to gradually increase. During this stage, the electric field has not yet exceeded the dielectric breakdown strength of the fluid, so the dielectric fluid remains in an insulating state. It is essential to ensure that the electrode surfaces are properly aligned to avoid discharge failure.

B. Discharge Initiation

When the distance between the two electrodes is reduced to approximately 0.1–0.05 μm, the electric field strength exceeds the dielectric breakdown voltage of the dielectric fluid. This causes the dielectric fluid to break down, initiating the formation of a discharge channel, with electrons moving from the lower electrode to the upper electrode.

C. Ionization
In the discharge channel, free electrons collide with neutral atoms, causing outer-shell electrons to be ejected, generating positive ions and additional free electrons. This process forms a stable discharge channel, which is a prerequisite for the formation of an electric arc.

D. Melting and Material Removal
The free electrons and positive ions collide with the electrode surfaces, converting their kinetic energy into thermal energy, generating a high-temperature arc (reaching up to 8000–12,000 K). This causes localized melting or vaporization of the electrode surface. Some metal particles are ejected and suspended in the dielectric fluid, forming nanoparticles.

E. Discharge Termination (Start of Toff)
During the Toff phase, the voltage (V_gap) and current (I_gap) decrease, and the electrodes stop releasing electrons. The discharge channel rapidly disappears. At this point, the molten metal particles that were ejected remain suspended in the dielectric fluid.

F. Restoration of Insulation
After the Toff phase ends, the electrodes return to an insulating state, with V_gap and I_gap returning to zero. The system is now ready to enter the next discharge pulse cycle. The nanoparticles continue to be suspended in the dielectric fluid, awaiting further processing or collection.

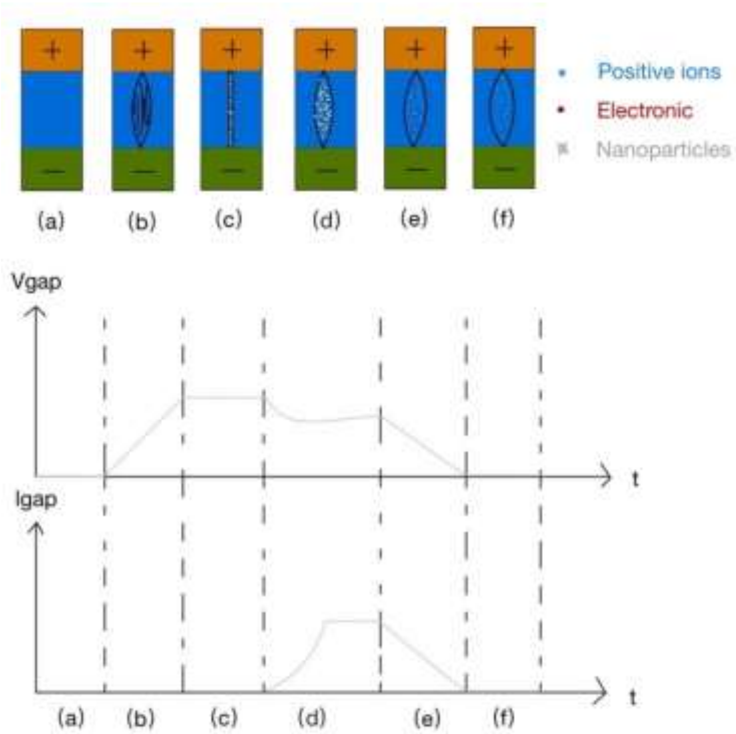


Figure 2. Electrical Spark Discharge Method.

RESULTS AND DISCUSSION

This study conducted experiments using traditional Electric Discharge Machining (EDM) and micro Electric Discharge Machining (mEDM) to synthesize titanium (Ti) nanoparticles, focusing on the effects of different Ton-Toff pulse conditions on particle size, Zeta potential, and absorbance. The experimental parameters were standardized with fixed machining time and dielectric liquid volume, using deionized water as the dielectric medium throughout for systematic comparison.

A. Particle Size Analysis
From the experimental data, the following observations were made:
(a) Nanoparticles produced by EDM exhibited a more stable size distribution, averaging 85.9 nm, with a range between 73.21 and 111.3 nm, indicating good control over thermal energy release and melting behavior.
(b) In contrast, mEDM resulted in more variation in particle size (ranging from 71.14 to 156.1 nm), especially under the condition of Ton-Toff = 10-10, where the size peaked at 156.1 nm, possibly due to energy concentration leading to particle agglomeration.

B. Zeta Potential Stability
(a) Zeta potential is a key parameter for evaluating colloidal stability; a more negative value indicates greater inter-particle repulsion and higher system stability.
(b) mEDM generally exhibited better Zeta potential, with a maximum of -54.4 mV, suggesting strong colloidal stability.
(c) While EDM showed slightly lower stability, it maintained Zeta potentials below -45 mV, still within the range of a stable dispersion system.

C. Absorbance (Concentration) Variation
(a) Absorbance reflects the concentration of generated nanoparticles. According to the data:
(b) Under the condition of Ton-Toff = 10-10, both EDM and mEDM recorded the highest absorbance, at 2.111 and 2.327, respectively, indicating that short pulse cycles effectively enhance nanoparticle yield.
(c) As Ton-Toff increased, absorbance gradually decreased—especially beyond 70-70, where a significant drop occurred, likely due to insufficient energy density and failure to maintain a stable discharge channel.

In this study, titanium colloids were prepared using the Electrical Spark Discharge Method (ESDM). A laser light scattering instrument (Zetasizer Nano System, Zetasizer) was used to measure the size of the nanoparticles and their surface potential (Zeta Potential). A higher Zeta potential indicates better suspension stability; when the absolute value of the Zeta potential exceeds 30 mV, the colloid is considered to be stably suspended. A UV-Visible Spectroscopy instrument (UV-Vis) was employed to analyze the absorption intensity and characteristic peaks of the samples. This instrument is used to assess the transmittance and reflectance of materials, as illustrated in Figures 3(a), (b) and Figures 4 (a), (b), (c), (d)

TABLE 2. ANALYTICAL DATA OF NANO TI COLLOID BY EDM

Ton-Toff	Size(d.nm)	Potential(mv)	Absorbance
10-10	83.93	-49.1	2.111
20-20	90.90	-53.0	1.886
30-30	111.30	-48.5	1.780
40-40	85.79	-52.2	1.269
50-50	83.04	-45.1	0.816
60-60	73.21	-47.9	0.572
70-70	70.81	-45.9	0.450
80-80	83.97	-46.5	1.060
100-100	78.47	-49.3	0.763

TABLE 3. ANALYTICAL DATA OF NANO TI COLLOID BY M-EDM

Ton-Toff	Size(d.nm)	Potential(mv)	Absorbance
10-10	156.10	-54.4	2.327
20-20	84.74	-47.6	0.821
30-30	100.70	-48.6	1.397
40-40	94.49	-49.4	0.943
50-50	79.57	-53.3	0.584
60-60	73.19	-47.4	0.514
70-70	76.37	-52.6	0.981
80-80	99.28	-51.9	0.578
100-100	71.14	-46.1	0.526

Analysis and Comparison

Absorbance

(a) The maximum absorbance for EDM reaches 2.111 (at Ton-Toff 10–10), while absorbance drops rapidly under other conditions, as shown in Figure 3(a).

(b) The maximum absorbance for m-EDM reaches 2.327, and although absorbance varies significantly, the optical properties under certain conditions are superior to those of EDM, as shown in Figure 3(b).

Zeta Potential

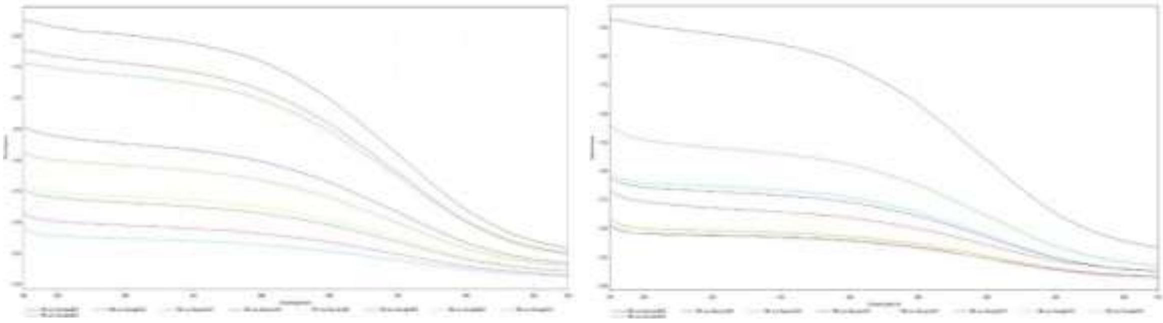
(a) The Zeta potentials for both methods are mostly negative, indicating that the colloids are negatively charged and exhibit a certain degree of stability.

(b) The average Zeta potential for EDM is approximately -49 mV, as shown in Figure 4(a), and for m-EDM it is close to -50 mV, as shown in Figure 4(b), suggesting comparable colloidal stability.

Particle Size

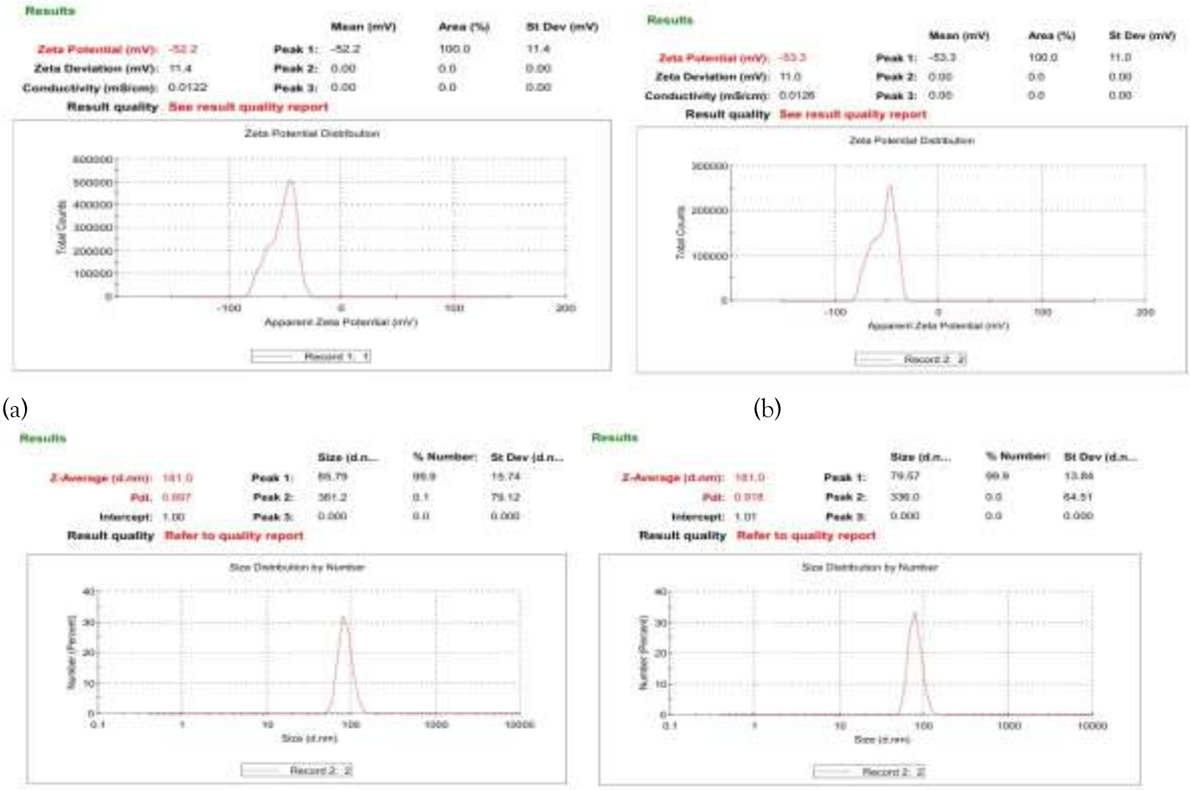
(a) EDM-produced colloids have particle sizes ranging from 70.81 to 111.30 nm, with relatively small variation and a more concentrated distribution, as shown in Figure 4(c).

(b) m-EDM-produced colloids range from 71.14 to 156.10 nm, with a larger initial size and more significant fluctuations, indicating unstable particle size control under certain conditions, as shown in Figure 4(d).



(a) (b)

Figure 3. UV-Vis Test Results (a) EDM,(b) mEDM



(a) (b)

(c) (d)

Figure 4. (a) EDM Zeta Potential (b) mEDM Zeta Potential (c) EDM size distribution (d) mEDM size distribution

CONCLUSION

This study compares the preparation efficiency of Ti materials using EDM and micro-EDM. Micro-EDM demonstrates advantages in nanoparticle generation and surface quality, with low equipment cost, optimal particle size (71.14 nm), stable Zeta potential (up to -54.4 mV), and high absorbance (maximum 2.327), making it suitable for small to medium laboratories and early-stage research. However, it is more sensitive to operating conditions. On the other hand, EDM offers higher stability and preparation efficiency, with better precision in particle size control (optimal: 70.81 nm), stable Zeta potential (up to -53 mV), and good absorbance (maximum 2.111), making it ideal for precision applications, despite its higher equipment cost. These comparative results provide valuable guidance for selecting the most appropriate fabrication technique for different application scenarios and offer important reference for nanomaterial processing.

Competing interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

Funding

The Ministry of Science and Technology (NSTC 113-2622-E-027-024 -).

REFERENCES

[1] **Thakur, Preeti, and Atul Thakur.** "Introduction to nanotechnology." Synthesis and applications of nanoparticles (2022): 1-17.
[2] **Thakur, Preeti, and Atul Thakur.** Introduction to Nanotechnology. In Synthesis and Applications of Nanoparticles, Springer, 2022, pp. 1–17.
[3] **Liu, L., & Chen, X. (2014).** Titanium nanomaterials: Self-structuring and enhanced photocatalytic activity. Chemical Reviews, 114(19), 9890–9918.
[4] **Yeo, S.H., & Tan, P.C. (2000).** "Electrolyte effects in micro-electro-discharge machining (μ-EDM)." Journal of Materials Processing Technology, 107(1–3), 107–113.
[5] **Kunieda, M., & Yoshida, M. (1997).** "Electrical discharge machining in water with high open voltage." Proceedings of the CIRP, 46(1), 143–146.
[6] **Yeo, S. H., & Tan, P. C. (2000).** "Electrolyte effects in micro-electro-discharge machining (μ-EDM)." Journal of Materials Processing Technology, 107(1–3), 107–113.
[7] **Klocke, F., & Arnold, R. (1998).** "EDM—State of the Art and Introduction of the Scientific Community." CIRP Annals - Manufacturing Technology, 47(2), 557–579.
[8] **Ho, K. H., & Newman, S. T. (2003).** "State of the art in electrical discharge machining." International Journal of Machine Tools and Manufacture, 43(13), 1287–1300.
[9] **Kunieda, M., Lauwers**, B., Rajurkar, K. P., & Schumacher, B. M. (2005). "Advancing EDM through Fundamental Insight into the Process." CIRP Annals, 54(2), 64–87..
[10] **Kumar, S., & Singh, R. (2010).** "Recent advances in electrical discharge machining: A review." International Journal of Modern Manufacturing Technologies, 2(2), 1–9.
[11] **Ho, K. H., & Newman, S. T. (2003).** "State of the art in electrical discharge machining." International Journal of Machine Tools and Manufacture, 43(13), 1287–1300.
[12] **Klocke, F., & Arnold, R. (1998).** "EDM—State of the Art and Introduction of the Scientific Community." CIRP Annals, 47(2), 557–579.
[13] **Ho, K. H., & Newman, S. T. (2003).** State of the art in electrical discharge machining. International Journal of Machine Tools and Manufacture, 43(13), 1287–1300.
[14] **Elhami, S., & Ghasemi, S. E. (2017).** A review on the modeling and simulation of EDM thermal aspects. Journal of Manufacturing Processes, 29, 41–52.
[15] **Klocke, F., Wirtz, T., & Veselovac, D. (2014).** Influence of process parameters on the thermal load in micro-EDM.Procedia CIRP, 14, 175–180.
[16] **Kunieda, M., Lauwers, B., Rajurkar, K. P., & Schumacher, B. M. (2005).** Advancing EDM through Fundamental Insight into the Process. CIRP Annals, 54(2), 64–87.
[17] **Simao, J., Lee, H. S., Aspinwall, D. K., et al. (2003).** Workpiece surface modification using electrical discharge machining. International Journal of Machine Tools and Manufacture, 43(2), 121–128.
[18] **Zhao, W. S., Meng, Y. F., & Wang, Z. L. (2008).** Colloidal nanoparticle formation during electrical discharge machining. Nanotechnology, 19(26), 265605.