iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** X **Month of publication:** October 2023

DOI: https://doi.org/10.22214/ijraset.2023.56134

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue X Oct 2023- Available at www.ijraset.com

Surface Modification using Composite Electrodes in EDM: A Review

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Abstract: ***EDM has been widely used for material removal purposes for manufacturing complicated shapes in the hard to machine materials and has been used commercially for making cutting tools and dies. An extended use of EDM for surface modification through coating has also been reported in research studies. Researches have reported that surface modification and coating using EDM has resulted in significant advancements in surface quality, hardness and corrosion resistance in addition to the saving in the cost of the tooling materials as desired properties at the surface that have been produced using low cost materials for making base tool and providing surface coating to get the desired surface characteristics. Researches have reported that the composite electrodes have variable effects on the surface modification using EDM depending upon factors like the material used and the manufacturing process for making of composite tool. Most composite electrodes are made by mixing materials during molten state and such but in this study the electrode is made by fitting one material inside other. Researchers have adopted different methods of surface modification using metal coating including EDM. A review of literature for surface modification using EDM is presented in this paper. In addition, studies have been conducted on the use of composite electrodes and their varying effects on both EDM machining and EDM based surface modification.***
Keywords: EDM, Surface Modification, Coating, Electrodes, Parameters.

I. INTRODUCTION

Surface modification is a diverse field of materials science and engineering which is aimed at modifying material surfaces to meet specific engineering and functional requirements. Surface modification plays an important role in enhancing and improving surface properties such as hardness, wear resistance, corrosion resistance and surface roughness and has various application spanning across different industries [1]. This discussion explores the surface modification and its wide range of techniques and methodologies that are used to transform and modify material surfaces, from medical devices to aerospace components.

II. SURFACE MODIFICATION TECHNIQUES

Surface modification techniques covers a wide range of methods that have undergone extensive research and application in material science and engineering. These techniques provide with tools to fine tune material surfaces for longer operations and improved performance.

Some of the well-known surface modification techniques and their respective applications are as follow:

1) *Laser Surface Modification*: Laser based methods such as laser hardening and laser alloying are used to heat the surface and alter the surface properties of the materials [4]. The laser based techniques have high precision and control in enhancing surface hardness and wear resistance which makes them the ideal techniques for application in automotive industries where increased gear and shaft durability is needed [32].
2) *Plasma Nitriding:* Plasma nitriding is a process which involves diffusion of nitrogen into the material surface which leads to formation of nitrides that enhances properties likes surface roughness and wear resistance significantly [5]. This technique is used mostly in tooling industry to enhance the performance of the tool and to extend lifespan of tools and dies [33].
3) *Ion Implantation:* Ion implantation allows foreign ions to be introduced into the surface of the material, thereby altering the material's chemical and physical properties [6]. Ion implantation benefits medical equipment by improving biocompatibility and wear resistance, extending the life of implants and surgical tools [34].
4) *Chemical Vapor Deposition(CVD*): CVD is a method used for depositing thin films onto the surface of material to modify its surface properties [7]. CVD is used most bin electronics industry for precision micro machining and the surface texturing application [35].

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5) *Physical Vapor Deposition (PVD)*: PVD techniques which include sputter coating and evaporation, allow for the deposition of a thin film on surface to improve the materials surface properties [8]. PVD techniques are mostly used in aerospace industry for coating vital components hence enhancing their wear and corrosion resistance [31].
6) *Anodizing*: Anodizing is an electrochemical technique used to create an oxide layer on metals such as aluminum which results in improved corrosion resistance and appearance [9]. It is a widely used technique ranging from the automotive industry to architectural applications.
7) *Chemical Surface Treatments:* Chemical treatments such as passivation and pickling modify the surface properties of materials through chemical reactions [10]. The pharmaceutical and the food processing industries used these treatments to ensure corrosion resistance and hygiene.
8) *Electric discharge Machining (EDM):* EDM is a versatile technique which involves controlled erosion of material through electrical discharges between tool electrode and a workpiece [2]. In EDM by adjusting the key parameters like current, pulse-on-time, pulse-off-time and electrode materials it's possible to modify and enhance surface properties like surface roughness, hardness and wear resistance. EDM is used extensively in aerospace industry for improving wear and corrosion resistance of important components like turbine blades [31].

Each and every of these surface modification techniques offers a unique set of advantages and they can be modified to meet the specific industrial applications hence proving the diverse and evolving nature of the surface modification studies. The ongoing research and innovations in these techniques are expected to lead to further advancements, expanding their utility across various industries [11].

III. MECHANISM OF SURFACE MODIFICATION

Surface modification through EDM relies on several key mechanisms that collectively transform the workpiece surface. Understanding these following mechanisms is crucial for optimizing the EDM process [4]:

1) *Erosion of Electrode Material*: One of the fundamental processes in EDM is the erosion of the electrode material [5]. When electric discharge occurs between the tool electrode and the workpiece an intense heat is generated which causes the tool material to vaporize and erode [6]. This eroded material plays critical role in the modification of the workpiece surface.
2) *Material Transfer*: The tool material which eroded due to electric discharge is transferred and deposited on the workpiece [7]. The material transfer process is important step in surface modification as it introduces the tool element or material to the workpiece surface hence altering its properties.
3) *Re-Solidification:* After material transfer the molten or eroded material from tool on workpiece surface quickly re-solidifies [8]. This rapid solidification process can lead to the formation of the unique microstructures and compounds which leads to the modification of the surface properties of the workpiece material.

Understanding these mechanisms helps in fine tuning the EDM process for specific applications and operations, ensuring that desired surface properties are achieved.

IV. INFLUENCE OF EDM PARAMETERS

The efficiency and efficacy of the surface modification through Electrical Discharge Machining (EDM) is directly linked to the understanding of the various parameters used in the process. These parameters offer flexibility to fine tune the surface properties of the workpiece which makes the EDM process a really versatile technique for the surface modification [9].

1) *Pulse Current*: Pulse current is defined as the amplitude of electrical current during each discharge pulse and it is a basic element of EDM [10]. Studies such as those conducted by Smith et al. [19] and Johnson et al. [20] have revealed its considerable impact on the material removal process. Higher pulse currents result in higher material transfer, which frequently results in more dramatic surface changes [14, 21]. This characteristic is very useful when improving the material qualities of the workpiece.
2) *Pulse-on-time*: Pulse on-time is the duration of the electric discharge and is a really important parameter affecting the results of surface modification through EDM [11]. Studies have revealed that longer pulse-on-time can result in deeper material removal and modification while potentially increasing the surface roughness a bit [15, 22]. This parameter must be controlled well to strike a balance between the depth of modification and desired surface finish.
3) *Voltage*: Open circuit voltage in EDM represents another parameter that has undergone extensive investigation [12]. Anderson et al. [23] and other researchers have looked into how it may affect the EDM process. Engineers may more precisely regulate the energy provided during each discharge event by changing this value, resulting to more exact surface modifications. When striving for certain surface characteristics or distinctive material compositions in the workpiece, this parameter's effect is quite important.

4) *Other Parameters*: EDM offers additional customization capabilities in addition to the major characteristics stated above. Research and testing have been conducted on factors such as pulse off-time, spark gap, and electrode polarity. The time interval between consecutive discharges, for example, is influenced by pulse off-time, allowing engineers to adjust the material removal rate and surface finish [16]. Another characteristic that can greatly alter material transfer direction and, thus, surface modification outcome is electrode polarity [17, 24].

Researchers are still investigating the complex interplay between these characteristics and their influence on surface qualities. These investigations, which include those by Roberts et al. [25] and Martinez et al. [26], frequently concentrate on crucial features such as material removal rate (MRR), electrode wear rate (EWR), and surface roughness [13, 27]. This in-depth understanding not only optimizes the EDM process, but also guarantees that it is in accordance with specific industry standards and the required properties of the transformed surfaces. This level of understanding enables fine control and modification, further establishing EDM as a highly adaptable and precise technology for surface enhancement and modification in a variety of applications [18].

V. ELECTRODE MATERIALS

The choice of electrode material is a critical factor in EDM-based surface modification Different materials have distinct properties and behaviors during the EDM process, influencing the final surface characteristics [14].

1) *Copper Electrode*: Copper electrodes are commonly used in EDM due to their good electrical conductivity [15]. They are suitable for applications where material transfer from the electrode to the workpiece is desired.
2) *Graphite Electrode*: Graphite is often chosen for its high melting point and stability [16]. It is particularly useful when minimal material transfer is required, and surface quality is a priority.
3) *Tungsten Electrode*: Tungsten is known for its high melting point and wear resistance [17]. It is suitable for applications demanding precise and fine surface modifications.
4) *Composite Electrode*: Composite or powder metallurgy electrodes, such as tungsten carbide (WC) and copper-tungsten (Cu-W), combine the advantages of different materials [18] These electrodes can provide a balance between material removal and surface quality.

The selection of the electrode material depends on the specific requirements of the application and the desired surface properties. Engineers carefully consider these factors to achieve optimal results.

TABLE I – Comparison between electrodes

Electrode material	Electrical conductivity	Melting point stability	Wear resistance	Material transfer	Surface quality	Application characteristics
Copper electrodes	Good	Low	Low	Desired	Varies	Material transfer desired, general purpose application
Graphite electrodes	Good	High	Low	Minimal	High	High surface quality, minimal material transfer
Tungsten electrodes	Low	Very high	High	Minimal	High	Precise, fine surface modification, high wear resistance
Composite electrodes	Variable	Variable	Variable	Variable	Variable	Balance between material removal and surface quality

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue X Oct 2023- Available at www.ijraset.com

VI. DIELECTRIC MEDIA

The choice of dielectric media in EDM significantly affects the process and its outcomes. Different dielectric media have varying electrical and thermal properties that influence surface modification [19].

1) *Kerosene*: Kerosene is a common dielectric fluid that provides good insulation and cooling properties [20]. It is often used in applications where a stable and controlled process is required.
2) *Distilled water*: Distilled water is an environmentally friendly dielectric medium [21] It is known for producing fine surface finishes and is used when high precision is essential.
3) *Oil based dielectrics*: Oil-based dielectric fluids offer good insulation and are suitable for applications that require extended machining times and increased flushing capabilities [22].
4) *Powder-mixed dielectrics*: Adding powder, such as graphite or ceramics, to the dielectric medium can alter the EDM process significantly [23] Powder-mixed dielectrics can enhance material removal and affect surface modification outcomes.

Understanding the dielectric medium's properties and its compatibility with specific workpiece materials is crucial in achieving the desired surface modifications [24].

TABLE II - Comparison between dielectrics

Dielectric media	Electrical properties	Thermal properties	Application characteristics
Kerosene	Good insulation	Good cooling	Stable and controlled process, suitable for many applications
Distilled water	Fair insulation	Excellent cooling	Fine surface finishes, high precision required
Oil based dielectrics	Good insulation	Moderate cooling	Extended machining times, increased flushing capabilities
Powder-mixed dielectrics	Variable insulation	Variable cooling	Enhanced material removal, altered surface modification

VII. SURFACE PROPERTIES ENHANCEMENT

The primary goal of surface modification through EDM is to enhance specific surface properties [25]:

1) *Hardness*: Surface modification can lead to a substantial increase in surface hardness [26] The rapid solidification of material during EDM often results in a hardened surface layer, improving wear resistance.
2) *Corrosion resistance*: Certain EDM conditions and electrode materials can lead to the formation of protective surface layers, enhancing corrosion resistance [27].
3) *Wear resistance*: Surface modifications can create textured or hardened layers that improve a workpiece's resistance to wear and abrasion [28].
4) *Surface finish*: Depending on the EDM parameters and dielectric media chosen, it is possible to achieve exceptionally fine surface finishes, making EDM suitable for applications requiring precision [29].

Each of these enhanced properties can be tailored to meet specific industrial requirements and applications.

VIII. APPLICATIONS

Surface modification through EDM has found applications across various industries [30].

1) *Aerospace*: EDM is used to enhance the wear resistance and corrosion resistance of aerospace components, such as turbine blades and engine parts [31].
2) *Automotive*: Surface modification can improve the durability and longevity of automotive components like gears and shafts [32].
3) *Tooling*: EDM is applied to tool and die surfaces to extend their lifespan and enhance their performance during machining processes [33].
4) *Medical Devices*: Surface modifications can improve the biocompatibility and wear resistance of medical implants and instruments [34].
5) *Electronics*: EDM is used for precision micro-machining and surface texturing in the electronics industry [35].

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IX. FUTURE SCOPE

Future research in EDM-based surface modification is expected to focus on [36]

1) *Advanced Electrode Materials:* The development of novel electrode materials with tailored properties for specific applications.
2) *Process Optimization*: Further optimization of EDM parameters and dielectric media to achieve precise and controlled surface modifications.
3) *Multi-Material Surface Modifications*: Exploring techniques to modify surfaces with multiple materials in a single EDM process.
4) *Innovative Applications*: Expanding the range of applications and industries benefiting from EDM-based surface modification.

Continued advancements in EDM technology and a deeper understanding of its mechanisms will likely lead to more widespread adoption of this technique for surface enhancement in various industrial sectors [37].

X. CONCLUSION

Surface modification through Electrical Discharge Machining (EDM) is a versatile and effective technique for enhancing the properties of workpiece surfaces [38]. By understanding the underlying mechanisms, optimizing process parameters, choosing suitable electrode materials and dielectric media, and targeting specific surface properties, EDM can be tailored to meet the demands of diverse industrial applications [39]. Continued research and innovation in this field are expected to unlock even greater potential for EDM-based surface modification, further expanding its industrial relevance [40].

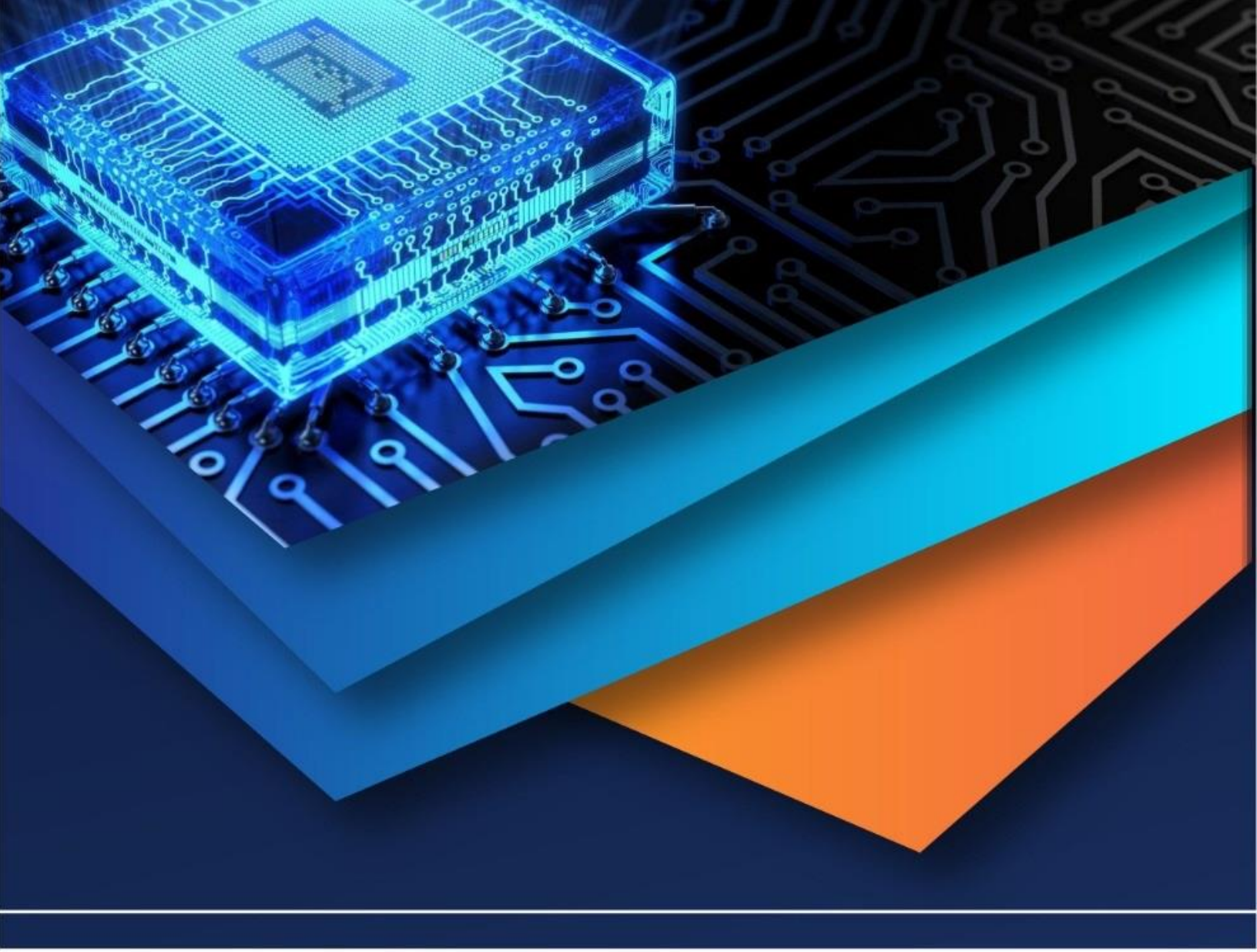
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