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A Comprehensive Review of Electrode Materials in Electrical Discharge Machining (EDM): Properties, Performance, and Recent Advancements

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Abstract
Electrical Discharge Machining (EDM) is a non-traditional thermal machining process indispensable for manufacturing complex geometries in high-strength, temperature-resistant conductive materials. The electrode, acting as the tool, is the primary vehicle for energy delivery. Its material properties directly dictate the Material Removal Rate (MRR), Tool Wear Rate (TWR), and the resulting Surface Roughness (SR). This paper provides an extensive review of electrode materials, categorizing them into metallic, carbon-based, and advanced composite materials. It further examines the thermo-physical interactions at the spark gap and the impact of electrode metallurgy on the heat-affected zone (HAZ) of the workpiece. Finally, current research trends in nano-composites and sustainable EDM practices are synthesized to provide a roadmap for future industrial applications.

Keywords: *EDM, Electrode Material, Copper, Graphite, Titanium, Tool Wear, TWR, MRR, Surface Integrity.*

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I. INTRODUCTION

The manufacturing industry constantly seeks methods to process advanced materials like Inconel, Titanium alloys, and Ceramic composites, which are often characterized by high hardness and low thermal conductivity. Traditional machining methods fail due to excessive tool wear and mechanical stress. Electrical Discharge Machining (EDM) offers a solution by utilizing thermal energy generated by electrical sparks to melt and vaporize the material [1].

In this process, the electrode selection is not merely a choice of "tool" but a choice of "energy carrier." The thermal and electrical properties of the electrode determine how much energy is localized at the workpiece versus how much is dissipated or causes tool erosion. Despite decades of development, finding a "universal" electrode material remains a challenge due to the trade-off between cost, machinability, and performance [2, 11].

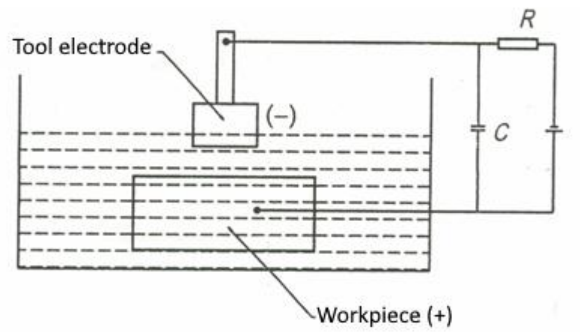


Fig 1. Schematic diagram of Electrical Discharge Machining (EDM)

II. THERMAL MECHANISM AND ELECTRODE SELECTION CRITERIA

The EDM process is governed by the Law of Thermodynamics. During a single discharge, temperatures can reach 8000ºC to 12000ºC[3].

2.1. Thermal Conductivity (λ)

A high λ value is essential for an electrode to rapidly conduct heat away from the sparking surface. This prevents the electrode from reaching its own melting or sublimation point too quickly, thereby reducing the Tool Wear Rate (TWR) [4].

2.2. Melting and Boiling Points

Materials with high melting points (Tungsten, Graphite,…) are more resistant to the thermal erosion of the spark. Graphite is unique because it sublimes (turns directly from solid to gas), which absorbs a significant amount of latent heat, cooling the tool surface effectively [6, 12].

2.3. Electrical Resistivity

Low electrical resistivity is required to minimize energy loss within the tool itself and to prevent the electrode from overheating due to Joule heating, especially in high-frequency micro-EDM [5].

Tab 1: Physical properties and main applications of common electrode materials

Material	Thermal Conductivity (W/m·K)	Melting Point (°C)	Main Application
Copper	~390	1083	High precision, fine finish
Graphite	100 - 400	3600 (Sublimes)	Large dies, high MRR
Cu-W	190 - 220	>2500	Hardened alloys, micro-EDM
Brass	110 - 150	900 - 940	Drilling, general purpose

III. DETAILED CLASSIFICATION OF ELECTRODE MATERIALS

3.1. Copper (Cu) and Copper-based Alloys

Copper is the "gold standard" for precision EDM. Its high ductility allows it to be manufactured into complex shapes via cold-forming or CNC machining. Performance: It provides a very stable discharge, making it ideal for finishing operations where a low Surface Roughness (SR) is required. Limitations: Copper has a relatively low melting point (1083°C) compared to refractory metals, leading to high TWR in roughing operations with high current [7].

3.2. Graphite

Graphite is the most widely used material in North America and Europe for die-sinking EDM. Grades: It is classified by grain size. Angstrofine graphite (grain size < 1 μm) can produce finishes comparable to copper, while Coarse graphite is used for rapid metal removal. Wear Resistance: Graphite exhibits "no-wear" characteristics under certain high-pulse duration conditions because carbon from the decomposed dielectric fluid often deposits onto the graphite surface, creating a protective layer [12, 13].

3.3. Tellurium-Copper (Te-Cu)

By adding approximately 0.5% Tellurium to copper, the machinability is vastly improved. This is critical when the electrode itself requires intricate cooling channels or very thin fins, which would be difficult to produce with pure electrolytic copper [4].

3.4. Tungsten-based Composites (Cu-W and Ag-W)

Produced through infiltration powder metallurgy, these materials are used when extreme precision and low tool wear are mandatory (e.g., machining carbides). Tungsten provides the structural "skeleton" that resists heat, while Copper or Silver provides the conductivity [14].

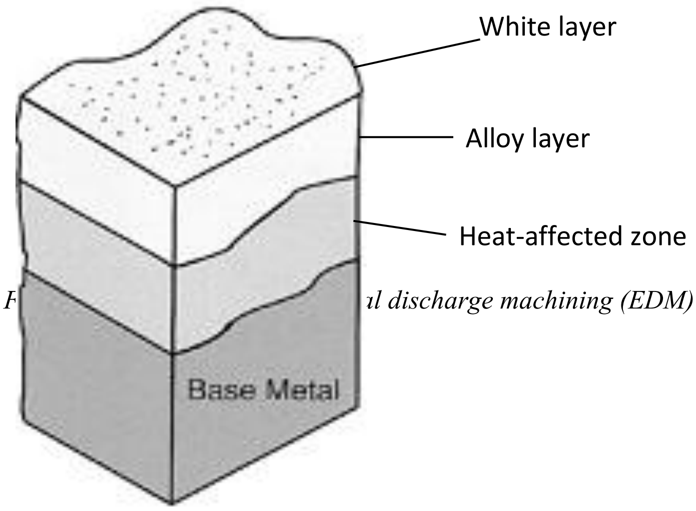
3.5. Titanium (Ti) as a Specialized Electrode for Surface Alloying

According to recent experimental research [10, 15], Titanium is not only used as a tool for material removal but also as a source for "Surface Alloying." In a study conducted on a **CNC-EA600L EDM machine** (JS EDM), Titanium electrodes were utilized to machine **SKD61 steel**—a material widely used for hot-die applications.

Surface Transformation and Migration

The interaction between the Ti-electrode and the SKD61 workpiece under a dielectric medium (transformer oil) leads to a complex metallurgical transformation. During the discharge process, the intense heat causes both the workpiece and the electrode to melt and vaporize. A significant amount of Titanium atoms migrate into the molten "White Layer" of the workpiece.

- White Layer Formation: A thin, hard recast layer is formed, consisting of a fine-grained or amorphous structure enriched with Ti-carbides.
- Heat Affected Zone (HAZ): Below the white layer, a tempered zone and a re-hardened zone are formed, which significantly affects the mechanical properties of the tool steel.



F ıl discharge machining (EDM)

Technical Parameters and Performance

The experimental data provides specific ranges for optimizing the EDM process with Ti-electrodes:

- Discharge Current (Ie): Essential for controlling the spark energy.
- Pulse Duration (ti/Ton) and Pulse Interval (to/Toff): These parameters directly influence the Material Removal Rate (MRR) and the thickness of the alloyed layer.
- Surface Quality: Using Ti-electrodes, a surface roughness (Ra) as low as 0.16 µm can be achieved, with a dimensional accuracy of approximately 0.01 mm.

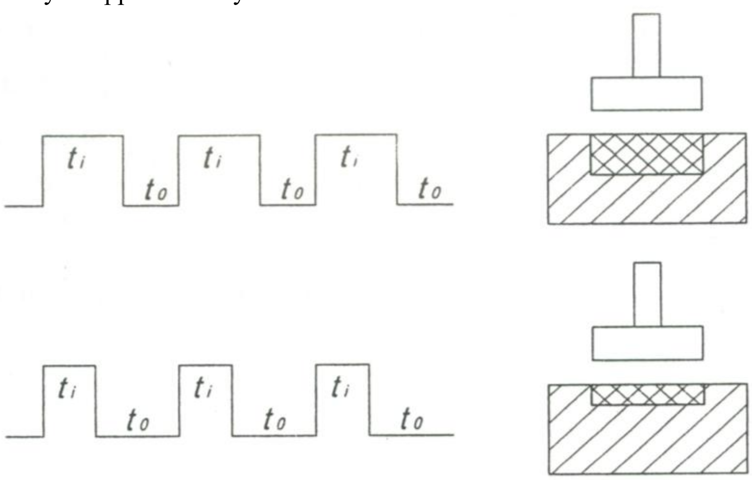
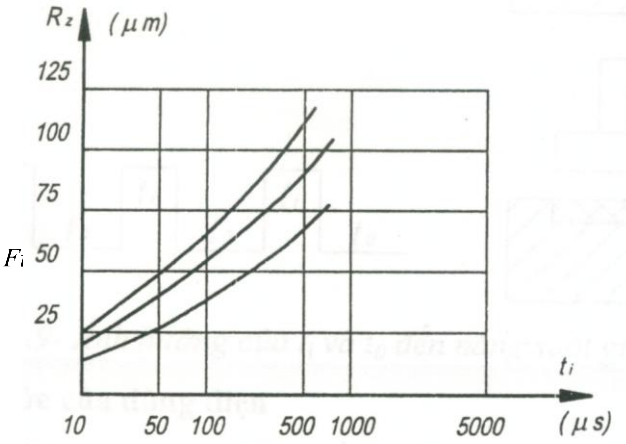


Fig 3. Effect of ti and to on machining productivity



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IV. IMPACT OF ELECTRODE MATERIAL ON SURFACE INTEGRITY

The choice of electrode significantly affects the "White Layer" (re-cast layer) on the workpiece. Carbon Migration: When using graphite electrodes, carbon atoms often migrate into the molten workpiece surface, forming carbides that increase the surface hardness but may introduce brittleness [9]. Metal Transfer: Copper electrodes can transfer small amounts of Cu to the workpiece, which may affect the biocompatibility of medical implants (Titanium bone screws) [10, 15].

V. EXPERIMENTAL COMPARISON AND PROCESS PARAMETERS

Tab 2: Performance characteristics of different electrode materials in EDM

Electrode	Workpiece	MRR (mm^3/min)	TWR (%)
Copper	Steel (H13)	Medium	1% - 5%
Graphite	Steel (H13)	High	< 1%
Cu-W	WC-Co	Low	Very Low
Brass	Low Carbon	Low	High

Note: Data represents average values under standard polarity settings [1, 8].

VI. FUTURE RESEARCH DIRECTIONS

6.1. Nano-powder Additives

Integrating Carbon Nanotubes (CNTs) into copper electrodes via spark plasma sintering has shown a 20-30% improvement in MRR due to enhanced electron emission [14].

6.2. Cryogenic Cooling

Research in Vietnam and globally has started looking into cryogenically treated electrodes. Cooling the electrode to liquid nitrogen temperatures before or during machining increases its conductivity and significantly reduces TWR [10, 15].

VII. CONCLUSION

The selection of electrode materials in EDM is a multi-objective optimization problem involving cost, time, and quality. While graphite dominates roughing for its speed and copper dominates finishing for its precision, the industry is moving towards composite materials. Advanced manufacturing in Vietnam is increasingly adopting specialized electrodes for titanium and inconel processing, highlighting the need for localized research into optimized machining parameters.

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REFERENCES

[1]. Abbas. N. M, Solomon. D. G. & Bahari. M. F. (2007). 'A review on current research trends in electrical discharge machining (EDM).' Journal of Materials Processing Technology, 186(1-3), 1-14.

[2]. Ho. K. H. & Newman. S. T. (2003). 'State of the art electrical discharge machining (EDM)' International Journal of Machine Tools and Manufacture, 43(13), 1287-1300.

[3]. Karthikeyan. R, Narayanan. P. R. & Naagarazan. R. S. (2010). 'Mathematical modelling for electric discharge machining of aluminum-silicon carbide particulate composites.' Journal of Materials Processing Technology.

[4]. Muthuramalingam. T. & Mohan. B. (2015). 'A review on influence of electrical process parameters in EDM.' International Journal of Precision Engineering and Manufacturing.

[5]. Jahan. M. P, Wong. Y. S & Fuh. J. Y. H. (2011). 'A study on the quality of micro-EDM drilling of tungsten carbide.' Journal of Engineering Manufacture.
[6]. Sommer. C. & Sommer. S. (2005). Complete EDM Handbook. Advance Publishing.
[7]. Tsai, Y. C., & Masuzawa, T. (2004). 'An index to evaluate the wear resistance of EDM electrodes' Journal of Materials Processing Technology.
[8]. Tan, H. K., & Yeo, S. H. (2008). 'Environmentally friendly EDM: A review' Proceedings of the Institution of Mechanical Engineers.
[9]. Samuel, M. P & Philip. P. K. (1997). 'Powder metallurgy electrodes for EDM' International Journal of Machine Tools and Manufacture.
[10]. Nguyen. H. P & Ngo. C (2019). 'Nghiên cứu ảnh hưởng của vật liệu điện cực đến chất lượng bề mặt khi gia công hợp kim Titan bằng EDM.' Tạp chí Khoa học và Công nghệ - Đại học Thái Nguyên.
[11]. Trần Văn Nga. (2015). Kỹ thuật gia công xung điện và các phương pháp gia công đặc biệt. Nhà xuất bản Bách Khoa Hà Nội.
[12]. Phạm Minh Tuấn. (2018). 'Phân tích đặc điểm và phạm vi ứng dụng của điện cực Graphite trong gia công khuôn mẫu' Tạp chí Cơ khí Việt Nam.
[13]. Kumar, S., & Singh, R. (2013). 'Surface modification by electrical discharge machining: A review Machining Science and Technology.
[14]. Singh, B., & Sharma, J. (2021). 'Graphene-based electrodes in EDM: Performance and prospects' Materials Today: Proceedings.
[15]. Lê Cung, & Nguyễn Hữu Phấn. (2020). 'Tối ưu hóa đa mục tiêu quá trình gia công EDM sử dụng điện cực đồng đỏ và dung dịch điện môi sinh học' Tạp chí Kỹ thuật Lê Quý Đôn.