

A Systematic Review on Electrochemical Discharge Machining Process

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This review paper highlights the important results of the investigations on Electro-Chemical Discharge Machining (ECDMing) conducted by the authors and their co-authors. Nuclear, aerospace, locomotives and automobile industries have certain specific desires in machining advanced materials. The growing demands of modern industries have increased the need for advanced machining techniques that can achieve higher material removal rates along with superior surface finish. ECDM is a hybrid machining process capable of meeting these requirements, particularly for machining advanced materials. In the ECDM process, the proper selection of process parameters plays a crucial role in enhancing material removal, improving surface quality and minimizing tool wear. This study examines the influence of key parameters such as electrolyte concentration, applied voltage, pulse-on/off time, tool rotational speed and feed rate during ECDM. The specific roles of each parameter in controlling material removal, tool wear and surface finish are analysed and the optional parameter ranges are summarized based on various optimization techniques.

Keywords: ECDMing; ToolWear; MRR; Optimization; Surface Finish

I. Introduction

The industrial technology is developing very rapidly and electronic components are becoming smaller in size and more efficient. In response to the global energy-saving attempts, the demand for saving energy in lighting the products and goods is also growing faster. Now a days advanced engineering materials such as glass, ceramics, polymers, composites and plastics find widespread applications in industries including optics, foundry, electronics, aerospace, defense, micro-electro-mechanical systems and biomedical devices. Although these materials are highly sophisticated, they are difficult to machine using conventional and even several non-conventional techniques. [1]. Electro Chemical Discharge Machining (ECDM) has emerged as promising solution for machining hard and brittle materials more effectively than many traditional methods. ECDM is a novel hybrid machining process that combines the principles of Electro-Chemical Machining (ECM) and Electric Discharge Machining (EDM) where material removal occurs through the combined action of thermal and chemical mechanisms driven by electrical energy. Hybrid machining processes like ECDM are developed to harness the advantages of their constituent process while overcoming their individual limitations [2]. Researchers have extensively studied ECDM through experimental investigations, focusing on its working principle, process parameters, and machining performance. Moreover, arrange of optimization techniques has been employed to identify the optimal process parameters of enhanced efficiently, surface finish and tool life. Advances in cutting and machine tools have accelerated recently. Selecting cutting parameters based on the work piece hardness and desired surface roughness yields multiple benefits when machining harder materials: lower machining costs, faster processing, improved surface finish, and reduced thermal distortion that can cause part deformation. [36], [37]. A trial-and-error approach was employed, adjusting ECM process parameters to enhance machining accuracy.[39]. Electrochemical grinding has been used to produce small holes with sharp edges by coating a rotating tool electrode with abrasive

particles. Material is initially removed through electrochemical machining, after which contact grinding is performed to improve the hole's surface finish [40]. The selection of electrolyte also affects the surface characteristics of the machined material.[41]. The non-contact nature of the machining process enables drilling holes with an inclination of 40° using wedged-shaped electrodes.[42]. It has been established that the material subtraction mechanism in the ECDM process occurs through thermal erosion, melting, and chemical etching. [43] [44]. The ECDM process has demonstrated its potential for generating microfeatures, microholes, microchannels, and complex 3D shapes in brittle and difficult-to-cut materials.[45]. The taper of microholes increases with applied voltage because the entrance of the machined hole remains in contact with the discharge energy for a longer time than the exit, leading to greater material removal at the entrance and thus higher taper. At higher voltage, the entrance is exposed to high-density discharge energy for a longer duration, which further increases taper in micro holes. This observation is consistent with previous studies on machining glass and ceramics. [46] [47]. The hole overcut was calculated by subtracting the tool electrode diameter from the measured maximum machined hole diameter. [48]. NaOH electrolyte was selected over other electrolytes due to its widespread use and high predominance in the ECDM process.[49]. A tungsten carbide drill bit with a diameter of $300\text{ }\mu\text{m}$ was used as the tool electrode for machining, as micro drill bits in the ECDM process produce better machined surface quality than cylindrical tool electrodes.[50]. A pragmatic mathematical form has been developed to study the influence of process parameters on tool wear (TW), material removal (MR), and the shape accuracy of machined holes [3]. In ECDM, the inter-electrode gap is maintained using an automatic feed mechanism operated by a minimum-speed motor [4]. This process is primarily employed for micromachining and scribing of advanced non-conductive materials like composites, glass, quartz, and ceramics [6]. Key factors affecting machining performance include electrolyte concentration, voltage applied and tool

geometry, which significantly influence MRR and surface quality [5] [6].

Research findings indicate that NaOH serves as a more effective electrolyte compared to KOH, providing superior material removal characteristics. The main input parameters studied in ECDM include applied voltage, electrolyte concentration and inter-electrode gap (IEG), while the output factors of interest are minimum radial overcut (OC) and reduced heat-affected zone (HAZ) [11]. Similar to EDM, the ECDM process also produces craters and changed layers on the work surface due to sparking action [12]. Krishnamurthy and Venkatesh [38] Studies have investigated the factors affecting surface roughness (Ra) and material removal rate (MRR) when machining composites, using the Taguchi method to identify optimal cutting conditions. Three cutting parameters speed, feed, and depth of cut were examined with a K20 carbide tool. Experiments followed a Taguchi L27 orthogonal array, and results showed the best parameter combination for the K20 insert was feed, speed, and depth of cut (in that order). ANOVA indicated that feed is the most influential factor on surface roughness, followed by cutting speed. Hybrid machining processes, such as ECDMing are developed to enhance material removal rate (MRR) and extend the capabilities of conventional methods. This review emphasizes the effect of different process factors on performance metrics such as MRR, Surface finish (SR) and tool wear rate (TWR). Additionally, optimized parameter values obtained through different optimization

techniques in electrochemical discharge machining are summarized.

II. Electrochemical Discharge Machining (Ecdm)

The operational principle of the Electro-Chemical Discharge Machining (ECDM) process relies on a combination of thermal effects and electrochemical reactions. In this process, the tool electrode (cathode) is designed with a smaller surface area compared to the counter electrode (anode). Both electrodes are immersed in an electrolyte, leading to the formation of hydrogen gas foams around the cathode and oxygen foams around the anode through electrolysis when a DC voltage is applied. As the voltage increases bubble formation intensifies, creating a dense insulating gaseous layer around the electrodes. This layer facilitates the initiation of spark discharges. When the non-conductive workpiece is positioned near the sparking zone, material removal occurs through these localized spark discharges. The inter-electrode gap (IEG) is crucial for efficient machining is continuously regulated by a feeding mechanism [5] [13].

A schematic sketch of the micro-ECDM (μ -ECDM) experimental arrangement, comprising X, Y and Z tool movement and an automated spring feed machinery along the vertical axis is shown in figure [31].

The different parameters of ECDMing for a work material and tool grouping and their effect on surface finish, tool wear (TW) and material removal (MR) have been listed in table..

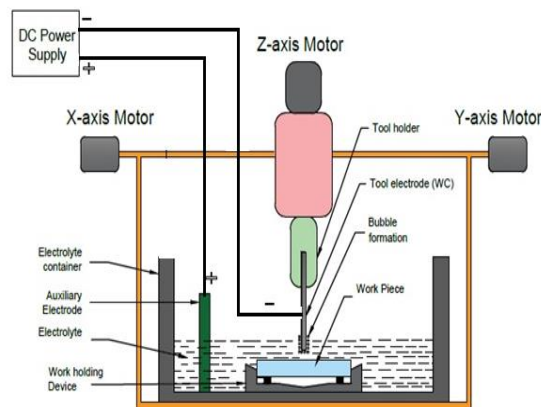


Fig.1 Schematic arrangement of μ -ECDM Experimental set-up

Table 1: Input parameters and their consequence on material removal, surface roughness and tool wear in ECDM

Sl. No	Researcher report	Input Parameters Range	Tool Material	Work Material	Input Parameters	Response Parameters		
						Tool Wear	Surface Finish	Material Removal
1	Lui J.W. [12]	Pulse duration:4-400µs Voltage : 20-120V Current : 0.5-5 amps	Cylindrical steel tool	MMC	Pulse duration Voltage Current	-	Poor surface finish	MRR Increases
2	B. Bhattacharya [13]	Electrodes Gap : 20-40(mm) Applied voltage:50-70 V Ele.Con.:10-30 wt%	Stainless steel	Silicon Nitride Ceramics	Electrodes gap Elec.Con Applied voltage	-	-	Effective MRR on the combination of 80V & 25%NaOH
3	Min- Seop Han, [14]	Voltage applied 35V Peak current 1:1 Elec.Con.(wt%) : 30 Graphite powder con=5-2wt%	-	Borosilicate Glass	Voltage applied, Peak Current Elec.ConGraphite conc.	-	Surface roughness Ra=1.4-4µm	MRR improved using rotational tool
4	Y.S Laio [15]	Voltage applied 50 to 70V Duty factor 0.75, Ele.Con.6M(KOH)	Tungsten Electrode	Quartz	Voltage applied Duty factor, Surfactant, Elec.Con	-	Drilling at higher speeds better surface quality, through the holes tend to be slightly oversized	Low machining rate due to lower surfactant addition
5	Chih-Ping [16]	Voltage applied 30to 45V, Elec.Con 6M(KOH), Rotational speed =500rpm	Graphite anode Tungsten Carbide cathode	Pyrex glass	Voltage applied, Elec.Con rotationaspeed	-	Smooth surface finish	High MRR is achieved
6	Facio and Wuthrich [17]	Applied Voltage:20 to 45V Elec.Con: 5to40(wt%) Pulse: 0=80(µs)	-	Pyrex glass	Applied Voltage Elec.con Pulse	Increases with voltage	-	Increase with DC Voltage, Elec.temp depending upon the work piece material.
7	Cheng-yang [18]	Duty Factor:50 Open voltage(v):150 Peak current(A):3 Gap voltage(V):100	Auxiliary Electrode (graphite)	Quartz	Open voltage Gap voltage, peak current, duty factor, rotational speed	Cylindrical electrode shows tool wear marks	The precision of the micro hole can be enhanced by	High MRR is achieved

							Spherical electrode tool	
8	WY Peng & YS [19]	Applied voltage (V):45-90, Elec.con: 5M	-	Optical glass and Quartz bars	Applied voltage Elec.con.	-	Min SR and better transparency (Ra)=3.5µm	MRR= 0.06mm ³ /min MRR can be attained using the duty factor 0.53, f=200Hz
9	Xuan Doan Cao Hyun [20]	Elec. (KOH)=30%wt Pulse Voltage=30V Pulse ratio=1ms/1ms	Tungsten carbide used as cathode	3D-micro-structures of glass (Pyrex glass)	Elec.Con Pulse on/off ratio, Voltage applied, feed rate in drilling development	-	Poor surface Finish when Voltage is high	-
10	Cheng-kung [21]	Applied voltage less than 30V, Elec.Con=20 to 30(wt%)	SS Tungsten Carbide and tungsten	Glass (Pyrex)	Applied Voltage, Elec.Con	Least tool wear in tungsten carbide electrode	Surface roughness up to 39.73 to 45.95 To 91.22 mm	Increase with use of KOH as electrolyte
11	Bellubbi et al. [35]	Voltage SOD	Tungsten Carbide	Silica Glass	-	--	-	-

TWR = Tool wear rate, V = Voltage, A = Ampere, Hz =Hertz,mm = millimetre, SR = Surface roughness, µRa =Avge. Roughness in microns, MMC=Metal Matrix Composite SiC=Silicon Carbide TW=Tool wear, MR=Material removal, g/l = grams/litre, Elec.Con. = Electrolyte concentration, MRR = Material removal rate, ECDMing=Electrochemical discharge machining.

In the following table 2 analysis was done based on all available literature resources data on work material, tool material and electrolyte type used in Electro chemical Discharge machining by segregating into different factors which were used by researchers.

Table 2: Different electrodes used in ECDMing

Sl. No.	Ref.no	Anode(Auxiliary Electrode)	Cathode (Electrode)
1	22	Graphite electrode	Tungsten
2	29	Graphite electrode	Tungsten Carbide
3	23	Graphite electrode	Throated tungsten electrode
4	20	Platinum	Tungsten carbide
5	27	Carbon rod	Carbon electrode
6	12	MMC	Cathode Steel electrode
7	24	Stainless steel	Tungsten carbide electrode
8	30	Cu & Graphite	Pt plate
9	28	Graphite	Tungsten Carbide
10	26	Graphite electrode	Copper Zinc alloy brass wire

Most of the researchers have preferred to use graphite as auxiliary electrode and tungsten carbide

as electrode for the well performance of ECDM process.

Iii Parameters Optimization In Electro Chemical Machining Process

The selection of an optimum range of process parameters is crucial for improving the performance of the ECDM process. In industrial applications, optimization problems are commonly addressed using the Taguchi's orthogonal array and design of experiments (DoE) approach. Moreover, the significance of input parameters has been evaluated effectively using ANOVA. Statistical analysis is employed to investigate the

effect of input parameters on critical response features, including MRR and SR. Based on the final conclusions of such studies, several suggestions for future research have also been proposed. The optimized values of influential parameters, obtained through applied optimization techniques are summarized below. Type of optimization techniques used detailed in Table.

Table 3. Taguchi's standard L₄ Orthogonal array (OA) and Analysis of variance (ANOVA)

Technique	Input Factors	Stages /levels	Output Factors	Optimum values of input Factors	Influential Factors	Researcher
OA L4	Voltage applied, Electrolyte concentration, work feed rate	2	TWR MRR,	Elec. Con. (50g/l) Applied voltage (80V) work Feed rate (6mm/min)	Voltage applied 94.08%	C.;S. Jawalkar [5]
OA L9	Voltage applied, Elec. Con. Electrodes gap	3	MRR, S/N ratio	Voltage applied (60V) Elec. Con. (20g/l) Electrodes gap (20mm)	Voltage applied 51.8%	M. L. Harugade [6]
OA L9	Voltage applied, Elec. Con. Electrodes gap	3	MRR, TWR	Voltage applied (60V) Elec. Con. (30%) Electrodes gap (0.3mm)	IEG= 47.05%	Sathisha N [7]
OA L9	Voltage applied, Elec. Con. Electrodes gap	3	MRR, S/N ratio	Voltage applied (50V) Elec. Con. (15%) Electrodes gap (30mm)	Voltage applied 62.76%	Doloi&Bhattacharya [9]
OA L16	Voltage applied, Elec. Con. Electrodes gap	4	MRR, average depth of ROC	Voltage applied (20V) Elec. Con. (75 g/l) Electrolyte flow (10 l/hr) Bare tool tip (1.5 mm)	Voltage applied 53.9%	Gaurav Chigal [5]
TLBO	Voltage applied, Elec. Con. Electrodes gap	--	MRR, average depth of ROC, HAZ	Voltage applied (50V) Elec. Con. (30%) Electrolyte flow (20mm)	Voltage applied	R.V.Rao [10]
GA	Voltage applied,	5	HAZ, ROC	ROC, min at Voltage applied	--	Ruben Phipon [11]

	Elec. Con. Electrodes gap			(50V) Elec. Con. 20g/l Electrodes gap (20mm)		
OA and ANOM	SOD, pulse on time, voltage	3	MRR, MD, OC	SOD (0.5 to 1.5mm) Pulse-on-time (40 to 60 μ s) Voltage (45 to 55V)	voltage	Bellubbi et. al [35]

HAZ= Heat affected zone, V=Voltage, g/l=gram per litre, ANOVA=Analysis of Variance, l/hr.=litre per hour, MRR=Material removal rate, ROC=Radial Over cut Elec. Con= Electrolyte Concentration. S/N ratio= Signal-to-Noise ratio. GA= Genetic algorithm, TLBO=Teaching Learning Based Optimization ANOM=Analysis of Means, SOD=Stand of Distance, MD=Machining depth

Following figures or charts/graphs indicates, work piece materials used versus number of publications,

different electrolyte used in the experimentations versus number of publications, electrolyte concentration percentages versus type of electrolytes used, different work materials used in percentages versus different type of work materials and fish bone diagram of ECDC parameters used in different researches

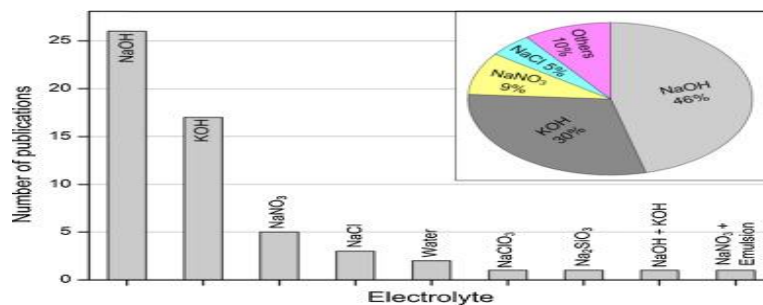


Fig: 2 Work piece materials v/s No. of publications

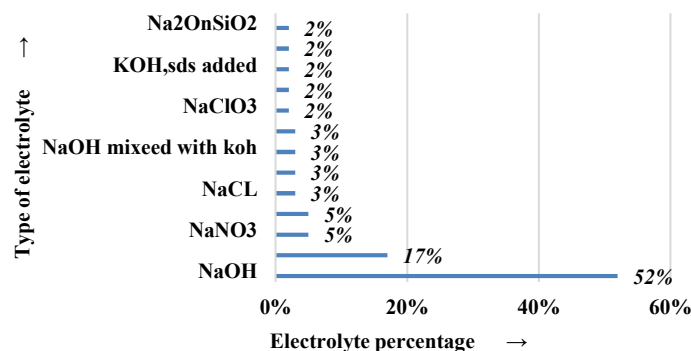


Fig:3 Electrolyte Percentages v/s

Type of electrolytes

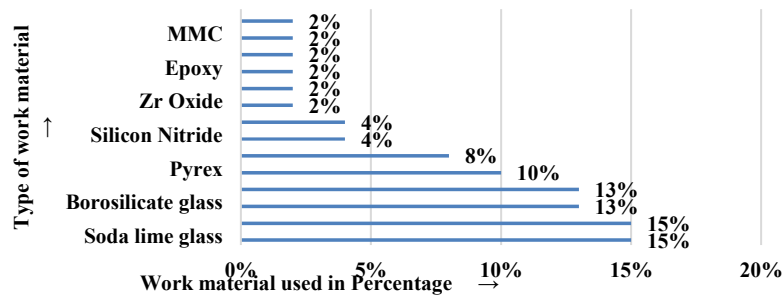


Fig: 4 Work materials used in Percentage v/s Type of work material

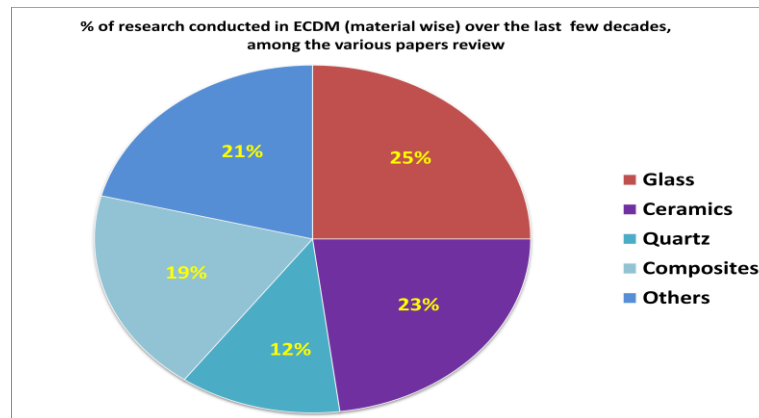


Fig: 5 Representing over last decade research conducted on EDM, [31]

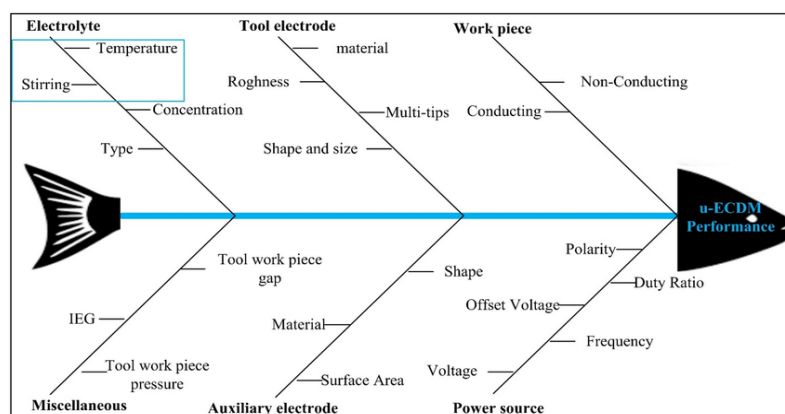


Fig:6 Fish (Ishikawa) Cause and effect diagram for the performance of EDM [33]

IV. Conclusions.

Following important observations were found during the EDMing process and can be concluded.

- Better results can be obtained only when proper optimization parameters were selected in EDMing process.
- MRR and TWR were affected by electrolyte concentration as the secondary parameter.

- For better performance of EDMing process the optimized values of parameters were to be known for optimization techniques.
- Researchers have consistently reported that applied voltage plays most critical role in determining MRR.
- Researchers were also found that some materials which were not possible to machine by any other machining processes can be easily machined by EDMing process.

• Important parameters and related factors are reviewed.

• Various polarities and their significance are presented.

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