A Study and Analysis on Machining of Hard to Cut Material

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ABSTRACT

Electro-Chemical Discharge Machining (ECDM) is an advanced non conventional machining process. The Electro-Chemical Discharge Machining (ECDM) process can be used effectively for the machining of non-conductive, hard and brittle materials like glass, ceramics & advanced composites considering the capability of machining a complex profile and better quality finish. The ECDM process has the potential application for micro-slotting operations on ceramic work pieces. This process has the possibility & feasibilities to slicing and producing grooves on the nonconductive materials. ECDM has great potential for machining of electrically non-conducting materials. OFAT (one-factor-at-a-time) technique based experiments are performed on ECDM setup to develop the optimized combinations of the process parameter to achieve better results. Within the limitations of the experimental set up of ECDM and its process parameters experiments were completed and from the results of the experiments conclusions can be drawn as the Material is not suitable for ECDM process due to burning of material. But we achieve better result on these parameters like 55 volt (voltage), 0.5mm/min(feed) and 200 (t on).

KEY WORDS: ECDM; OFAT and ECM

1. Introduction

The Electro-Chemical Discharge Machining (ECDM) is an emerging micro-manufacturing process.It is a hybrid material removing process which comprises the combination of principle of Electrochemical Machining (ECM) and Electro discharge Machining (EDM). It is used for machining of very hard, brittle and electrically non conducting materials like borosilicate glass, ceramics, metal matrix composites and single crystal materials, which are becoming very useful for some of the advanced applications, have some mechanical properties such as high wear and chemical resistance and high strength. Industrial applications of these materials are increasing with a rapid rate. For machining of these materials various non conventional machining processes are developed.

1.1. BASIC PRINCIPLE OF ECDM

Electro-Chemical Discharge Machining (ECDM) is an advanced non conventional machining process. In this process, the work material gets dominantly removed by spark-based thermal erosion, while chemical action also plays some role in the overall outcome. In ECDM (Fig. 1)[1], the work-piece is placed in an electrolytic solution and the tool-electrode is dipped a few millimeters in the electrolytic solution and the counter-electrode, a large flat plate also submerged in the electrolytic solution. The tool-electrode surface is always significantly smaller than the counter-electrode surface (by about a factor of 100). A pulsed DC voltage is supplied between the tool-electrode and the counter-electrode. The tool-electrode is generally polarized as a cathode, but the opposite polarization is also possible.

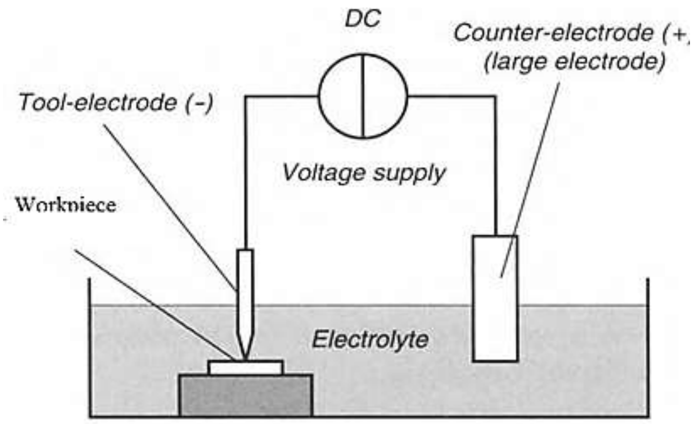


Figure 1: Electro-Chemical Discharge Machining [1]

When the cell terminal voltage is low (i.e. lower than a critical value called critical voltage, typically between 15 and 30 V), traditional electrolysis occurs (Fig. 2). Two electrodes are submerged into an electrolytic solution. The terminal voltage is progressively increased from 0 to 40 V. A gas film is formed around the cathode at around 25 V and the electrochemical discharges are clearly visible at around 30 V. Hydrogen gas bubbles are formed at the tool-electrode and oxygen bubbles at the counter-electrode depending on their polarization and the electrolyte used. When the terminal voltage is increased, the current density also increases and more and more bubbles are formed. A bubble layer develops around the electrodes and density of bubbles and their mean radius increase with increase in current density. As the terminal voltage is increased above the critical voltage, the bubbles coalesce into a gas film around the tool-electrode. Light emission can be observed in the film when electrical discharges occur between the tool and the surrounding electrolyte.

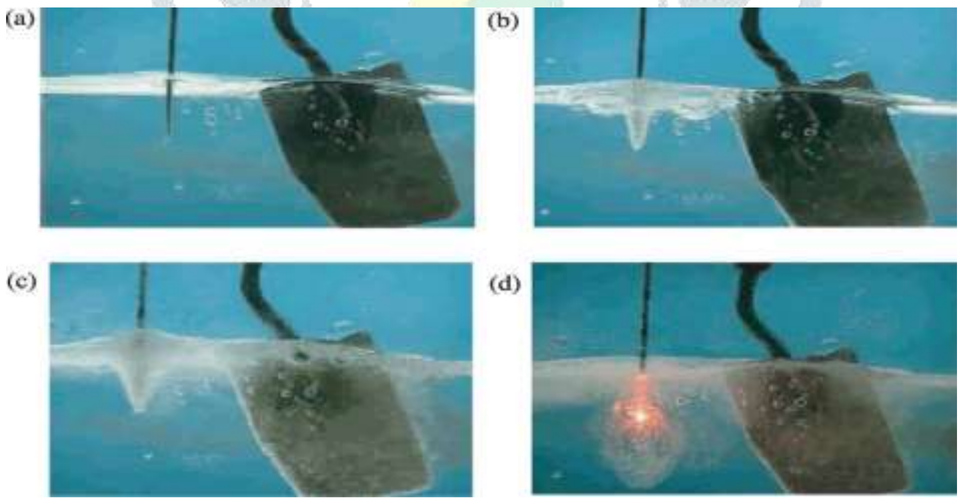


Figure 2: Successive steps towards the electrochemical discharge phenomena:

(a) 0 V; (b) 7.5 V; (c) 15 V; (d) 40 V. [1].

1.2.Nature of the Electrochemical Discharges

There are three types of gas discharge as reported by [1]. They are (a)Townsend discharge (b) Glow discharge (c) Arc discharge

Electrical discharges characterized according to voltage drop (V) and current (I) of the discharge as shown in Fig. 3. Townsend and glow discharges are high-voltage discharges (a few hundred volts). Arc discharges happen typically at 10 V. Arc discharges carry high currents (form one to several hundred amperes), whereas Glow and Townsend discharges are characterized by very small currents.

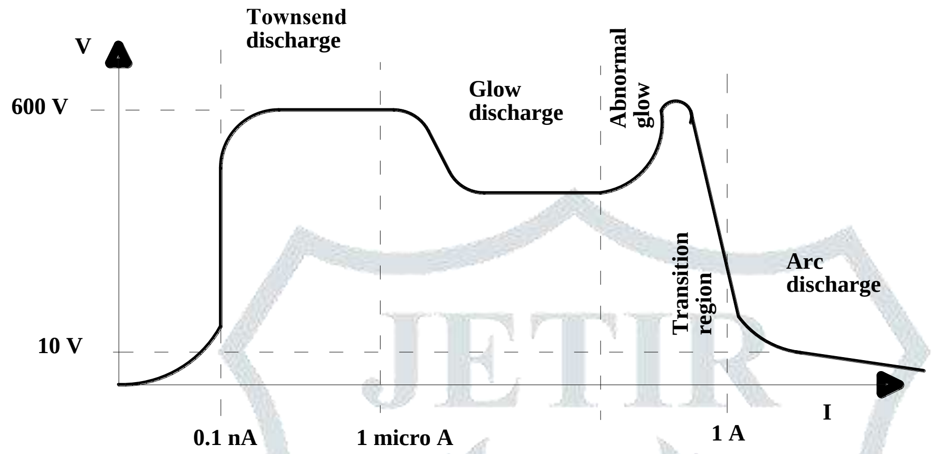


Figure 3: Gas discharge circuit and corresponding *V-I* characteristics [1].

1.2.1. Townsend Discharges

In Townsend discharges, the free electrons ionize the gas molecules. Several processes for gas ionization are shown in Table 1. The ionization of a neutral gas molecule A takes place if the kinetic energy of the electron e is more than the ionization potential VI of the gas molecule. The probability of the process increases linearly with the kinetic energy of the impacting electron up to a maximum (at around 100 – 200 V). After this maximum, the probability decreases slowly. The two electrons produced by the process are accelerated by the electrical field and they ionize other gas molecules.

Table 1: Excitation and Ionisation Potentials of Some Gases

Gas	Excitation Potential V_e (V)	Ionization Potential V_I (V)	Ionization Process
Argon (Ar)	11.7	15.7	$Ar \rightarrow Ar^+ + e$
Hydrogen (H_2)	7.0	15.4	$H_2 \rightarrow H_2^+ + e$
Nitrogen (N_2)	6.3	15.6	$N_2 \rightarrow N_2^+ + e$
Water (H_2O)	7.6	12.6	$H_2O \rightarrow H_2O^+ + e$

1.2.2. Arc Discharges

Arc discharges are high-pressure discharges (pressures ranging from 0.5 up to 100 atm) characterized by low voltages (in the range 10-50 V) and high currents (in the range 1-100 A). The physical difference between Glow and Arc discharges is the electron production mechanism at the cathode. In Glow discharges, the electron emission from the cathode is mainly due to secondary electron production by heavy ion impacts. In Arc discharges, the electron production is due to thermionic or field emission.

1.3. Process Analysis

Machining using electrochemical discharge is a combination of softening, melting, and etching of the work-piece. As shown in Fig.4, the electrochemical discharges heat up the machining zone locally resulting in softening and melting of the work-piece. Material is removed by high-temperature chemical etching. Heating of work-piece due to electrochemical discharges lowers the viscosity of glass and enhances chemical etching, which results in formation of zone of low viscosity glass with electrolyte salt in front of the tool-electrode.

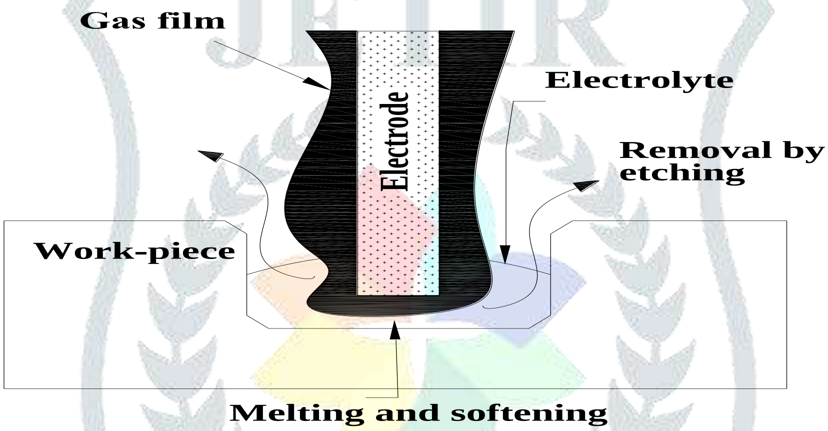


Figure 4: Mechanism associated with electrochemical discharge [1].

Machining is different at low and high depth; increasing depth affects the flow of electrolyte to the tip of the tool-electrode, which results in lowering of the material removal rate due to reduction of discharge activity and chemical etching.Therefore, the material removal rate is a function of the machining depth. Machining is also affected by the electrolyte due to its complex nature. Fig. 5. shows the effects of the main parameters on the material removal rate in ECDM as suggested by Wüthrich [1].

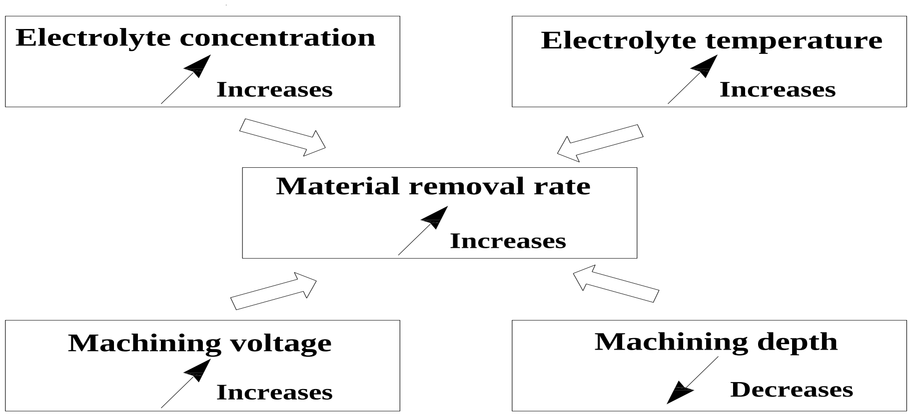


Figure 5: Effect of the main parameters on the material removal rate in ECDM process [1].

Therefore, optimizing machining by electrochemical discharges means taking control of the following three aspects:

- Stable discharge activity,
- Localized heating,
- High-temperature chemical etching.

Optimal surface quality is achieved by maximizing the chemical etching and at the same time minimizing the local heating in order to avoid the formation of heat affected zones. This implies in particular an optimal supply of electrolyte to the machining zone.

Compared with ECM and EDM, there is a major difficulty in ECDM machining. The machining gap (the distance between the tool-electrode and the work-piece) cannot be controlled actively. Another significant difference is the effect of the discharges. In EDM each discharge melts the work-piece locally. It is possible to control the machining based on the observation of electrical discharges by monitoring current pulses. In ECM, the machining can be controlled directly through the current, as in this case the material removal mechanism is anodic dissolution of the work-piece. In ECDM machining the electrochemical discharges provide the heat needed for promoting the local chemical etching. To date, no clear evidence about the effect of a single electrochemical discharge is known.

1.4.FORMATION OF GAS BUBBLES

From the study of the electrochemistry of ECM, it has been concluded that the following two types of reactions occur in the system: (i) electrochemical reactions at the electrode (gas evolution, plating, electrode dissolution and oxidation, etc.) and (ii) chemical reactions in the bulk of the electrolyte (chemical combinations, the complex formation or precipitation). The electrochemical reaction occurs at the boundary layers of electrolyte and work-piece and the transfer of ions in the electrolytic solution takes place by: (i) diffusion; (ii) movement in electric field; and (iii) convection in the flow. The different cathode and anode reaction occurs as soon as a suitable potential is reached amid the inter electrode gap of the machining zone.

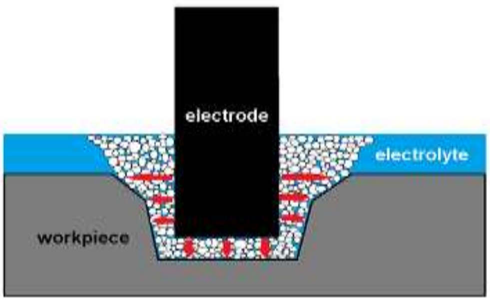


Figure 6: Scheme of small bubbles acuminated at entrance[20]

a. Cathodic Reaction

Common reactions at the cathode terminal are plating due to metal ions and generation of hydrogen gas bubbles.

$$M^{+} + e^{-} = M$$

Here M is material at anode

Hydrogen evolution takes place by following reaction

$$2H^{+} + 2\,e^{-} = H_2 \quad \text{(in acidic electrolytic solution)}$$

$$2H_2O + 2e^{-} = 2(OH^{-}) + H_2 \text{(in alkaline solution)}$$

b. Anodic Reaction

In a similar way to cathodic reaction there are 2 types of reaction at the anode. In the electrolytic solution dissolution of ions takes place. Also at the electrode surface evolution of the oxygen takes place.

$$M = M^{+} + e^{-}$$

$$2H_2 + 2O = O_2 + 4H^{+} + 4e^{-}$$

$$4(OH^{-}) = 2H_2O + O_2 + 4e^{-}$$

1.5.APPLICATION OF ECDM

The Electro-Chemical Discharge Machining (ECDM) process can be used effectively for the machining of non-conductive, hard and brittle materials like glass, ceramics & advanced composites considering the capability of machining a complex profile and better quality finish.

- The ECDM process has the potential application for micro-slotting operations on ceramic work pieces.

- This process has the possibility & feasibilities to slicing and producing grooves on the nonconductive materials.

1.7. ADVANTAGES OF ECDM

- Electrically non-conductive, hard & brittle materials like glass, ceramics, fiber composites, quartz etc. can be machined very easily.

- Slicing of a work piece made of non-conductive material can easily be done.

- Profile cutting and contouring operation on hard, brittle non-conducting materials can be done.

- Low machining and maintenance cost. Etc.

1.8. LIMITATIONS OF ECDM

- Machining is limited because it can be used for non-conducting material machining only.

- High over cut appears due to side sparking.

- Poor surface finish.

- Low material removal rate and time taking process.

2. Literature Review

Jawalkar et al. [2] have experimentally compared material removal while using NaCl and NaOH electrolytes and found that material removal using NaCl was much slow as compared to NaOH. The authors have also found that at higher voltage (70 V) and at higher electrolyte concentration (22%) with stainless steel tool electrode caused more material removal using NaCl solution. **Jawalkar *et al*. [3]** have also studied metal removal and tool-electrode wear while machining micro-channels on soda lime glass with stainless steel tool using NaOH electrolyte. Their experimental result shows the micro cracks and craters in machined channel, which was due to thermal effect during sparking process. Some bright edges were visible along the edges of the channel in field emission scanning electron microscopy which is due to chemical etching effect. **McGeough et al. [4]** have studied the effects of pulsed voltage and vibrating tool-electrode and found that the influence of the electrical discharge is the major factor that enhances metal removal rate, as phase-angle and vibration amplitude increase, but structural damage has been found on the machined surface. **Yang et al. [5]** proposed a spherical tip tool electrode to overcome the problems of increase in machining time and entrance diameter with increase in machining depth. They have compared machining performance of cylindrical tool electrode and the proposed spherical tool electrode and found the reduction in machining time (120 s to 20s at 500 µm depth), decrease in hole diameter (310 µm to 225 µm) and increase in hole depth (215 µm to 295 µm in 6 s). **Kulkarni et al. [6]** have proposed a mechanism to study the temperature rise and mechanism of material removal during the ECDM process by measuring the time-varying current. They observed the generation of high electric field (107 V/m) across the tool electrode and electrolyte initiating an arc discharge in the gas film covering the tool tip. **Yang et al. [7]** tried to improve the over cut quality during ECDM process by adding SiC abrasive to the electrolyte and reported their effects on roughness and material removal rate. In ECDM, the electrochemical reaction produces hydrogen bubbles, which accumulate around the cathode. A thin gas layer forms on the surface of the electrode and isolates the electrode from the electrolyte. When a voltage that exceeds the critical voltage is applied, continuous discharge occurs. **Kulkarni et al. [8]** have been able to achieve micro-level machining, deposition, and surface modification simultaneously or one at a time. Simultaneous surface treatment, micromachining, and copper deposition on a silicon water, are achieved using this process. **Jana et al. [9]** have measured the forces exerted on the tool-electrode during Spark Assisted Chemical Engraving with constant velocity-feed glass micro-drilling for different machining voltages, tool feed-rates and tool sizes. This finding allows the usage of the current signal to detect the contact between the tool and the glass surface. **Harugade et al. [10]** have conducted experiments on ECDM to identify the effect of electrolyte solution on material removal rate. In controlling the machining performance, such as material removal rate the signal-to-noise (S/N) ratio is performed to find the relative contributions of the main machining parameters, such as applied voltage, electrolyte concentration and inter-electrode gap. **Krotz et al. [11]** examined single discharges of electrochemical arc machining. The heat-affected zone is analyzed, and a model is set up to simulate the heat transfer into the workpiece. They found that varying diameters of the heat-affected zone have to evolve from different diameters of the plasma channel's arc spot. **Coteaţa et al. [12]** presented some theoretical considerations and experimental results concerning the electrode tool wear at the electrochemical discharge drilling of spring steel. The influence exerted by the diameter of the electrode tool, the voltage applied to the electrode, the capacitance of the electrical circuit and the density of the work liquid on the axial wear of the electrode tool was studied. **Kudla [13]** has presented fundamentals and technology of electrochemical discharge machining (ECDM) of microholes in borosilicate glass and partly in diamond crystals. The both mentioned materials have very useful technical properties but are difficult to machine using conventional or even laser techniques. **Zheng et al. [14]** have conducted microgroove machining experiments to improve the machining quality of the ECDM micro milling process. Three factors affecting ECDM micro milling performance - pulse voltage, tool rotational rate and travel rate of tool were taken up as machining parameters to investigate their influences on machining performance. **Bhuyan et al. [15]** have reported the machining characteristics of non-conductive material and experiments were also conducted to analysis the effects of supply voltage, pulse on-time and electrolyte concentration on the material removal rate (MRR) and surface roughness (Ra). Material removal rate and surface roughness are found to increase with increase in supply voltage and pulse on-time. But MRR and Ra increase with increase in electrolyte concentration at certain value (20%), beyond that value it decreases. **Gaurav et al. [16]** have performed analysis and results on machining of Al 6061/Sic (10%) Composite by ECDM process. It was observed that overcut and dimensional ovality was high that may due to cause of deflection of tool and increased the sparkling area during drilling. It was also observed that overcut around the machined hole but this can be minimized by controlling the gap between the bare tool tip and work piece. **Bhattacharyya et al. [17]** have performed Experimental investigations into ECDM of non-conductive ceramic materials and analyse that at low applied voltage, the MRR is very low, but at higher voltage and higher electrolyte concentration, a higher MRR can be achieved. However, at higher electrolyte concentration the over-cut is more. Hence for improving machining accuracy, a lower concentration is preferred. With a higher voltage, the MRR is greater, but micro-cracks and other defects are generated on the machined surface. **Sanjay et al. [18]** have studied Trepanning of Al_2O_3 by ECDM process using abrasive electrode with pulsed DC supply. In this paper a spring fed cylindrical abrasive electrode of 1.5 mm diameter has been used under the effect of the three most influential parameters pulsed DC supply voltage, duty factor and electrolyte conductivity, each at five different levels to assess the volume of material removed, machined depth and diameteral overcut. **Hourng et al. [19]** investigated that overcut and surface finish was improved, on comparing the machining with pure KOH, overcut was reduced upto 57% when electrolyte mixed with the 6.5% ethanol. KOH 30%wt mixed with ethanol 6.5% wt under the condition of applied voltage 40V, frequency 2kHz, duty 50%,electrolyte 1mm,optimum hole with average diameter of 135.5µmwas obtained and HAZ was very small. **Jui et al. [20]** investigated that high aspect ratio micro tools had been used for microhole drilling on glass at low electrolyte concentration. On lowering the electrolyte concentration reduction in overcut, tool wear and hole taper by 22%,39% and 18% respectively. Aspect ratio of 11 was obtained while machining of glass with 1M NaOH at 40V. **Laio et al.[21]** investigated that the effects of Sodium Dodecyl Sulfate (SDS) surfactant mixed with electrolyte in ECDM process. Due to SDS the current density was increased and more bubble generated then parks became brighter and take place in large area and more stable current was obtained and found better surface finish and low tapering and also consumed less time.

3. EXPERIMENTAL SETUP

A proper understanding has been developed with the basic elements and parameters of ECDM.

In order to achieve the experimental results, ECDM system can be classified into some subsystems as a) Structural subsystem; b) Power supply unit; c) Motion control unit etc. A pulsed DC power source has been used between tool electrode (-) and counter electrode (+). The tool and the work piece are just in contact and are submerged into the pool electrolyte solution up to a certain depth. Stepper motors are used to provide motion to the tool along x direction and y direction and also help in the motion of tool towards upward and downward movement. For varying the speed of the stepper motor the motor control unit (MCU) is applied and it also results in the variation of velocity.

3.1. STRUCTURAL SUBSYSTEM

There are various modules in the structural subsystem of ECDM experimental set-up. The picture of ECDM experimental set-up has been shown in Fig. 7.

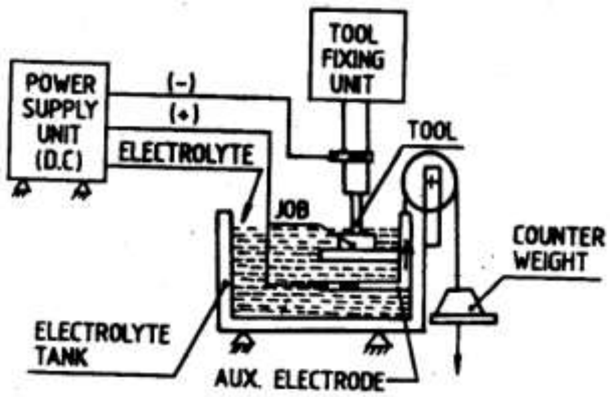


Figure 7: Schematic diagram of ECDM system [23]

3.1.1. Machining Chamber

The chamber for machining process is fabricated by Perspex material. There is a rectangular base of dimensions are 40cmx35cmx25cm. The thickness of Perspex plate used in the rectangular box is 12mm. Four plates have been vertically positioned with a bottom base plate. The job holding arrangement has been fixed inside the box and tool arrangement and motion controlling unit have been hold above the workpiece.

3.1.2. Job Holding Apparatus

The job holding apparatus has been mounted inside the rectangular electrolyte tank, which can move along x and y direction. A stepper motor is applied for giving the motion to the job holding unit and a transmitting mechanism for converting the rotating motion to translating motion. For holding the job a hub is made up of Perspex material and it is fixed on the bottom plate of box.

3.1.3. Tool movement and controlling unit

In ECDM experimental setup the electrically non-conductive work piece is held with the help of holding unit and immersed in the electrolyte pool. Stepper motors are used to provide movement to the workpiece in x and y direction. Also tool is rotated with the help of stepper motor and the whole system operated with the help of CNC controller setup. Downward movement of tool is depend on the feed rate provide by us for proper machining. Mostly material of tool is made up of tungsten carbide or stainless steel. The tool is directly connected to the negative pole of continuous DC power supply and the tool electrode is made cathode.

3.2. POWER SUPPLY SYSTEM

A pulsed DC power supply is used in ECDM. A main DC power supply unit (120 volt, 20 A) is used as input and output voltage. Pulse generator is there to control the frequency. The D.C. output power characteristics are observed by a Cathode Ray Oscilloscope is connected to observe the DC output power characteristics. Some control units are used such as frequency control unit, voltage controlling unit. Current is supplied to the tool and gas bubbles start forming which finally causes the electrical discharge. Fig.8. shows the photograph of pulsed DC power source.

Figure 8: Photograph of pulsed DC Power Source

3.3. MOTION CONTROLLING UNIT

Mach3 software is used to control the motion of the stepper motors attached with the tool and the job moving unit. Basically Mach3 software converts a PC into a CNC controller. According to the required movement of the tool and job holder, the programming on CNC controller can be done.

4. EXPERIMENT METHODOLOGY

For conducting experiments on ECDM three process parameters have been considered. The experiments have been designed with the help of an optimization technique call OFAT (One-factor-at-a-time). A stainless steel tool, having diameter as 690 µm, has been used as the tool. Electrolyte selection is also one of the influential parameter in this variety of machining because the chemical reaction depends upon the concentration of electrolyte. KOH solution is selected as the electrolyte for this experiment. The three process parameters taken for conducting the experiments are applied voltage, feed rate and pulse generating time(t on). The other important decision was to select the power supply nature and the range of applied voltage. A continuous DC power source was selected for the power supply requirement. The experiments were done according to OFAT (one-factor-at-a-time) experimental design. During experimentation some of the process parameter were kept fixed, are listed in Table 2.

Table 2: Fixed Process Parameters

FIXED PARAMETERS	DESCRIPTION
Work piece material	Glass fibre (glass + epoxy)
Tool material	Stainless steel (690µm diameter)
Material Thickness	6.5 mm
Electrolyte	KOH(30%)

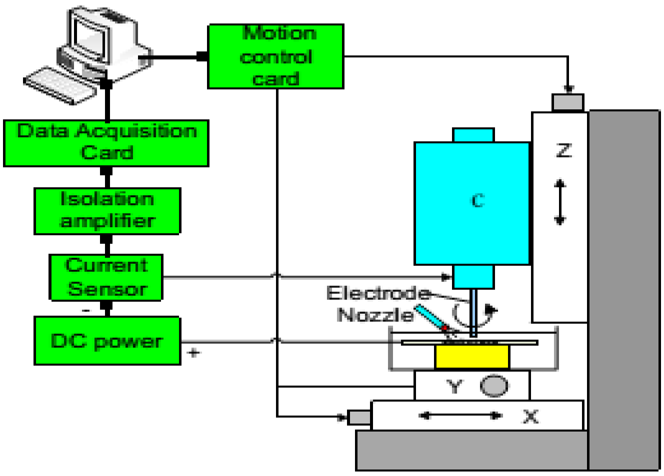


Figure 9: A schematic diagram of the micro-ECDM machine system [24]

4.1. PARAMETRIC DESIGN

In this experimental procedure for ECDM process design of experiments is done in an optimized way. An optimization technique called OFAT (one-factor-at-a-time) is applied. IN OFAT technique only one parameter is varied and other parameters are set fixed and this procedure is repeated to find the optimum values of the parameters to get the desirable results.

The aim of this experimental procedure is to find the maximum material removal rate. The three process parameters taken for conducting the experiments are applied voltage, feed rate and pulse generating time (t on) so for achieving the radial over cut these three parameters should be optimized. The optimization has been done in three steps. In the first step applied voltage is set to be varied and the values of remaining two parameters are fixed. After the experiment has completed the value of the applied voltage having maximum material removal rate is known. Now in the second step applied voltage is kept fixed at the maximum MRR voltage, the inter electrode distance is also kept fixed and the electrolyte concentration is varied. After this step the value of electrolyte concentration having maximum

MRR is known. IN step three the value of electrode gap having maximum MRR is known and the optimum values of the all three parameters for maximizing the material removal rate are known.

4.2.Selection of Electrolyte

The electrolyte selection is also very vital factor for ECDM process. The electrolyte affects on material removal rate (MRR) of the work-piece and the over cuts. The accuracy for machining process varies with the electrolytic concentration, which affects the radial over cut. The lesser amount of over-cuts has been seen when machining with KOH rather than machining with NaOH and machining efficiency attained using KOH exceeds NaOH because the mobility of potassium ions is more than that of the Na ions. KOH has high mobility so KOH can form more Hydrogen bubble.

RESULTS AND DISCUSSION

According to the process parameters selected, the experiments are done to study the radial over cut. Three parameters (voltage, feed rate, pulse generating time) are selected and varied to get the radial over cut from the glass fibre work-piece.

5.1. EXPERIMENTAL MODELING

For conducting experiments on ECDM three process parameters have been considered. The experiments have been designed with the help of an optimization technique call OFAT (One-factor-at-a-time). In the first step applied voltage is set to be varied and the values of remaining two parameters are fixed. After the experiment has completed the value of the applied voltage having enterance diameter is known. Then we calculate the radial over cut by (entrance dia - tool dia)/2. Now in the second step feed rate is set to be varied and the values of remaining two parameters are fixed. Then in the third step pulse generating time is set to be varied and the values of remaining two parameters are fixed.

5.1.1. VARIATION IN VOLTAGE

EXPERIMENTS	VOLTAGE (volt)	FEED (mm/min)	t on (1 millisec)	INLET DIA(μm)	OUTLETDIA(μm)	OVER CUT(μm)	MACHINING TIME(min)
1	55	0.5	200	1376.864	742.692	1276.864	22.29
2	60	0.5	200	1871.106	774.556	1771.106	21.38
3	65	0.5	200	1992.366	821.234	1892.366	20.42

5.1.2. VARIATION IN FEED

EXPERIMENTS	VOLTAGE (volt)	FEED (mm/min)	t on (1 millisec)	INLET DIA(μm)	OUTLET DIA(μm)	OVER CUT(μm)	MACHINING TIME(min)
4	55	0.4	200	1455.498	864.112	1355.498	27.36
5	55	0.6	200	1542.188	876.123	1442.188	19
6	55	0.8	200	1973.306	890.324	1873.306	14.34

5.2.Graphical representation of Over Cut variation with respect to the process parameters

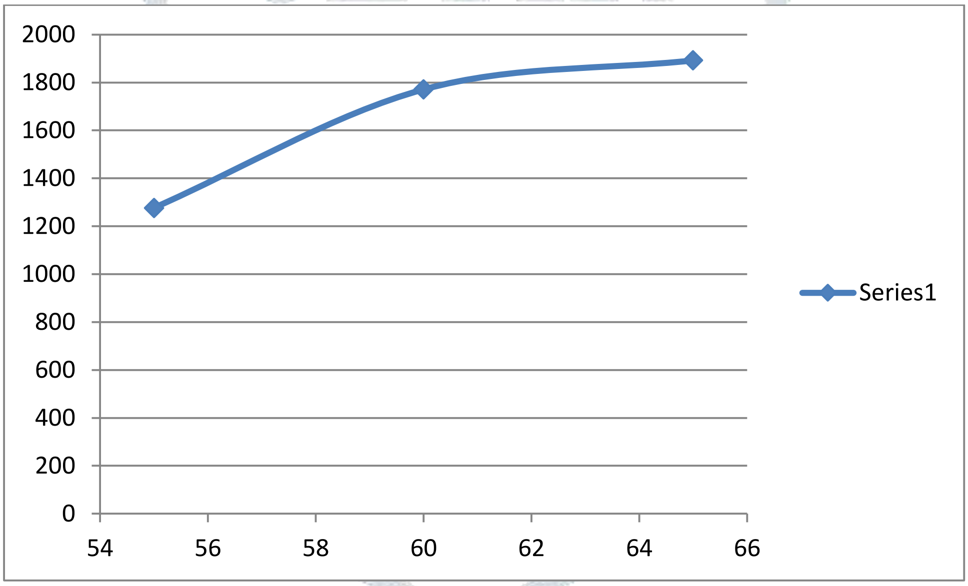


Figure 10 : Relationship between radial over cut and voltage

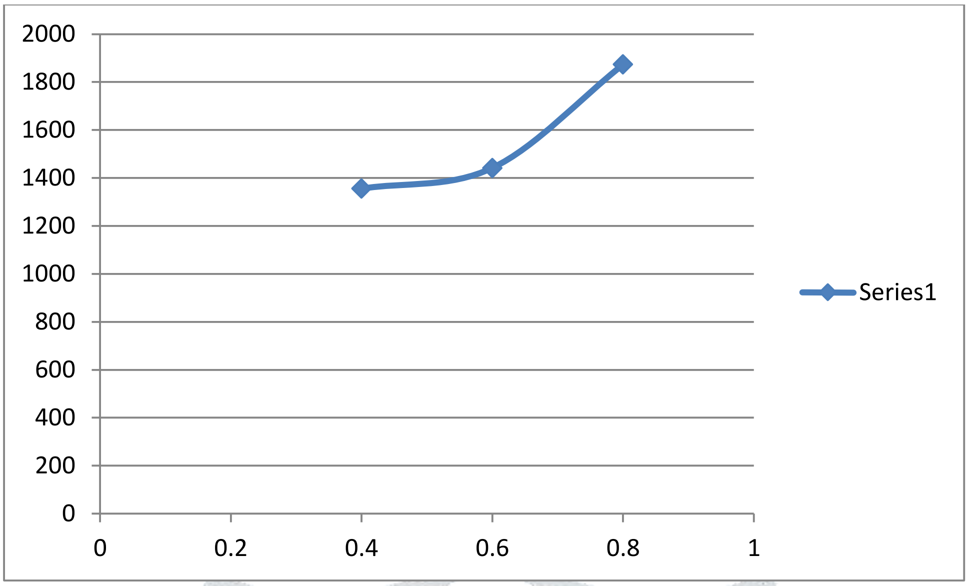


Figure 11 : Relationship between radial over cut and feed rate

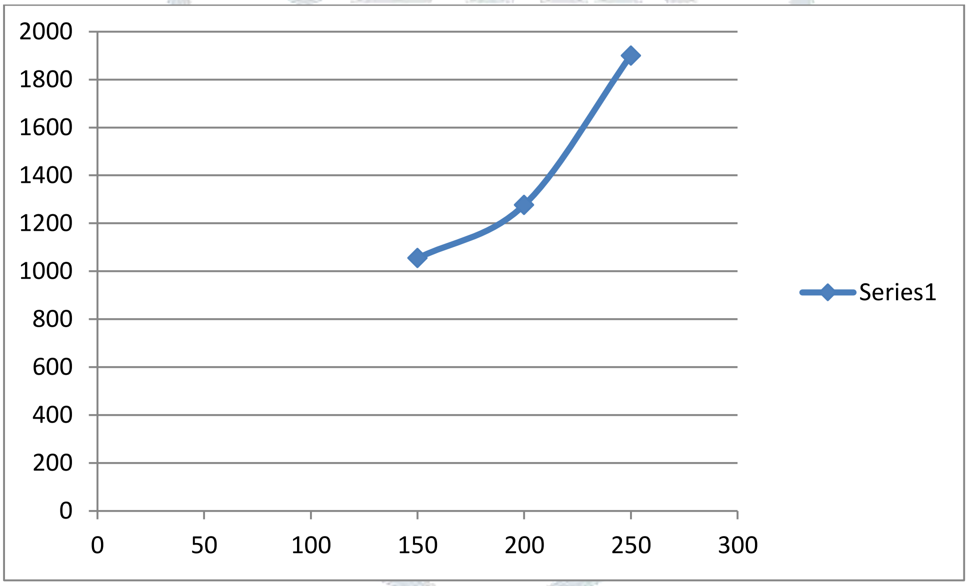


Figure 12 : Relationship between radial over cut and pulse generating time

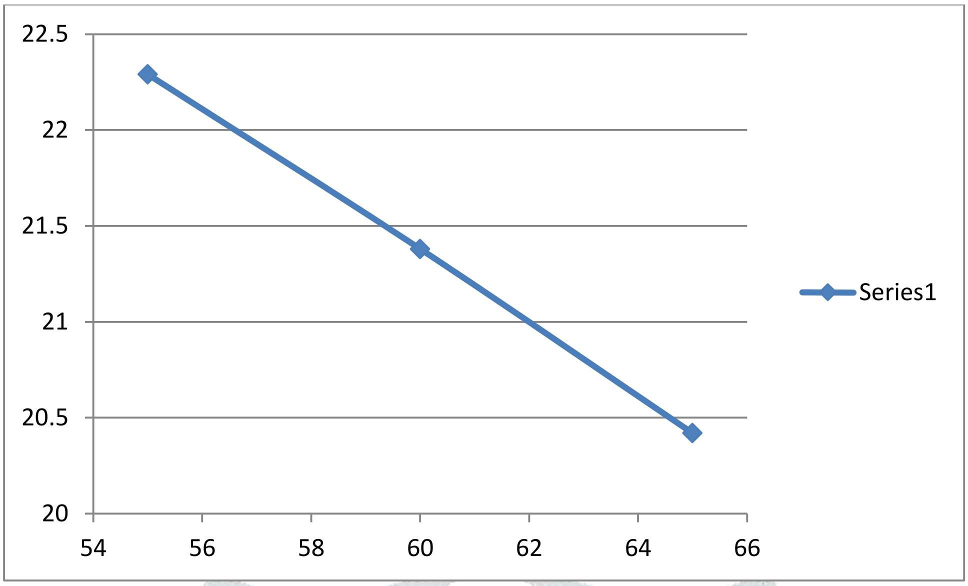


Figure 13 : Relationship between machining time and voltage

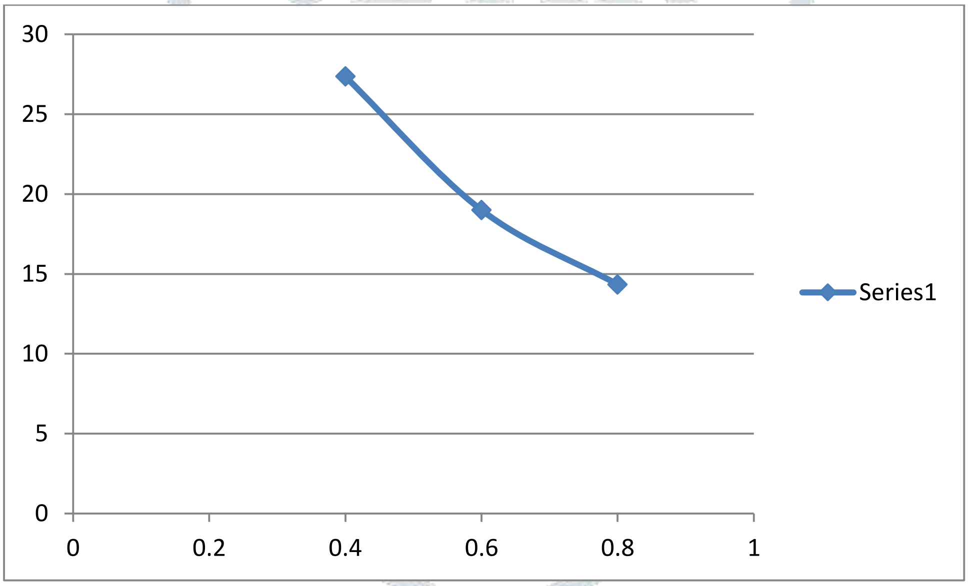


Figure 14 : Relationship between machining time and feed rate

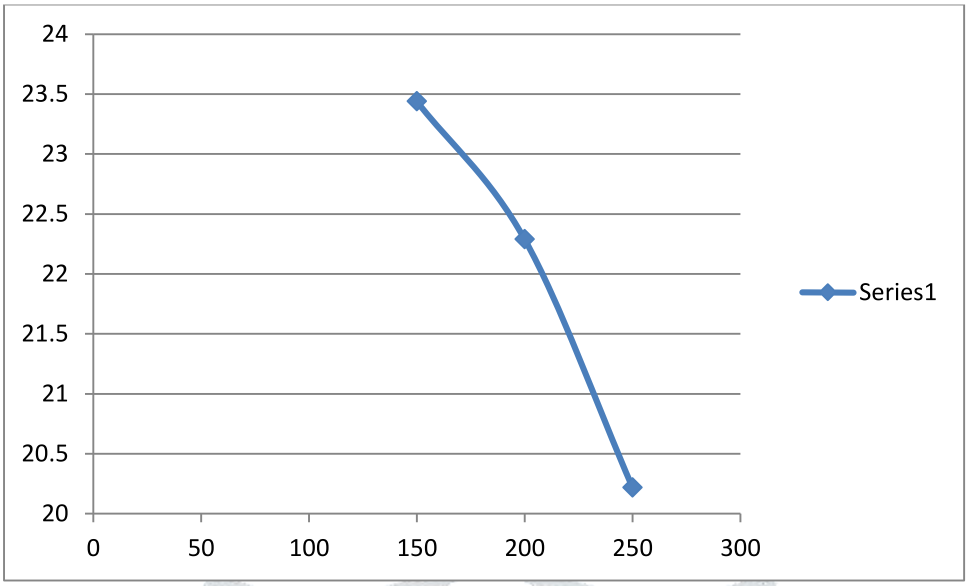
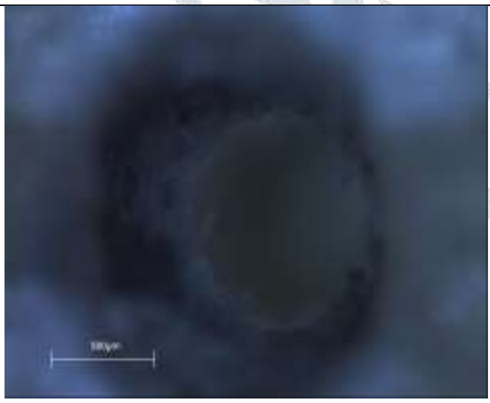
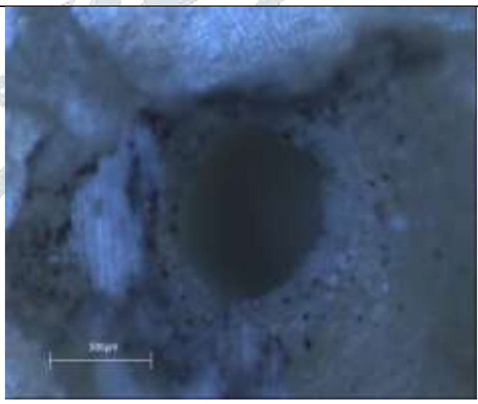
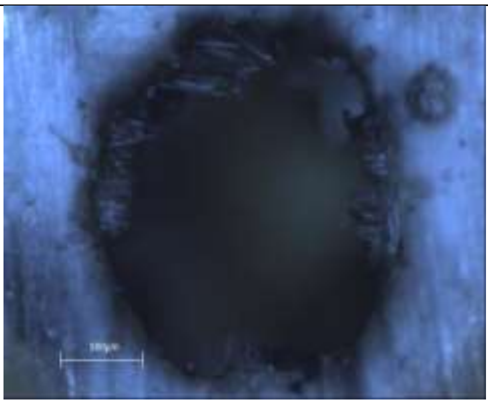
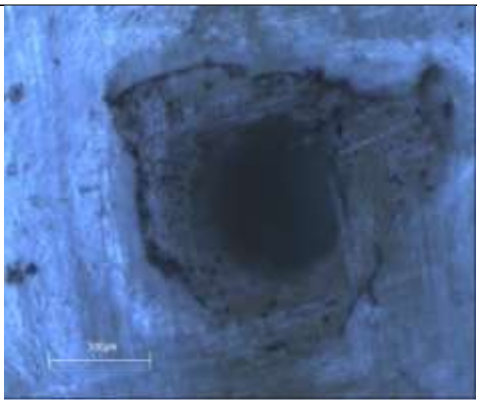
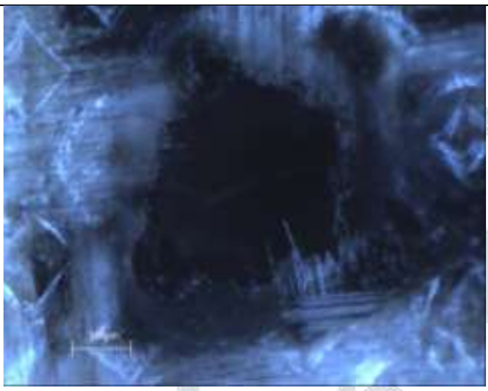
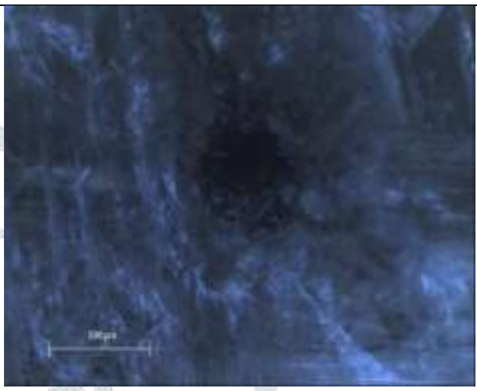


Figure 15 : Relationship between machining time and pulse generating time

5.1.MAGNIFIED (500X) VIEW OF THE MACHINED WORK-PIECE

The magnified image (500X) of the machined work-piece was taken with the help of Stereo Microscope. It is evident from the picture that the surface finish of the machined surface is not good. Surface finish of the machined surface also depends upon the process parameters. Fig 14 shows the magnified view of machined surface.

Voltage variation(in volts)	**Hole entrance**	**Hole exit**
55		

60		
65		

CONCLUSIONS

ECDM has great potential for machining of electrically non-conducting materials. OFAT (one-factor-at-a-time) technique based experiments are performed on ecdm setup to develop the optimized combinations of the process parameter to achieve better results. Within the limitations of the experimental set up of ECDM and its process parameters experiments were completed and from the results of the experiments following conclusions can be drawn:

a. This Material is not suitable for ECDM process due to burning of material.
b. But we achieve better result on these parameters like 55 volt (voltage), 0.5mm/min(feed) and 200 (t on).

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