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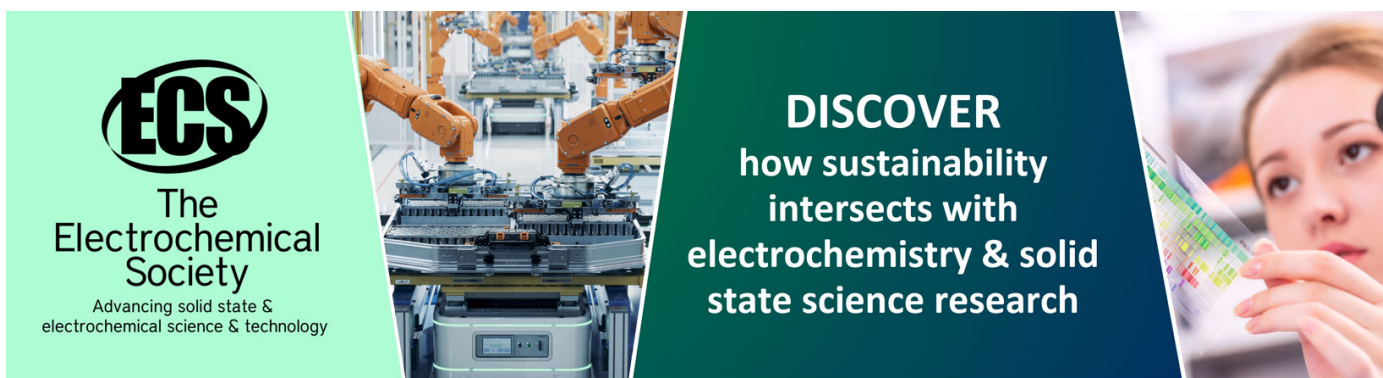
Electrochemical discharge machining process, variants and hybridization: A review

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Electrochemical discharge machining process, variants and hybridization: A review

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Abstract. Electrochemical discharge machining has been proven to fabricate micro holes, micro-channels and three dimensional shapes on difficult to machine non conductive materials very efficiently. Researchers have proposed some modification in the basic configuration of the ECDM process to increase the efficiency. These modifications result in the development of ECDM variants. Further improvement in the process researchers hybridized the ECDM process. In this review article different areas of electrochemical discharge machining have been focused, which includes sparking phenomena, variants and recent hybridization. Furthermore, the article provides the knowledge to understand the research potential of an ECDM process.

1. Introduction

The today's scenario of the product development totally depends on customer needs and a product's performance. Modern customers want the best features and reliability of the product without quality being compromised. The best example is a car which is available with wide varieties, features, size, aesthetic (graphics, color and finishing) and flexible price range to suit customer requirement and market segments. The rising customer demands and varied choices lead to explosive growth which can be achieved by advancement in technology and by manufacturing diversity in the same product. Researchers have faced many challenges to fulfill the demand of customers by conventional techniques. Thus machining of non conducting advance materials with unconventional processes has basic keystones to achieve goals. However, some of the unconventional machining processes like abrasive jet machining (AJM), ultrasonic machining (USM) and laser beam machining (LBM) can machine such materials. Even some of the natural problems like poor surface quality and low machinability, etc restrict the use of these materials in advance manufacturing industries. To overcome this above challenge, researchers have combined electro chemical machining (ECM) and electric discharge machining (EDM) processes. This combined process is known as electro chemical discharge machining process (ECDM).

1.1 Electro Chemical Discharge Machining Process (ECDM)

ECDM is a novel and hybrid process. ECDM is a combined characteristic of EDM and ECM which gives better result on machining electrically non conductive materials. It is mainly used for machining hard and brittle non conductive materials such as glass, ceramics, optical glass, quartz and composite materials [1-9]. Water decomposition with static electricity was introduced in 1789 [10]. An electrochemical discharge phenomenon described by Fizeau and Foucault [11]. Sir William Rovert Grove invented the fuel cell in 1839 [12]. Decomposition of water into hydrogen and oxygen bubbles and also observed discharges takes place above a critical voltage by Jules Violle and Michel Chassagny [13]. P.Hoho [14] was the first one who described a gas film formation phenomenon and practical utilization of the ECDM process. In the year 1968 Kurafuji and Suda [15] gave the name of



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the ECDM process called electrical discharge drilling. Many researchers gave different names to ECDM process such as discharge machining (DM) for non-conductors by Cook et al., [16] electro-chemical arc machining (ECAM) [17,18], electro erosion-dissolution machining (EEDM) [19], spark-assisted etching (SAE) [20], spark-assisted chemical engraving (SACE) [21-23] and an electro chemical spark machining (ECSM) [24,25]. The basic diagram of the ECDM process is shown in figure 1. ECDM set up consist of two electrodes .i.e. Tool electrode (cathode) and Auxiliary electrode (anode). Workpiece is fixed with holder and placed below the tool electrode which is partially immersed in the electrolyte. As the size of both the electrodes are different, usually size of the auxiliary electrode much larger than the tool electrode which helps to generate potential difference in between two electrodes when DC supply voltage supplied to both the electrodes which is the main cause to initiate the electrolysis process. As voltage higher than a critical voltage, the electric discharge produces in between the tool electrode and the workpiece.

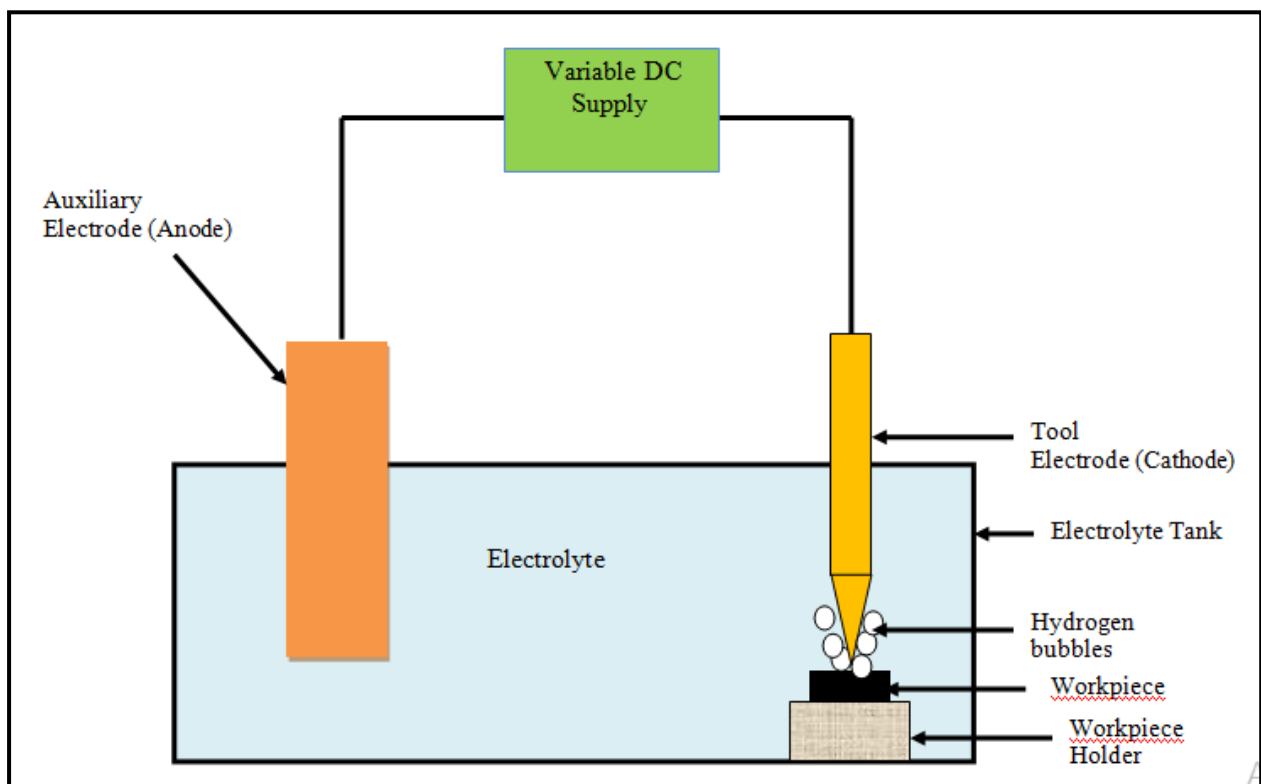


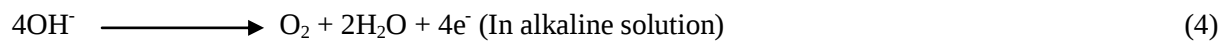
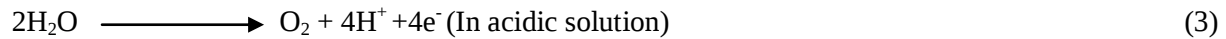
Figure 1. Schematic sketch of Electrochemical Discharge Machining (ECDM) Process

1.2 Spark Formation Phenomenon of ECDM

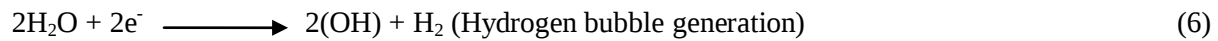
In the ECDM process, the material removal is a combined effect of ECM and EDM processes. The major cause of material removal is the formation of the spark between tool and the workpiece. The material is removed from workpiece during the process is due to melting, vaporization, high temperature chemical etching, thermal stress and mechanical shocks due to expanding gases. The generation of gases is the important aspect in the ECDM process because uniform and stable gaseous layer creates the stable spark formation while an unstable gaseous layer not used in the machining due to an unstable formation of the spark. Different researchers have carried out the number of investigations for the development of the ECDM process, however still spark formation is an undermined phenomenon. In this segment, a spark formation has been explained considering the bubble formation into the gaseous layer. In the ECDM process, the constant DC supply voltage (continuous or pulse) is applied to the tool and auxiliary electrode, dipped in the electrolyte solution.

Also an electrochemical reaction happens between the anode and the cathode dipped in the electrolyte medium during the process. As the difference in the respective sizes is approximately 1:100, the potential difference is created between the tool and auxiliary electrode as a result; there is a generation of hydrogen (H_2) and oxygen (O_2) gases on their surfaces respectively.

Reactions between the anode and an acidic electrolyte as given below



Reactions between cathode and an acidic electrolyte as given below



The formation of H_2 gas bubbles during machining are the main reason for a generation of spark in tool and workpiece. The different phases of a spark generation phenomenon are shown in figure2.

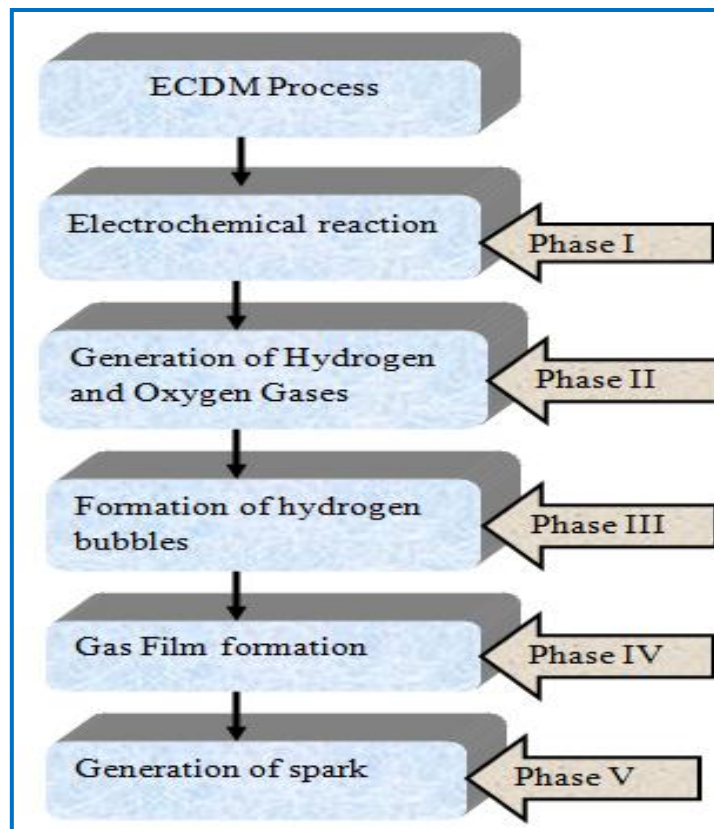


Figure 2. Different phases of spark generation phenomenon

The generation of the controlled H_2 gas bubble in between the tool electrode and workpiece is an important aspect in the ECDM process. Density and the mean radius of the bubble are two important parameters for gas bubbles formation which rely on DC supply voltage. As DC supply voltage rise, gas bubble formed at the vicinity of the tool also increases which results into increase in gas bubble

density. Because of bubble coalescence there is formation of gaseous film around tool as the DC supply voltage increases. Gaseous film acts as a dielectric medium which protects the tool electrode from the direct contact with electrolyte solution when DC voltage reaches to the critical voltage. The spark in the ECDM process is directly linked to the critical voltage. Critical voltage depends on many factors like tool material, tool geometry, electrolyte concentration and conductivity of the electrolyte which directly effects the spark formation during the process. As in the spark phenomenon, tool electrode generally dipped 2 to 3 mm in the electrolyte solution otherwise there is no spark generation happen during the process.

2. Variants of ECSM process

ECDM is used to do different machining operation such as drilling, turning, die-sinking, cutting, milling, and dressing. Types of ECDM depend upon the operations they performed and are named accordingly such as in drilling operation, the name of the machine called electrochemical discharge drilling and for milling called electrochemical discharge milling etc. These operations are effectively used for making different profile on the hard and brittle non conducting materials. Different ECDM processes and their process capabilities are shown in figure3.

2.1 Electrochemical Discharge Drilling (ECDD)

The ECDD process is used to drill through or blind hole, with the high aspect ratio in advance conductive and non conductive materials. Some conductive materials like cobalt, chrome and titanium can easily drill with ECDD and achieve the similar surface finish which is attained with an ECM process [26]. Silicon nitride [27], stainless steels [28], soda lime glass [29], Kevlar fiber–epoxy and glass fiber–epoxy [30], quartz [31], beryllium copper alloys [32], mild steel [33], ceramic [34], silicon wafers [35] also drill with the ECDD process.

2.2 Electrochemical Discharge Milling

This process has similarity with the conventional milling process. In this technique, rotary wheel act as a cutting tool and travels in a defined path. This technique is use to fabricate 3-D microstructures on pyrex glass [36], glass ceramic [37] and quartz metallic materials [38] and also produce different profiles like micro channels [39-41] and micro grooves [36,42].

2.3 Electrochemical Discharge Turning (ECDT)

In ECDT process, continuous rotary motion provided to the workpiece and is dipped in an electrolytic solution. During machining, rotation of the workpiece made easy to feed a fresh electrolyte in the narrow gap between the tool and the workpiece. The key factor which affects the performance of the process is rotation of the workpiece. This process specially used for turning different profiles such as cylindrical turning, taper turning [43,44] and deep grooves with sharp edges[45], etc.

2.4 Electrochemical Discharge Dressing

In this process, auxiliary electrode dipped in an electrolyte solution and grinding tool face is contacted with electrolyte surface, and both anode (grinding bit) and cathode (auxiliary electrode) are connected to power supply. In dressing process, removal of the bond in between the tool and electrolyte interface due to spark energy results generation of new grains. Electrolyte acts as cooling dresser and flushing agent in electrochemical discharge dressing to avoid the burs during machining. The quality of the generated machined surface and morphology of the grinding tool surface are the decided parameters to check the performance of the machine. Machining with electrochemical discharge dressing reduces the grinding force as well as surface roughness of the work piece by 50% [46].

2.5 Wire Electrochemical Discharge Machining (WECDM)

The WECDM process has been used to cut hard and brittle materials [47]. In this process traveling wire act as a cathode and auxillary electrode act as anode and both immersed in electrolyte solution. The researchers used different feeding mechanism like dead weight [45], slide [48] and ball screw [49]

which was the most important aspect in WECDM to maintain the gap between wire and the workpiece,. WECDM does not depend on the electric conductivity of the workpiece and it can machine both conductive and non-conductive materials like metal matrix composites [50], borosilicate glass [49], ceramics [51], quartz [52].

2.6 Die-Sinking Electrochemical Discharge Machining (DS-ECDM)

The Die sinking ECDM technique is used for making small and shallow dies on conductive [53] and non conductive materials [54] with higher MRR than ECM and EDM processes [53,54]. Further geometrical tolerance were much better than ECM process and close to EDM process. The hollow tool is used to achieve high sinking rate [52, 53].

2.7 Electrochemical Discharge Trepanning

This process is mostly used for making the deep holes on hard and brittle materials. The tool electrode provides the orbital motion by offsetting the tool axis from spindle axis. Electrochemical discharge trepanning is the most inexpensive method for making the deep holes. Jain et al., [54] reported through holes in an alumina and quartz materials. Chak et al.,[34] observed the higher MRR by using spring feed abrasive particle embedded the tool instead of a gravity fed tool and also reduce the taper of the machined hole.

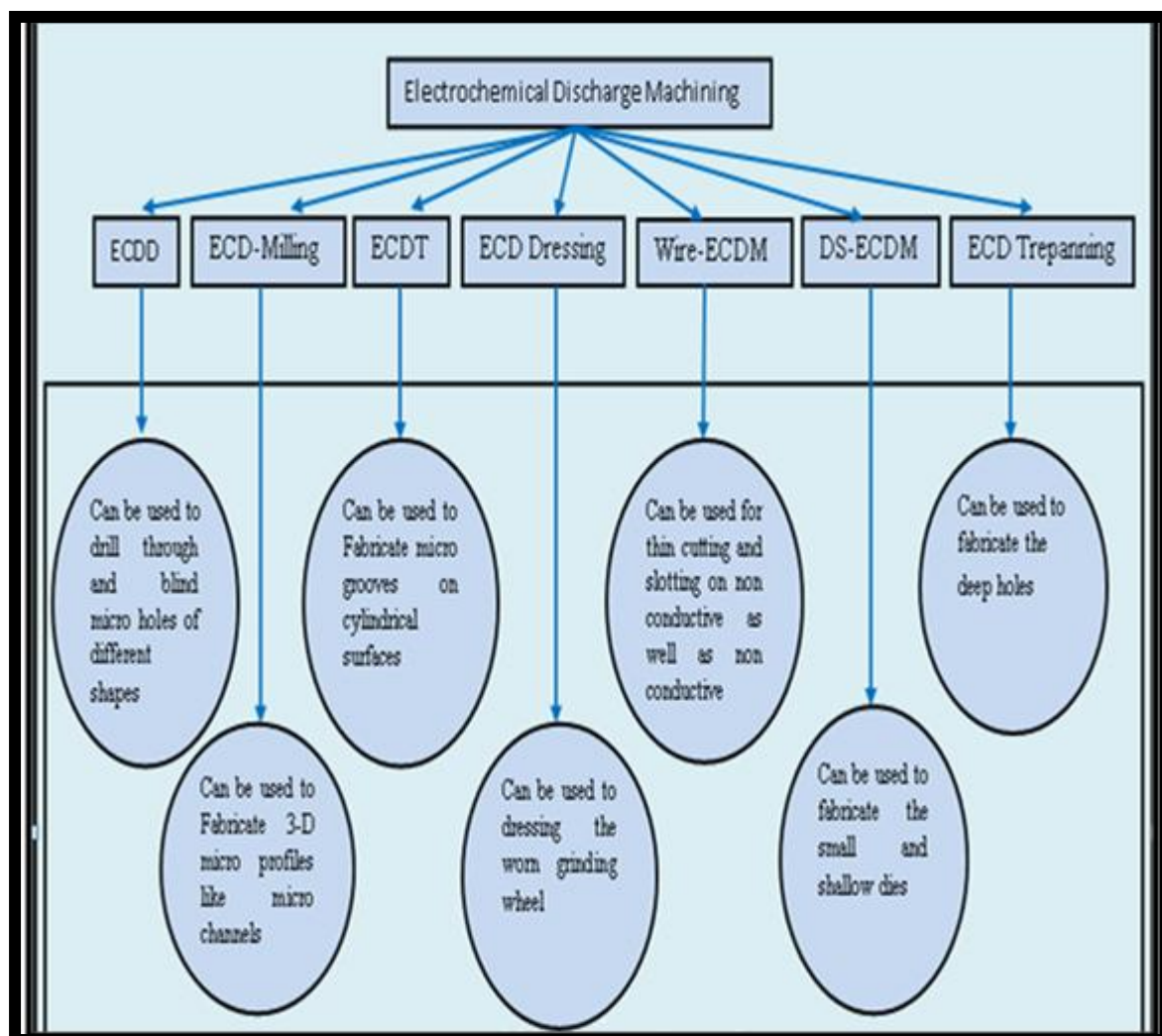


Figure 3. ECDM variants process capabilities

3. Classification of hybridized ECDM processes

ECDM is a combination of ECM and EDM processes. In these processes two different energies performed the various machining operation like milling, drilling, dressing, turning etc. For more improvement in the process, different energies combined together in a controlled manner with ECDM configuration to develop hybrid processes.

3.1 Rotary Assisted Electrochemical Discharge Machining (RAECDM)

In the rotary ECDM process (figure 4), the rotary motion of the tool [56] can drill depth micro holes, with a small entrance diameter due to the rotary movement of the tool and also improved the electrolyte circulation in between the tool electrode and workpiece. The major advantage of this technique is that equally energy dispersion of the spark on the entire machining zone instead of one point and machined holes are straight and smooth. Production of micro holes on glass workpiece with tungsten carbide based the rotary tool [57]. To produce micro holes on borosilicate glass [58], Pyrex glass [59], steel [56] and stainless steel [60] with R-ECDM technique.

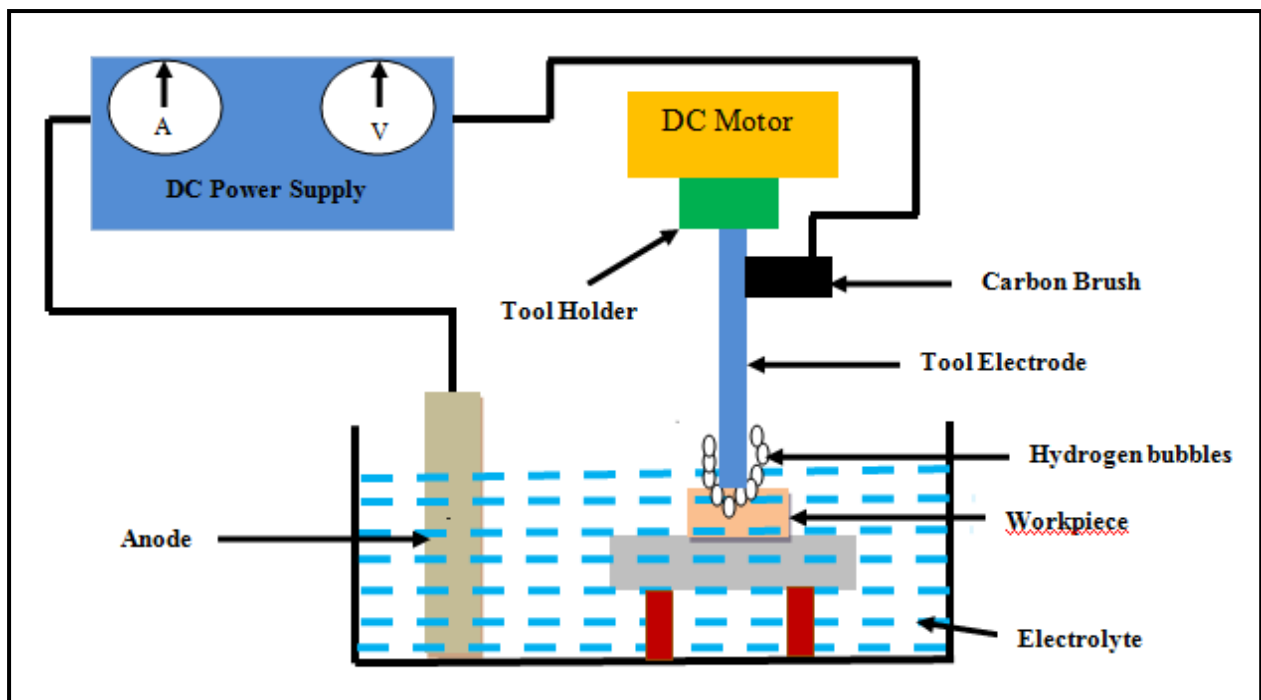


Figure 4. Schematic sketch of basic rotary-assisted ECDM.

3.2 Powder Mixed Electrochemical Discharge Machining (PM-ECDM)

In this process (figure5) abrasive particles are mixed with an electrolyte solution which improves the surface quality of the machined surface. The abrasive particle reduced the direct spark which impact on the workpiece surface, results the generation of smooth surface finish. The conductivity of abrasive particles decides the generation of spark energy in between the tool electrode and workpiece. The use of sodium hydroxide electrolytic solution with graphite abrasive for machining borosilicate glass material gives better machined surface quality [54]. This process helps to achieve the surface quality of the workpiece up to nano level [60].

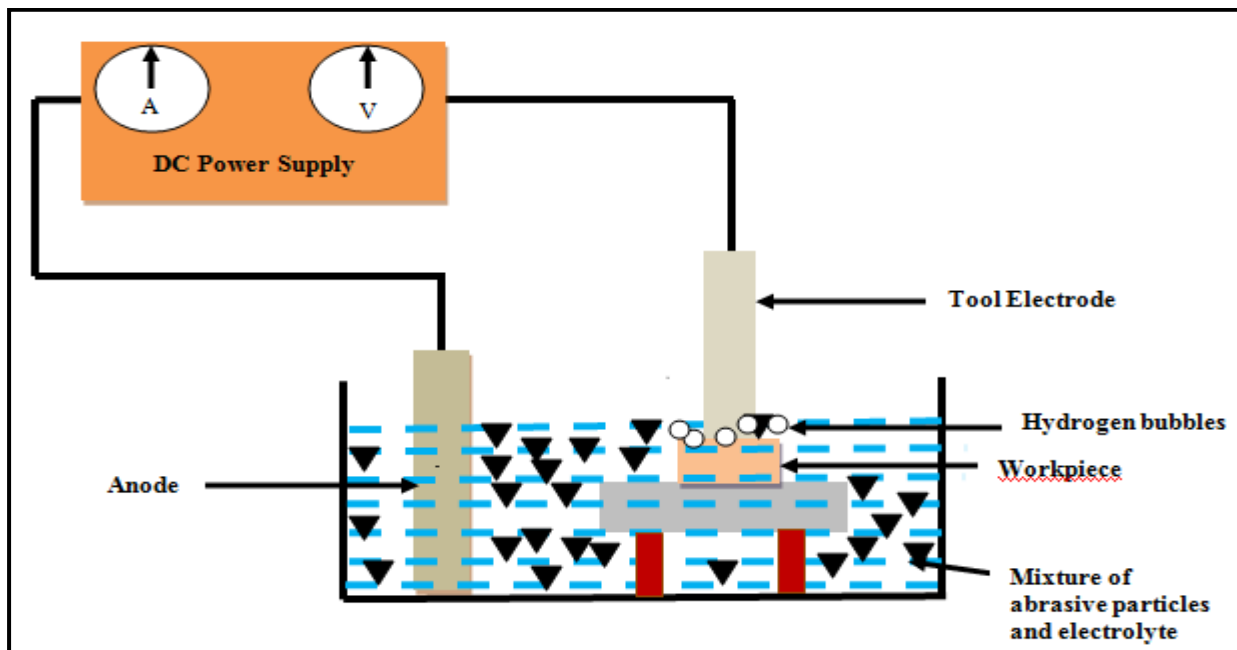


Figure 5. Schematic sketch of basic powder mixed ECM.

3.3 Grinding Assisted Electrochemical Discharge (GAECM)

In this process grinding wheel (rotary tool) covered with the abrasive particle layer and having a metallic bonding system between these particles (figure 6) [54]. The spark is generated on the abrasive coated tool covered with electrically conductive metallic bond and removed the material from the workpiece due to melting because of the generated spark. It is also notice by Chak et.al., [61] that material removes from workpiece due to mechanical abrasion. A better surface finished is achieved with grinding assisted electrochemical discharge as compared to conventional ECM [62-64]. Liu et al.,[62] proposed different shapes (conical and cylindrical) of the grinding wheel to enhanced the machining of non conductive materials. This process is also used to machine metal matrix composites [65], Al/Al₂O₃ [62] and glass [66] materials.

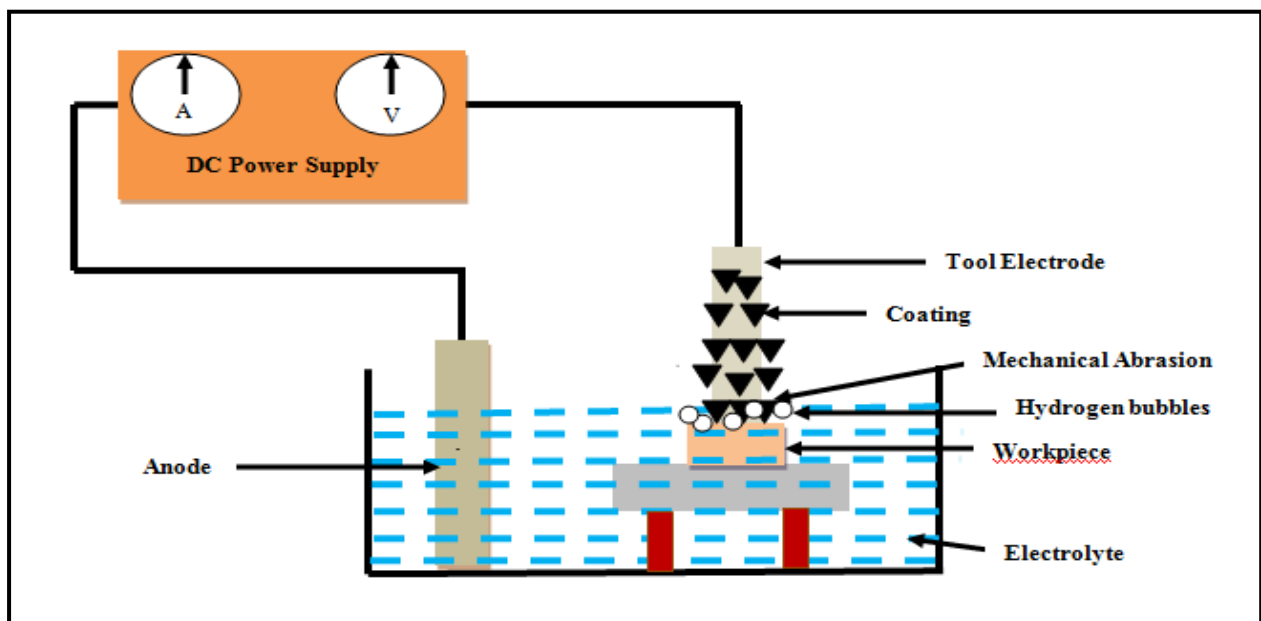


Figure 6. Schematic sketch of basic grinding assisted ECM.

3.4 Magnetic Field Assisted Electrochemical Discharge Machining (MAECDM)

A special magnetic chuck is designed for holding the tool electrode in MAECDM process as shown in figure 7. In this process, magneto hydrodynamic convection is used for better circulation of the electrolyte in narrow holes. Due to better circulation of the electrolyte a stable gas film formed near the tool because convection helps to break gas bubbles formation at the vicinity of the tool. It required higher voltage for machining. In this process a better dimensional accuracy is easily achieved due to formation of steady gas film which produces stable discharges. Better surface quality [67-69] and reduction in machining time as well as overcut achieved with MAECDM [70]

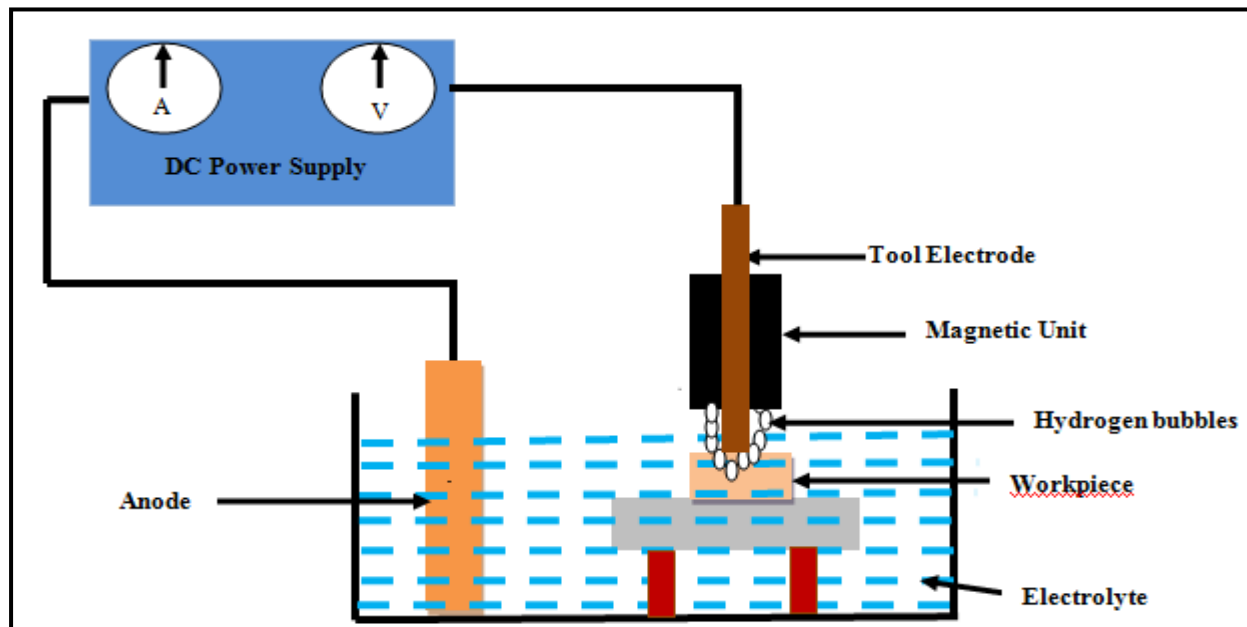


Figure 7. Schematic sketch of basic magnetic field assisted ECDM.

3.5. Vibration Assisted Electrochemical Discharge Machining (VAECDM)

The main reason to develop this technique (figure 8) was to fabricate the deep micro holes. Many researchers apply vibration either to the work-piece [71], tool electrode or electrolyte [72]. Direct [73-75] or indirect [70] ultrasonic vibrations used in this technique reduced the unstable gas film formation in the hydrodynamic regime [76,77]. Wüthrich et al., [71] fabricated deep micro hole by providing vibration to the tool. Higher MRR found when ultrasonic vibrations provided to the tool electrode as compare to ECDM without any vibration.

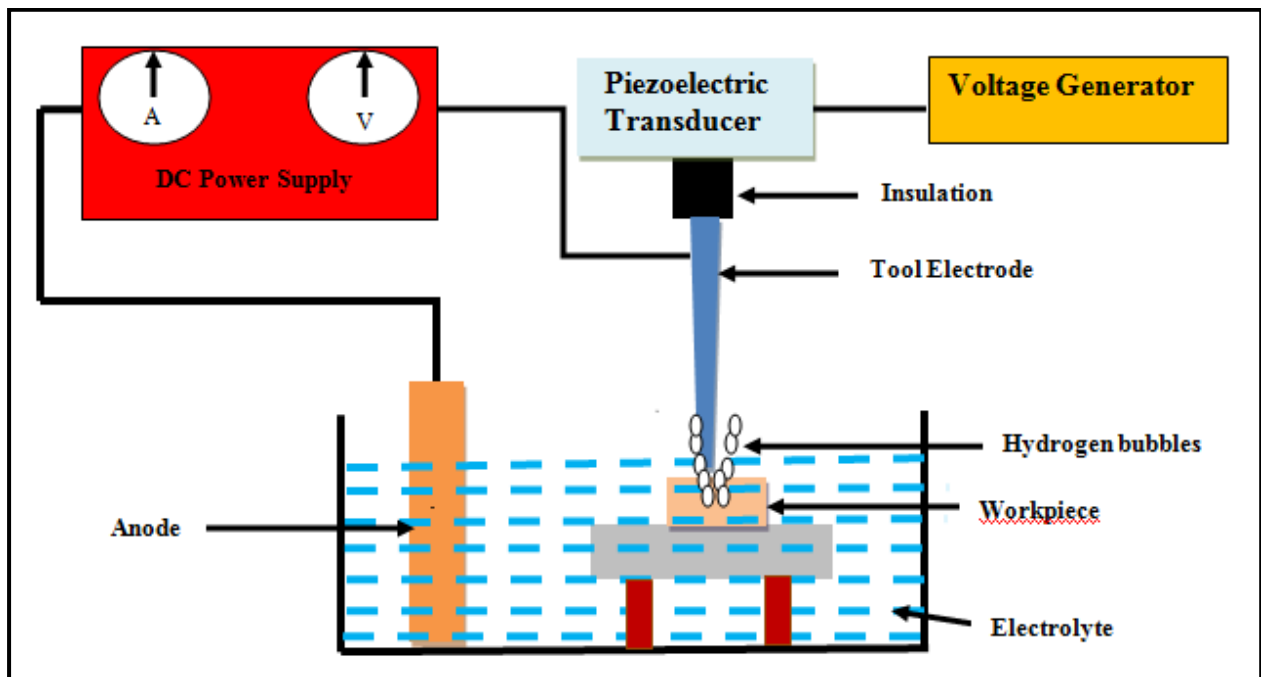


Figure 8. Schematic sketch of basic vibration assisted ECDM.

Table 1. Advantages of hybridized ECDM processes

S.No	Hybridized ECDM processes	Advantages
1.	Rotary Assisted Electrochemical Discharge Machining (RAECDM)	Uniform generation of gaseous film, high surface quality, less overcut and material removal rate
2.	Powder Mixed Electrochemical Discharge Machining (PM-ECDM)	Higher material removal rate and achieving surface finish upto the level of nano scale.
3.	Grinding Assisted Electrochemical Discharge (GAECDM)	Easy removal of recast layer, micro cracks and debris, better surface finish and
4.	Magnetic Field Assisted Electrochemical Discharge Machining (MAECDM)	Better circulation of electrolyte, less micro cracks, reduction in taper angle, higher surface quality
5.	Vibration Assisted Electrochemical Discharge Machining (VAECDM)	Stable spark generation, high aspect ratio, less kerf width and higher machining rate

4. Conclusion

This study provides the importance of understanding the mechanism of spark generation. Electrochemical discharge machining is a novel hybrid non conventional machining process for machine especially non conductive materials. Different variants enhance the machining capability of electrochemical discharge machining which were effectively used for making complex shapes on the hard and brittle non conducting materials with good surface quality. The purpose of different variants in electro chemical discharge machining is to cut a particular shape on the workpiece. The hybridization triplex ECDM process improves the productivity of ECDM process. Ultrasonic vibration-assisted ECDM enhances the flushing action at higher depth while machining, results increase in surface quality. The magnetic field-assisted ECDM process gives higher machinability due to uniform spark generation in machining zone. Surface quality achieved up to nano level with the powder mixed ECDM process. This paper is beneficial for readers to understand the basic phenomenon of spark generation in ECDM process and for the selection of particular ECDM variant or triplex hybrid process for machining non conductive materials.

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