PARAMETRIC OPTIMIZATION OF ELECTRO CHEMICAL DISCHARGE MACHINING FOR NON-CONDUCTIVE MATERIALS

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ABSTRACT

The brittle material like Glass, Ceramics and Non-plastic composites play a major role in automobiles, aeronautics & other industrial applications due to their enhanced mechanical properties. Machining of such materials is difficult and expensive. The increase in needs for machining of Ceramics for semi conductor, electronic device LEDs has lead to new developments in machining technology. The material removal process is based on the erosion of materials. Need for new Techniques for machining of these advanced engineering materials cannot be over emphasized. Electrical Discharge Machining (EDM) & Electro Chemical Machining (ECM) play a major role in many industrial applications to machine conducting materials but they fail to machine non-conducting materials. In this project an attempt has been made to combine the principle of both EDM & ECM process & explore the feasibility of using an Electro Chemical Discharge Machining (ECDM) process for machining of non-conducting materials Experimental set up for Electro Chemical Discharge Machining (ECDM) was developed. Experiments were conducted according to the Taguchi method to drill holes in borosilicate glass at different voltage & concentrations of the electrolyte and stainless steel material used as tool. Hole sizes were checked by using optical microscope.

Key words: Electro chemical discharge machining (ECDM); Electrolyte concentration; Applied voltage; material removal rate(MRR);

1. INTRODUCTION

1.1 Machining Processes:

The concept of material removal by cutting tool, involving plastic deformation and formation, has been known to man for several hundred years. In recent years an increasing demand for the machining of components of complex shapes made of hand difficult to machine materials with good tolerance & surface finish has resulted in the development of new machining processes. On the basis of the machining processes employed in removing material.

1.2 Electro Chemical Machining: Michael Faraday discovered that if two electrodes are placed in a bath containing a conductive liquid & D.C potential is applied across them, metal can be depleted from the anode & plated on the cathode. This principle was called as Electroplating.

ECM uses a shaped tool or electrode. Since the term machining implies the removal of material from the work piece, the tool is connected to cathode & the work piece to the anode. An electrolyte is pumped through the small gap which is maintained between the tool & work piece. The chemical properties of the electrolyte are such that the constituents of the work material get into the solution by the electrolytic process.

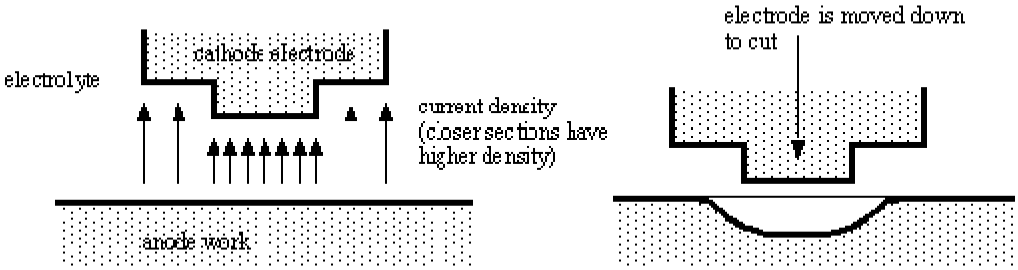


Fig. (a) **Fig. (b)**

Fig. 1 Schematic diagram of Electro Chemical Machining.

1.3 Electric Discharge Machining: EDM is the removal of materials, conducting electricity by electrical discharge between two electrodes, a dielectric fluid being used in the process. The aim of the process is controlled removal of material from the work piece. A necessary condition for producing a discharge is the ionization of the dielectric that is splitting up of its molecules into ions and electrons.

Consider the case of discharge between two electrodes through dielectric medium (gaseous liquid). As soon as suitable voltage is applied across the electrodes, the potential intensity of the electric field then builds up until some predetermined value and the individual electrons break loose from the surface & are impelled towards the anode under the influence of field forces. While moving in the inter electrode space, the electrons collide with the neutral molecules of the dielectric, detaching electrons from them and causing ionization. At some time or the other, the ionization becomes such that a narrow channel of continuous conductivity is formed. When this happens, there is a considerable flow of electrons along the channel to the anode, resulting in a momentary current impulse or discharge.

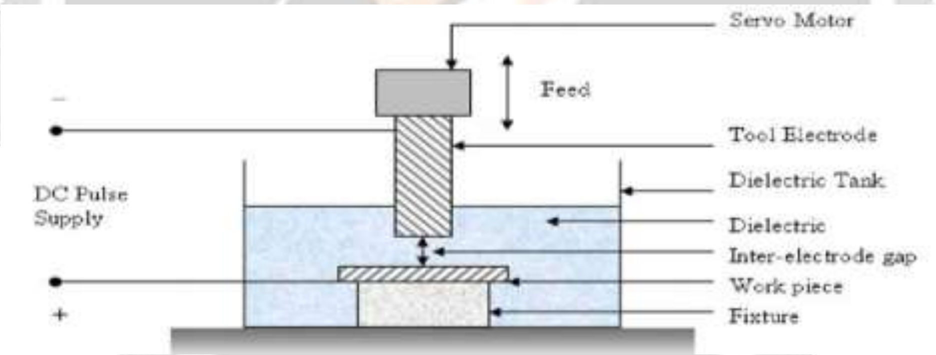


Fig. 2 Schematic diagram of Electrical discharge machining

1.4 Introduction to Electro Chemical Discharge Machining (ECDM):

There is a constantly increasing demand for engineering materials having properties superior to those possessed by customary engineering materials. The properties of interest in these materials (advanced engineering materials) are ultra high strength, high temperature and thermal shock resistance, high fatigue strength, high wear resistance, high strength to wear ratio, etc.

However, high values of these properties make it more difficult to machine these materials by using conventional methods, thereby limiting their widespread applications. Ceramics and fiber reinforced polymer composites have very attractive properties. However, conventional machining of fibre composites leads to delaminating and fussing, while machining of ceramics by conventional methods is either not possible or uneconomical.

The non-conventional machining techniques being explored for use with ceramics and composites fall into two categories-those in which a consideration of others which do not depend on the electrical properties of the work material techniques such as abrasive water jet machining, laser beam machining, etc, fall in the later group but there have problems associated with them. For the first category of techniques, the materials can be divided into three groups based on,

a) Electrically conductive.

b) Partially electrically conductive.

c) Insulators.

The process involves a complex combination of the electrochemical reaction and electro discharge action. The electrochemical reaction helps in generation of the positively charged ionic gas bubbles in hydrogen. The electrical discharge action takes place between the tool and the work piece due to the breakdown of the insulating layer of the gas bubbles as the DC power supply voltage is applied between the tool(or cathode) and the anode, resulting in material removal due to the melting, vaporisation of the work piece material and mechanical erosion.

Micro machining, as the name implies, machining of the materials in which removal of material from the work piece will be in micron level, i.e.in milligrams. Micro machining has many applications in the recent world, in new technologies, where there is more demand for micro fabricated products.

1.5 Working principle of ECDM:

ECDM is a process in which non conducting material is machined by removing material through melting or vaporization by electric sparks and arcs. The spark discharge is produced by applying controlled pulsed direct current between electrode and tool. The standoff distance generally maintained from 0.005 to 0.015 mm.

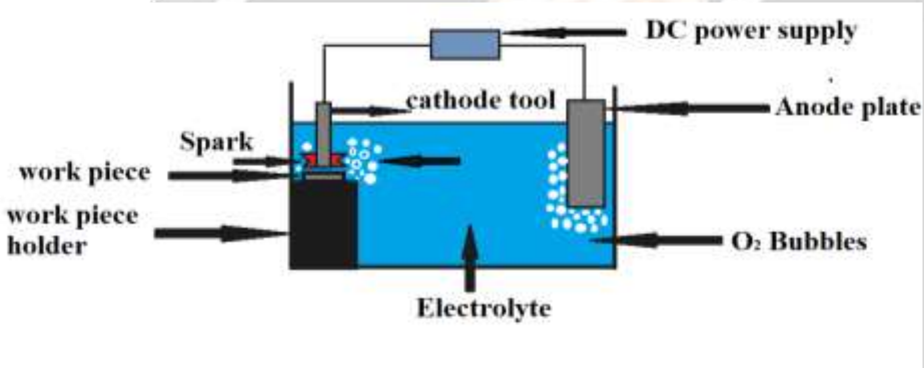


Fig. 3 Schematic diagram of Electro Chemical Discharge machining

The DC voltage enables a spark discharge to pass between the tool & work piece. Each spark produces enough heat to melt & vaporise a small quantity of the work piece there by leaving tiny pit or crater in the work surface.

2. LITERATURE REVIEW:

During the past decades, several authors attempted to give the explanation of physical and chemical mechanism of the electrode effects and many researchers and manufacturing engineers are trying to overcome the problematic area in ECDM process so that it can be used successfully in modern manufacturing industries. The survey of past research investigations from different engineers and researchers have been enlisted as follows:

Bhattacharyya et al. [1] The authors stated that the material removal took place due to the combined effects of electrochemical (EC) reaction and electrical spark discharge (ESD) action and it was found that two types of reactions usually occurred in the system (i) electrochemical reactions at the electrode. They showed that the material removal rate increases with increase of the applied voltage at different electrolyte concentrations and MRR was not very significant, but at higher voltage (i.e. 80, 85 and 90V).The influence of electrolyte concentration was more predominant as the rate of gas bubbles generation increased, resulting in a greater amount of spark generation in the sparking zone, which in turn increased MRR. Further the authors observed that at higher applied voltage for different electrolyte concentrations, over-cut was higher because of more possible stray sparking at the side wall of the tool tip, the tool tip geometry greatly influenced the material removal rate and over-cut criteria in the ECDM system .MRR for straight side wall-flat front, taper side wall-flat front and taper side wall-curvature front tool tips were 0.056, 0.154 and 0.248 mg/min, respectively. Finally the authors concluded that though the machining rate of ceramic materials was low in the ECDM process but the method is more effective for cutting those non-conductive materials considering the capability of machining a complex profile.

Ghosh et al [2]. The author explained the mechanism of ECDM by ECD phenomenon and suggested that a resistant layer developed around the tool electrode was mostly used as cathode and H2 evolved in the form of very fine bubbles. Electrochemical discharge starts only when the applied voltage reaches a critical value which depends on the type of electrolyte and its concentration. The author also suggested that blanketing could be a major factor in the occurrence of electrochemical discharge as both H2 evolution and vapor production through boiling depend on the power only and by proper controlling the location of heat source, the required shape of the work piece could be achieved. From the experiment it has been showed that the hemispherical bubbles covered the surface completely. The authors documented that the breakdown of insulting layer was analogues to the switching phenomenon and studied the process capability of ECDM process.

Somashekar et al. [4] analyzed the effects of various process parameter of ECDM process and developed a second order non linear mathematical model for establishing the relationship among the machining parameters such as applied voltage, electrolyte concentration and the machining process criteria MRR and radial overcut and heat affected zone during machining on silicon nitride. The model was developed based on response surface methodology using the relevant experimental data which were obtained during an ECDM micro-drilling operation on silicon nitride ceramics. To carry out the experiment, a stainless steel tool was selected and aqueous NaOH salt solution was used for the electrolyte due to its higher electrical conductivity which allowed it to achieve a faster rate of gas bubble generation due to an increase rate of chemical reaction. From the parametrical analysis based on mathematical model it was shown that applied voltage has more significant effect on metal removal rate radial overcut and heat affected zone thickness. The authors showed that MRR rate increased with increase of the applied voltage at different concentrations of NaOH electrolyte solution. At 25% concentration, the over-cut was low compared to that for 20% concentration.

3. EXPERIMENTATION

Figure 3.1 shows the simple experimental setup made by using an open type box structure of acrylic sheet which is open from one side, with a plastic box of appropriate dimensions serving as machining chamber glued inside it at its base. Connections are made by joining one end stainless steel tool with cathode terminal of variable DC Power supply and joining one end of GI sheet with anode terminal of variable DC Power supply.

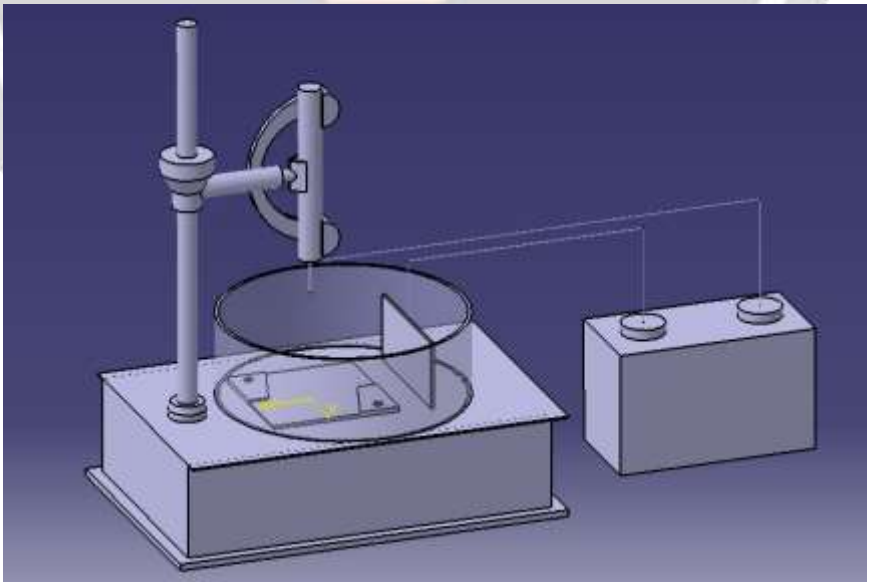


Fig. 4 Experimental setup of ECDM

Both electrodes are dipped inside electrolyte tank according to specifications and experiments are done with the dipped work piece using high value DC voltage varying between(40-90V) keeping in mind the other factors such as type and concentration of electrolyte used, cathode tool material and MRR required.

3.1 Mechanism of Material Removal:

If any electrically, non-conducting material is placed in the closed vicinity of electrical discharge, material removal takes place. The most acceptable mechanism of material removal is by thermal machining and chemical machining.

In thermal machining the work piece is heated by fraction of spark energy which even vaporizes the work piece material raises the local spot temperature to a very high value, sufficient for melting and may even vaporize the work piece material. Hence, correct estimation of energy per spark is crucial. In chemical machining mechanism is supported by the fact that the machining performance depends on the type of electrolyte.

3.1.1 Bubbles Generation Mechanism:

In ECDM process the gas bubbles which are produced during electrochemical reaction are low ionic positively charged in nature. With increase of the voltage supply the bubble formation increases and at a critical voltage sparking will be observed to take place in the gap. This sparking is between the tool and the electrolyte across a hydrogen or steam bubble layer. The critical voltage at which sparking starts will depends upon the concentration and conductivity of the electrolyte and the tool geometry. A high voltage D.C. power supply of 40 V is applied between the tool (or cathode) and the auxiliary electrode (or anode). The tool is placed to 1 mm below the upper level of the electrolytic solution.

The different cathode and anode reaction takes place as soon as an appropriate potential is reached between the inter electrode gap of the machining zone.

Reactions at the cathode (or tool):

The usual types of reactions at the cathode are:

(i) Plating of metal ions

The reaction for metal plating is: $M^{+}+e^{-} \rightarrow M$, where M represents Metal

present in electrolyte solution.

(ii) Evolution of hydrogen gas

The reaction for hydrogen evolution is:

$2H^{+}+2e^{-} \rightarrow H_2$ (in acidic electrolytic solution)

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

Reaction at anode (auxiliary electrode):

There will be one type of anodic reaction i.e. evolution of oxygen gas at the auxiliary electrode surface.

The oxygen evolution reaction is:

$4(OH)^{-} \rightarrow 2H_2O+O_2+4e^{-}$ (in alkaline electrolyte solution)

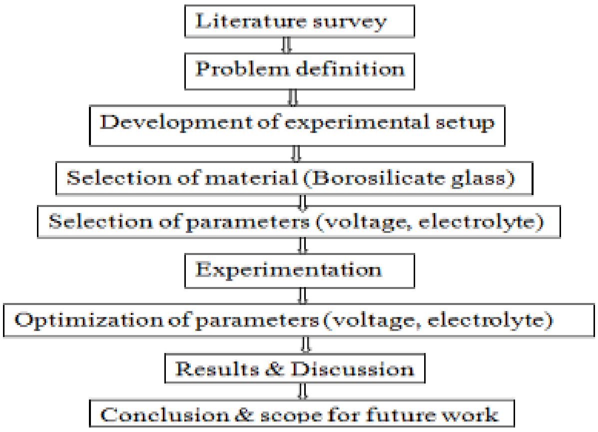
The electrolyte present in the micro-gaps is responsible for the formation of gas bubbles and steam generation. The rate of generation of hydrogen gas bubbles is very high in the vicinity of the tool. As a result of heating of the electrolyte, some electrolyte is evaporated.

3.1.2 Tool Wear Mechanism:

In electro chemical discharge machining process, a work piece normally an electrically non-conducting material is placed just below the tool along with the auxiliary electrode. The work piece material is immersed in an electrolyte solution in the machining chamber and the electrolyte is maintained about 1 to 1.5 mm above the tool tip. As the area of tool electrode is much more smaller than the auxiliary electrode the bubbles, which are evolved due to electro chemical reactions are accommodated at the surroundings of tool and forms a bubble layer. When the voltage is increased beyond the breakdown voltage of gas layer spark is initiated from the tip of tool with emission of light and releases heat energy.

A fraction of this energy is absorbed by tool-electrode as conduction mode of heat transfer, which raises the temperature of tool. When this temperature exceeds the melting temperature of tool material, the tool starts to melt and sometimes it also vaporizes. Basically material removal from tool takes place in the same way as the removal of work piece material. When applied voltage and electrolyte concentration increases more tool wear takes place.

3.2 Methodology :



3.3 Experimental parameters:

Table 3.1 Experimental conditions for tests.

Tool(cathode)	Stainless steel needle of diameter 0.8mm
Anode	GI plate
Work piece	Borosilicate glass
Electrolyte	NaOH solution
Machining condition	Applied voltage: Peak current: 2 amps Electrolyte concentration:20%

4. EXPERIMENTAL RESULTS

4.1 Introduction to Taguchi technique:

Every experiment has to plan and conduct experiments to obtain enough and relevant data so that he can refer the science behind the observed phenomena. He can do so by,

4.1.1 Trial and error approach:

Performing a series of experiments which gives some understanding, this requires making measurements after every experiment so that analysis of observed data will allow him to decide what to do next, which parameter should be varied and by how many times such series does not progress much as negative results may discourage or will not allow the selection of parameters which thought to be changed in the next experiment. Therefore, such experimentation usually ends well before the number of experiments reach a double digit. The data is insufficient to draw any significant conclusions and the main problem still remains unsolved.

4.1.2 Taguchi method:

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should
be varies. Instead of having to test all possible combinations like the factorial design, the
Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resource.

Taguchi Method Design of Experiments:

The general steps involved in the Taguchi Method are as follows:

- Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value used to define the loss function for the process
- Determine the design parameters affecting the process. Parameters are variables within the process that affects the performance measure such as temperatures. Pressures etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. For example, a temperature might be varied to a low and high value of 60° C and 100° C. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.
- Create orthogonal array for the parameter design indicating the number and conditions for each experiment. The selection of orthogonal array is based on the number of parameters.
- Conduct the experiments indicated in the completed array to collect the data on the effect on the performance measure.
- Complete the data analysis to determine the effect of the different parameters on the performance measure.

4.1.3 Introduction to Orthogonal Array:

Taguchi employs design experiments using specially constructed table, known as "Orthogonal Array" to treat the design process.

An experiment during product design stage, involves the material used in the manufacturing the experiment product which affect the final quality outcome. Factors such as variation in the electrolyte concentration, Applied voltage, and how the product is formed together, will contribute to the variation in the targeted value of the final product.

Orthogonal array is a special set of Latin squares, constructed by Taguchi to lay out the product design experiments. By using table, an orthogonal array of standard procedure can be sued for the number of experimental situation. Consider the common 3-level and 3-factors OA as shown in table 1 below.

Table 1 L9 Orthogonal Array

Experiment Number	Factors		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.1.4 Taguchi experiment result:

The effects of major process variables such as the applied voltage, electrolyte concentration and time taken on the material removal rate (MRR) have been analysed for obtaining the optimal machining characteristics of work piece material (Borosilicate glass) using ECDM process.

Experiments were carried out based on the basis Taguchi orthogonal array. Since there are 3 factors and 3 levels the orthogonal array chosen consists of 9 set of experiments. The table 4.2 shows the experiments conducted and respective MRR.

MRR were calculated by taking the difference of initial weight and final weight of the work piece.

Table 2 Process parameters and its levels

Factor	Level 1	Level 2	Level 3
Concentration	25	20	15
Voltage	80	90	100
Time	20	25	30

Table 3 Taguchi orthogonal array

Trial Number	Time Taken in min	Conc. in %	Voltage in V	Initial Weight In g	Final Weight In g	MRR in g/min
1	20	25	80	6.20	5.416	0.0392
2	20	25	90	6.20	5.376	0.0412
3	20	25	100	6.20	5.227	0.0486
4	25	20	90	6.20	5.578	0.0248
5	25	20	100	6.20	5.532	0.0267
6	25	20	80	6.20	5.643	0.0222
7	30	15	100	6.20	5.811	0.012
8	30	15	80	6.20	5.951	0.0083
9	30	15	90	6.20	5.843	0.011

Formula used:

1) Material removal rate (MRR) = [Initial weight – final weight]

4.2 Optical Photographs of the machined work surface:

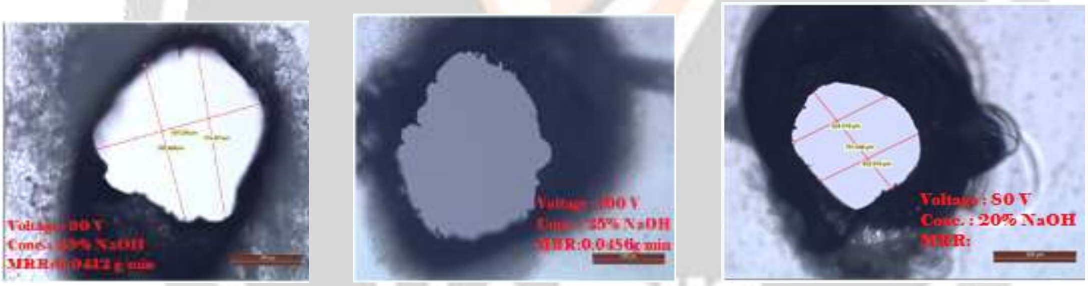


Fig.5 (a) (b) (c)

4.3 Photographs of the machined work surface:

Fig. 6 (a) (b)

5. CONCLUSION

This work concentrated on the Electro Chemical Discharge Machining which is non-conventional hybrid process, it is combination of ECM & EDM processes used for machining of non-conductive materials. Less work has been reported on the effect of process parameters on output characteristics. Hence the present work focused on development of experimental setup of ECDM. Machining of non-conductive materials is carried out by drilling a hole in Borosilicate glass with the use of stainless steel as tool. Experiments were conducted as per L_9 orthogonal array by selecting different parameters like electrolyte concentration, applied voltage and machining time and then observed the drilled hole by using optical microscope.

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