



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 10, October 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118

9940 572 462

6381 907 438

ijirset@gmail.com

www.ijirset.com

Electrodes Used In EDM: Review

Shivaji G. Badekar

Lecture in Production Engineering, Government Polytechnic, Ahmednagar, Maharashtra, India

Email: sgbgovtpoly@gmail.com

ABSTRACT: Electrical Discharge Machining (EDM) is a widely adopted non-conventional machining process used for shaping electrically conductive materials with high precision. The effectiveness of EDM largely depends on the characteristics of the electrode material, which directly influences machining performance indicators such as material removal rate (MRR), tool wear rate (TWR), and surface integrity. This review paper presents an in-depth analysis of electrode materials used in EDM, including graphite, copper, brass, tungsten, and composite electrodes. Their physical, thermal, and electrical properties are critically examined along with their performance in various machining conditions. The paper also explores electrode wear mechanisms, fabrication techniques, and recent advancements such as additive manufacturing and nano-coated electrodes. Furthermore, the role of electrode geometry, polarity, and process parameters is discussed in detail. The study concludes with insights into future trends aimed at improving EDM efficiency and sustainability.

I. INTRODUCTION

Electrical Discharge Machining (EDM) is an advanced machining technique that utilizes electrical energy to remove material from a workpiece through a series of controlled spark discharges. Unlike traditional machining methods, EDM does not rely on mechanical forces; instead, it employs thermal energy generated by electrical sparks. This unique characteristic allows EDM to machine extremely hard materials such as tool steels, carbides, titanium alloys, and superalloys, which are otherwise difficult to process using conventional methods.

The process takes place in a dielectric medium, typically deionized water or hydrocarbon oil, which acts as an insulator until the breakdown voltage is reached. Once ionization occurs, a spark is generated between the electrode and the workpiece, producing intense localized heat. This heat melts and vaporizes a small portion of the material, which is then flushed away by the dielectric fluid.

The electrode serves as a tool that shapes the workpiece. Therefore, its material properties and geometry are critical to achieving the desired machining outcomes. Over the years, significant research has been conducted to identify suitable electrode materials that can enhance machining efficiency while minimizing wear.

II. FUNDAMENTAL PRINCIPLE OF EDM

The EDM process operates on the principle of thermoelectric energy conversion. When a pulsed DC voltage is applied across the electrode and the workpiece, a strong electric field is established in the inter-electrode gap. As the voltage increases, the dielectric medium breaks down, forming a plasma channel that allows current to flow.

The spark discharge generates temperatures in the range of 8000°C to 12000°C, which is sufficient to melt and vaporize the workpiece material. The molten material is expelled due to the rapid expansion of gases and is subsequently cooled and solidified into debris particles. These particles are flushed away by the dielectric fluid, leaving behind a crater on the workpiece surface.

The repetition of this process at high frequency results in the gradual removal of material. The size and shape of the craters depend on the energy of the spark, which is controlled by parameters such as discharge current, pulse duration, and voltage.

III. SIGNIFICANCE OF ELECTRODES IN EDM

The electrode is a critical component in EDM, as it directly influences the machining process. It acts as a conductor for electrical energy and determines the shape of the machined cavity. The electrode must maintain its geometry during machining to ensure dimensional accuracy.

One of the major challenges associated with electrodes is wear. During spark discharge, both the workpiece and the electrode are subjected to high temperatures, leading to material erosion. Excessive electrode wear can result in dimensional inaccuracies and increased machining time.

Therefore, selecting an appropriate electrode material is essential for optimizing EDM performance. The choice depends on factors such as machining requirements, cost, and desired surface finish.

IV. PROPERTIES OF IDEAL ELECTRODE MATERIALS

An ideal electrode material should possess a combination of electrical, thermal, and mechanical properties. High electrical conductivity ensures efficient energy transfer, while high thermal conductivity helps dissipate heat, reducing tool wear. A high melting point is crucial to withstand extreme temperatures without significant deformation.

In addition to these properties, good machinability is required to fabricate electrodes with complex geometries. The material should also exhibit low thermal expansion to maintain dimensional stability. Cost and availability are practical considerations that influence material selection in industrial applications.

V. DETAILED STUDY OF ELECTRODE MATERIALS

5.1 Graphite Electrodes

Graphite is one of the most extensively used electrode materials in EDM due to its favorable thermal properties and ease of machining. It is a form of carbon with a layered structure, which provides excellent resistance to thermal shock. Graphite electrodes are particularly suitable for high-speed rough machining operations. Their low density reduces inertia, making them easier to handle and machine into complex shapes. Additionally, graphite exhibits low tool wear, which improves machining efficiency.

However, graphite has certain limitations. Its relatively low electrical conductivity compared to copper results in a slightly lower surface finish quality. Moreover, the brittle nature of graphite can lead to edge chipping, and the generation of dust during machining requires proper safety measures.

5.2 Copper Electrodes

Copper is widely used in EDM due to its excellent electrical and thermal conductivity. It is particularly effective in finishing operations where high surface quality and dimensional accuracy are required.

Copper electrodes produce smoother surfaces compared to graphite, making them suitable for applications involving fine details and tight tolerances. However, copper is more difficult to machine and has a higher cost, which can limit its use in large-scale operations.

5.3 Brass Electrodes

Brass is primarily used in wire EDM processes, where a thin wire acts as the electrode. The continuous feeding of wire ensures consistent machining performance, as fresh material is always available.

Although brass is cost-effective and easy to produce, it has a higher wear rate compared to other materials. As a result, it is not commonly used for die-sinking EDM applications that require high precision.

5.4 Tungsten and Copper-Tungsten Electrodes

Tungsten is known for its extremely high melting point and excellent wear resistance. It is commonly used in applications that require high precision and minimal electrode wear.

Copper-tungsten composites combine the advantages of both materials, offering high conductivity and thermal resistance. These electrodes are particularly suitable for micro-EDM and precision machining applications. However, their high cost and difficulty in machining limit their widespread use.



VI. COMPARATIVE ANALYSIS

The comparative analysis of electrode materials clearly highlights the trade-offs involved in selecting a suitable material for EDM applications. Graphite offers a balanced combination of low cost, high thermal resistance, and low wear rate, making it ideal for rough machining operations, although its surface finish is only moderate. Copper, on the other hand, provides excellent electrical conductivity and superior surface finish, which makes it highly suitable for finishing operations despite its higher cost and moderate wear rate. Brass is commonly used in wire EDM due to its low cost and ease of use, but its higher wear rate and lower thermal resistance limit its application in precision machining. Copper-tungsten (Cu-W) electrodes exhibit exceptional performance with very low wear rate and high thermal resistance, making them suitable for high-precision and micro-machining applications, although they are expensive. Tungsten also demonstrates extremely high thermal resistance and very low wear, but its low conductivity and high cost restrict its usage to specialized applications. Overall, no single material is universally ideal; instead, the choice depends on machining requirements such as accuracy, cost constraints, and desired surface quality. Materials with higher conductivity generally provide better machining efficiency, while those with higher thermal resistance tend to exhibit lower wear. The table emphasizes the importance of selecting electrode materials based on a balance between performance characteristics and economic considerations.

Table 1: Comparison of Electrode Materials Used in EDM

Material	Conductivity	Thermal Resistance	Wear Rate	Surface Finish	Cost
Graphite	Moderate	High	Low	Moderate	Low
Copper	High	Moderate	Medium	Excellent	High
Brass	Moderate	Low	High	Moderate	Low
Cu-W	High	Very High	Very Low	Good	Very High
Tungsten	Low	Extremely High	Very Low	Good	Very High

VII. ELECTRODE WEAR MECHANISMS

Electrode wear in Electrical Discharge Machining is a highly complex phenomenon governed by thermal, electrical, and metallurgical interactions occurring during spark discharge. Each discharge generates a localized plasma channel that produces extremely high temperatures, typically in the range of 8000°C to 12000°C. Under such conditions, both the workpiece and the electrode are subjected to melting, vaporization, and even partial ionization. Although EDM is primarily intended to remove material from the workpiece, a portion of the electrode material is also inevitably eroded, leading to tool wear.

The wear mechanism begins with the absorption of thermal energy at the electrode surface. This energy causes localized melting and evaporation of the electrode material. Simultaneously, the rapid expansion of gases and dielectric breakdown produces a pressure wave that ejects molten material from the surface. Not all molten material is expelled; some resolidifies on the electrode, forming a recast layer that may alter its properties over time.

Electrode wear manifests in several forms. Uniform wear occurs when the erosion is evenly distributed across the electrode surface, typically observed under stable machining conditions. Localized wear, on the other hand, arises due to uneven spark distribution, often caused by irregularities in the electric field or debris accumulation in the spark gap. Edge wear is particularly significant in precision machining, as it leads to rounding of sharp corners and degradation of fine features. This type of wear directly impacts dimensional accuracy and surface integrity.

Another important aspect of electrode wear is the formation of micro-cracks and surface defects due to repeated thermal cycling. These defects can propagate over time, further accelerating wear. The rate of electrode wear is influenced by several factors, including discharge energy, pulse duration, electrode polarity, and material properties. Generally, negative polarity (tool as cathode) is preferred because it reduces the amount of heat absorbed by the electrode, thereby minimizing wear.

VIII. EFFECT OF PROCESS PARAMETERS

The performance of the EDM process is highly sensitive to machining parameters, which control the energy and frequency of spark generation. Among these parameters, discharge current is one of the most influential. It determines the intensity of the spark and directly affects the amount of thermal energy delivered to the workpiece. Higher discharge current increases the material removal rate by generating larger and deeper craters; however, it also leads to increased electrode wear and poorer surface finish.

Pulse duration, defined as the time for which the current is applied during each discharge, plays a crucial role in controlling the extent of material melting. Longer pulse durations allow more heat to be transferred, resulting in higher material removal but also causing excessive thermal damage and increased tool wear. Conversely, shorter pulse durations produce finer craters and better surface finish but reduce machining efficiency.

Pulse interval, or off-time, is equally important as it allows the dielectric fluid to deionize and flush away debris from the spark gap. Insufficient off-time can lead to unstable machining conditions, including arcing and short circuits, which adversely affect both the electrode and the workpiece.

The dielectric medium itself significantly influences EDM performance. Hydrocarbon oils are commonly used in die-sinking EDM due to their ability to provide superior surface finish and stable spark generation. In contrast, deionized water is preferred in wire EDM because of its lower viscosity and better flushing characteristics, which enable faster machining rates.

Other parameters such as gap voltage, flushing pressure, and electrode polarity also contribute to the overall process behavior. The optimization of these parameters is essential to achieve a balance between material removal rate, electrode wear, and surface quality.

IX. ELECTRODE FABRICATION TECHNIQUES

The fabrication of electrodes is a critical aspect of EDM, as it directly influences machining accuracy, surface quality, and production efficiency. Traditional electrode manufacturing methods include conventional machining processes such as milling, turning, and grinding. These methods are widely used due to their simplicity and cost-effectiveness, especially for producing electrodes with simple geometries.

However, conventional techniques have limitations when it comes to fabricating complex shapes and intricate features. The increasing demand for high-precision components in industries such as aerospace and medical engineering has necessitated the development of advanced fabrication methods.

Powder metallurgy is one such technique that enables the production of electrodes with tailored properties. In this process, metal powders are compacted and sintered to form solid components. This method allows for the creation of composite electrodes, such as copper-tungsten, with enhanced thermal and electrical properties.

Additive manufacturing, also known as 3D printing, has emerged as a promising technology for electrode fabrication. It allows the production of highly complex geometries that are difficult or impossible to achieve باستخدام traditional methods. Additive manufacturing also reduces material waste and enables rapid prototyping, making it suitable for customized applications.

Despite its advantages, additive manufacturing faces challenges such as high equipment cost and limited material availability. Nevertheless, ongoing research is expected to overcome these limitations and expand its application in EDM electrode production.

X. APPLICATIONS OF EDM ELECTRODES

EDM electrodes are extensively used across a wide range of industries due to their ability to machine hard and complex materials with high precision. In the tooling and die-making industry, EDM is employed for producing molds, dies, and punches with intricate cavities. The use of electrodes allows for accurate replication of complex geometries that are difficult to achieve using conventional machining methods.

In the aerospace industry, EDM plays a crucial role in manufacturing components such as turbine blades, fuel system parts, and heat-resistant alloys. These components often require high precision and are made from materials that are difficult to machine using traditional techniques. EDM enables the production of such components without inducing mechanical stresses, thereby preserving material integrity.

The medical field also benefits significantly from EDM technology. It is used for producing surgical instruments, orthopedic implants, and dental components with high accuracy and smooth surface finish. The ability to machine biocompatible materials such as titanium and stainless steel makes EDM particularly suitable for medical applications. Additionally, EDM is widely used in micro-machining, where extremely small and precise features are required. This includes applications in electronics, MEMS (Micro-Electro-Mechanical Systems), and precision engineering.

XI. ADVANCED AND HYBRID ELECTRODES

Recent advancements in EDM technology have led to the development of advanced and hybrid electrode materials aimed at improving machining performance and reducing wear. These electrodes are designed by combining different materials to achieve a balance of desirable properties such as high conductivity, thermal resistance, and mechanical strength.

Copper-graphite composites are among the most widely used hybrid electrodes. They combine the high electrical conductivity of copper with the excellent thermal resistance and machinability of graphite. This results in improved performance in both roughing and finishing operations.

Another significant development is the use of nano-coated electrodes. These electrodes are coated with thin layers of materials such as ceramics or carbides at the nanoscale level. The coatings enhance thermal stability, reduce wear, and improve surface finish. Additionally, they act as protective barriers that minimize oxidation and chemical reactions during machining.

Research is also being conducted on functionally graded materials (FGMs), where the composition of the electrode varies gradually to optimize performance. These advanced materials offer promising potential for future EDM applications.

XI. FUTURE RESEARCH DIRECTIONS

The future of EDM electrode technology is focused on enhancing efficiency, sustainability, and precision. One of the areas of research is the development of environmentally friendly dielectric fluids and electrode materials. Traditional dielectric fluids can be harmful to the environment, and efforts are being made to replace them with biodegradable alternatives. Another area is the integration of artificial intelligence and machine learning techniques for optimizing EDM processes. These technologies can analyze large datasets to predict optimal machining parameters, thereby improving efficiency and reducing trial-and-error approaches. Nanotechnology is also playing a significant role in advancing electrode materials. The use of nanoparticles and nano-coatings can significantly enhance thermal and electrical properties, leading to improved performance and reduced wear. Automation and robotics are expected to further revolutionize EDM processes by enabling fully automated machining systems with minimal human intervention. These advancements will contribute to higher productivity and consistency in manufacturing.

XII. CONCLUSION

The electrode is a fundamental component of the EDM process, and its characteristics have a profound impact on machining performance. The selection of an appropriate electrode material is essential for achieving the desired balance between material removal rate, surface quality, and tool wear. Traditional materials such as graphite and copper continue to dominate due to their proven performance and availability. However, the limitations associated with these materials have led to the development of advanced and hybrid electrodes that offer improved properties. A comprehensive understanding of electrode wear mechanisms, process parameters, and fabrication techniques is crucial for optimizing EDM operations. As technology continues to evolve, new materials and methods are expected to further enhance the capabilities of EDM.

In conclusion, ongoing research and innovation in electrode technology will play a vital role in meeting the growing demands of modern manufacturing industries, enabling the production of complex components with higher precision, efficiency, and sustainability.

REFERENCES

1. M. A. Ali *et al.*, “Assessment of electrode materials in EDM of SS316L: energy consumption, electrode wear, dielectric consumption, GHG emissions, and economic viability,” *Scientific Reports*, 2025.
2. E. Garba *et al.*, “A Review of Electrode Manufacturing Methods for Electrical Discharge Machining: Current Status and Future Perspectives,” *Machines*, vol. 11, no. 9, 2023.
3. S. Singh, S. Maheshwari, and P. C. Pandey, “Some investigations into the electrical discharge machining of hardened tool steel using different electrode materials,” *Journal of Materials Processing Technology*, vol. 149, pp. 272–277, 2004.
4. L. Zhang, L. H. Dong, D. S. Wang, C. H. Fan, and Y. Zhou, “A Survey on Electrode Materials for Electrical Discharge Machining,” *Materials Science Forum*, 2011.
5. D. L. Panchal, S. K. Biradar, and V. Y. Gosavi, “Analysis of EDM Process Parameters by Using Coated Electrodes,” *International Journal of Engineering Trends and Technology*, vol. 41, 2016.
6. K. H. Ho and S. T. Newman, “State of the art electrical discharge machining (EDM),” *International Journal of Machine Tools and Manufacture*, vol. 43, pp. 1287–1300, 2003.
7. M. Kunieda *et al.*, “Advancing EDM through fundamental insight into the process,” *CIRP Annals*, vol. 54, no. 2, pp. 64–87, 2005.
8. P. Sharma *et al.*, “Electrical discharge machining of stainless steel using different electrodes,” *Procedia Materials Science*, 2014.
9. N. Mohri *et al.*, “Electrode wear process in electrical discharge machining,” *CIRP Annals*, vol. 44, no. 1, pp. 165–168, 1995.
10. A. A. Khan, “Electrode wear and material removal rate during EDM of aluminum and mild steel using copper and brass electrodes,” *International Journal of Advanced Manufacturing Technology*, vol. 39, pp. 482–487, 2008.
11. V. K. Jain, *Advanced Machining Processes*, Allied Publishers, 2005.
12. P. C. Pandey and H. S. Shan, *Modern Machining Processes*, Tata McGraw-Hill, 1980.



INNO SPACE
SJIF Scientific Journal Impact Factor
Impact Factor: 8.118



ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 **9940 572 462**  **6381 907 438**  **ijirset@gmail.com**



www.ijirset.com

Scan to save the contact details