# Optimization of ECDM Process Parameters of Alumina Bioinert Ceramics

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***Abstract-*** *Electrochemical discharge machining (ECDM) is one of the non-traditional processes which employs physical and chemical phenomena to remove the material from non-conductive workpiece. Bioinert ceramics are a class of advanced ceramics that are having stable physiochemical properties, which finds application in the field of medical and dental applications, mainly as implants and replacements. Alumina Bioinert ceramics has characteristics of high hardness, high abrasion resistance, excellent wear and friction behavior.In this project, Alumina was fabricated by compaction process and further machined using ECDM process by varying the process parameters like Voltage, Duty cycle and Electrolyte Concentration. Experiments were conducted based on Taguchi L9 orthogonal array and material removal rate for each parameter setting was measured.*

***Keywords***- Alumina, Bioinert ceramics, ECDM process, Optimization, Material Removal Rate

## I. INTRODUCTION

The process of creativity proceeds by way of research, design and development. The project work concerned with creation of new system, process, and equipment for the benefit of mankind is engineering. The new system emerging from innovation may be constituted by mechanical, Electro mechanical, hydraulic, thermal, or other such elements. ECM is an anodic dissolution process based on the phenomenon of electrolysis. In ECM, electrolytes serve as conductor of electricity. The ECM technique now plays an important role in the manufacturing of a variety of parts ranging from machining of large metallic pieces of complicated shapes to opening of windows in silicon that are a few microns in size. Electro-discharge machining (EDM) is a reproductive shaping process in which the form of the tool electrode is mirrored in the work piece. This reproductive process exploits the physical phenomenon of material erosion of electrically conductive materials by means of electrical discharges. The thermal erosion process involved is characterized by the separation of solid, liquid or gaseous particles under the influence of heat[1-3].

Electrochemical Discharge Machining (ECDM) is an advanced hybrid machining process comprising the techniques of Electrochemical Machining (ECM) and Electro Discharge Machining (EDM). The process is also referred as Electrochemical Spark Machining (ECSM) process. The process is important since it can support a variety of materials including metals, ceramics, composites, alumina, glass, etc. This process has wide scope in applications for machining non-conducting engineering ceramic materials, such as Aluminum Oxides, Zirconium Oxides, Silicon Nitrides, etc. Such non-conducting ceramic materials have wide industrial applications in bearings, computer parts, artificial joints, cutting tools, electrical and thermal insulators, electronic devices, aerospace Components, etc. ECDM has greater applicability of machining non-conducting engineering materials. Now-a-days the requirement is of producing parts of intricate shapes and profiles as well as achieving enhanced productivity, dimensional quality features at reduced cost**.** The Electrochemical Discharge Machining (ECDM) process is a complex physical chemical system, where work piece material is removed by an anodic dissolution of the material and also by electrical sparks that occur between the working surfaces of the electrode tool and of the work piece. The electrical discharges assure a chain of micro explosions in the work piece surface layer; thus, micro quantities of work piece material are removed.

T.Singh et.al has stated that**,** Electro-Discharge Machining (EDM) provides a means of machining ceramic materials, irrespective of their hardness and strength. The complex work piece geometries and high accuracy to shape and size attainable with Electro-Discharge Machining particularly favor its use in tool making [4].M.Coteaţăet.alhas stated that Electrical Discharge Machining (EDM) is a well-established machining option for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. In recent years, EDM researchers have explored a number of ways to improve the sparking efficiency including some unique experimental concepts that depart from the EDM traditional sparking phenomenon [5].P.K.Guptaet.al has informed Machining with Electrochemical discharges is an unconventional technology able to machine several electrically non-conductive materials like glass or some ceramics [6].J. W. Liuet.alstudied the behavior of wire Electrochemical Discharge Machining of $Al_2O_3$ particle-reinforced aluminum alloy 6061 was studied. The effects of machining voltage, current, pulse duration, and electrolyte concentration, on Material Removal Rate (MRR) were evaluated in the light of the contribution of the Electrical Discharge Machining (EDM) and Electrochemical Machining (ECM) actions [7].M.Hajian.al stated that Electrochemical discharge machining is a very recent technique in the field of non-conventional machining to machine electrically non-conducting materials using the Electrochemical Discharge (ECD) phenomenon. If a beyond-critical voltage is applied to an electrochemical cell, discharge initiates between one tool of the electrodes and the surrounding electrolyte, which is termed here ‘electrochemical discharge [8].

SK.Cha et.alhas investigated the analysis of the basic material removal mechanism in the ECDM process for the effective machining of non-conducting ceramic materials with enhanced machining rate and higher machining accuracy. The ECDM process is influenced by various process parameters such as the applied voltage; the inter electrode gap, the temperature, concentration and type of electrolyte; the shape, size and material of the electrodes; and the nature of the power supply, etc. [9].M. Rusli et.alstudied the principle and properties of electro chemical discharge machining process. The mechanism of spark generation is found to be similarly the machining phenomenon rather than breakdown of gas layer. Behinds machining the ECDM phenomenon can be very effectively used for micro-welding [10].

The objectives of this work are to study the influence of ECDM process parameters such as electrolyte concentration, machining voltage, duty cycle on MRR of Alumina specimen. Hence, it is essential to use suitable optimization technique to study the complete range of level of process parameter with least number of experiments and to find the optimal parameter setting.

## II. MATERIALS AND METHODS

The material selected for the machining is Alumina (Aluminium Oxide). $Al_2O_3$ is significant in its use to produce Aluminium metal as an abrasive owing to its hardness, and as a refractory material owing to its high melting point. $Al_2O_3$ is an electrical insulator but has a relatively high thermal conductivity for a ceramic material. Aluminium Oxide is insoluble in water. In its most commonly occurring crystalline form, called corundum or α-Aluminium Oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools. Aluminium Oxide is responsible for the resistance of metallic Aluminium to weathering. Aluminium Oxide also exists in other, metastable, phases, including the cubic γ and η phases, the monoclinic θ phase, the hexagonal χ phase, the orthorhombic κ phase and the δ phase that can be tetragonal or orthorhombic. In this project taguchi method carried out for optimization of machining parameters. Taguchi’s approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence, it has gained a wide popularity in the engineering and scientific community. In the Taguchi design method, the design parameters (factors which can be controlled) and noise factors (factors which cannot controlled), which influence product quality, are considered. The optimization of process parameters is the key step in the Taguchi method. Nine experimental runs (L9), based on the Orthogonal Array (OA) of Taguchi methods were carried out.

The design of experiments to be conducted is selection of machining parameters and their levels which will contribute as primary input for calculating the design of experiments and further operations. The feasible range of machining parameters for the material was recommended as Voltage in the range of 70-100 V, Electrolytic concentration in the range of 20-35 g/l, Duty cycle range of 60-80 %.

**Table 1. Machining parameters and their levels**

| Parameters | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Voltage(V) | 80 | 90 | 100 |
| Electrolyte concentration (g/l) | 25 | 30 | 35 |
| Duty cycle (%) | 60 | 70 | 80 |

The table 1 shows the values of parameters and its level on experiments. After machining process, material removal rate is calculated based on the data’s obtained during the machining.Table 2 shows design of experiments based L9 Orthogonal array of Taguchi method having, Factors = 3; Levels = 3; and Runs = 9. In this project three levels, three factors are used to form L9 Orthogonal Array.

**Table 2. Design of experiments**

| S. NO | VOLTAGE (V) | ELECTROLYTE CONCENTRATION(g/L) | DUTY CYCLE (%) |
|---|---|---|---|
| 1. | 80 | 25 | 60 |
| 2. | 80 | 30 | 70 |
| 3. | 80 | 35 | 80 |
| 4. | 90 | 25 | 60 |
| 5. | 90 | 30 | 70 |
| 6. | 90 | 35 | 80 |
| 7. | 100 | 25 | 60 |
| 8. | 100 | 30 | 70 |
| 9. | 100 | 35 | 80 |

### III. EXPERIMENTAL PROCEDURE

Alumina plate produced by using compaction and sintering process. The principle goal of the compaction process is to apply pressurize and bond the particles to form a cohesion among the powder particles. The powders are pressed to produce green compact**.** In this project, die pressing is imparted for the compaction. The apparatus used for compaction is the hydraulic press. Powders are introduced in to die cavity by having the stud closed in the bottom of the die. The upper punch is inserted in the cavity. The die is a placed between the upper head and lower head of hydraulic press. The pressure is then applied. The pressure used for producing green compact of the component was 120 Mpa.Then the pressure is released and the punches are removed and the green compact is removed out of die. Hydraulic presses are used for compacting objects at high pressure. A mixture of lubricant oil and graphite powder is applied on the die wall and punches for easy removal and to prevent excess temperature during compaction. Sintering refers to heating of the compacted powder to a specific temperature (below the melting temperature of the principle powder particle while well above the temperature that allow diffusion between the neighboring particles). The equipment used for sintering is Box furnace**.** The compacts were placed inside the furnace for 1 hour and sintered at 1550$^0$C.After sintering the compacts are allowed to cool in atmosphere.

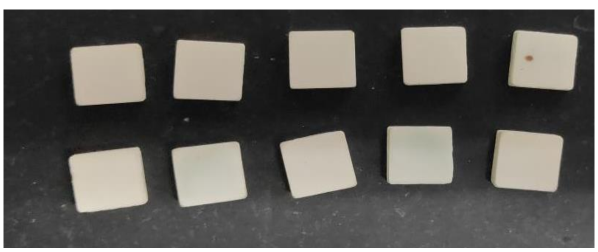

**Figure 1.Alumina specimen**

Work piece of Alumina was machined in the ECDM machine. Material Removal Rate values was measured in each trial of each parametric conditions. Tungsten electrode is used as tool for machining. The chamber is filled with electrolyte (NaOH), according to need. The level of electrolyte in the electrolyte chamber is maintained in such a way that the machining zone (work piece and tool electrode) is immersed during the machining process. Electrically non-conductive and chemically non-corrosive materials are used at places where the electrolyte directly contacts the setup such as electrolyte tank. The ECDM machining process was carried out for 30 minutes.After conducting the experiments Material Removal Rate (MRR) for the design parameters were measured and calculated using the formula,

$$MRR = (W1-W2)/t$$

Where,W1= weight sample before machining weight **(g),** W2=weight sample after machining weight **(g),** t = time duration of machining(min)**.**

### IV. RESULT AND DISCUSSION

Table 3 shows the Material Removal Rate obtained during the machining of Alumina Plate by ECDM process.In this method, signal to noise ratio (S/N) was used to represent a performance characteristic and largest value of S/N ratio is required. There are three types of S/N ratio, lower the best, higher the best, and nominal the best. The S/N ratio with higher the best characteristic is chosen and that can be expressed.

**Table 3. Experimental results**

| S.NO | VOLTAGE(V) | ELECTROLYTE CONCENTRATION(g/L) | DUTY CYCLE(%) | INITIAL WEIGHT(g) | FINAL WEIGHT(g) | MRR (g/min) X $10^{-3}$ |
|---|---|---|---|---|---|---|
| 1. | 80 | 25 | 60 | 1.364 | 1.335 | 0.97 |
| 2. | 90 | 25 | 70 | 1.292 | 1.237 | 1.83 |
| 3. | 100 | 25 | 80 | 1.395 | 1.276 | 3.97 |
| 4. | 80 | 30 | 60 | 1.334 | 1.262 | 2.40 |
| 5. | 90 | 30 | 70 | 1.359 | 1.288 | 2.37 |
| 6. | 100 | 30 | 80 | 1.330 | 1.202 | 4.26 |
| 7. | 80 | 35 | 60 | 1.382 | 1.309 | 2.43 |
| 8. | 90 | 35 | 70 | 1.279 | 1.209 | 2.33 |
| 9. | 100 | 35 | 80 | 1.337 | 1.168 | 5.63 |

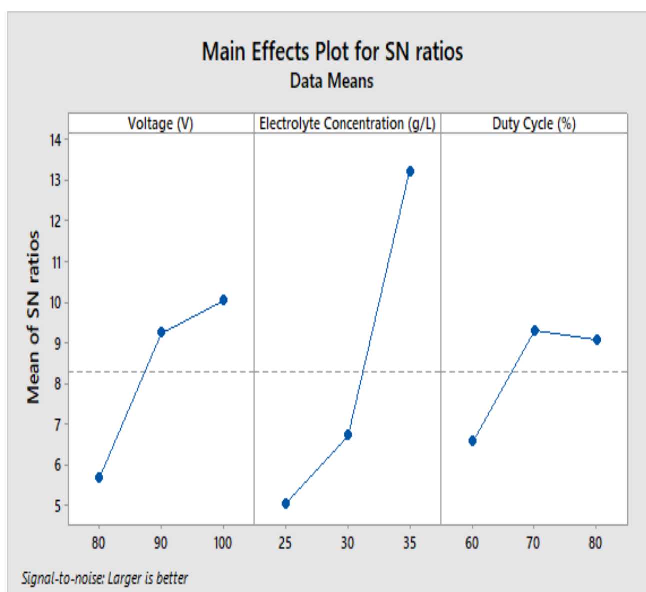


**Figure 2 Main effect plot for the S/N ratio**

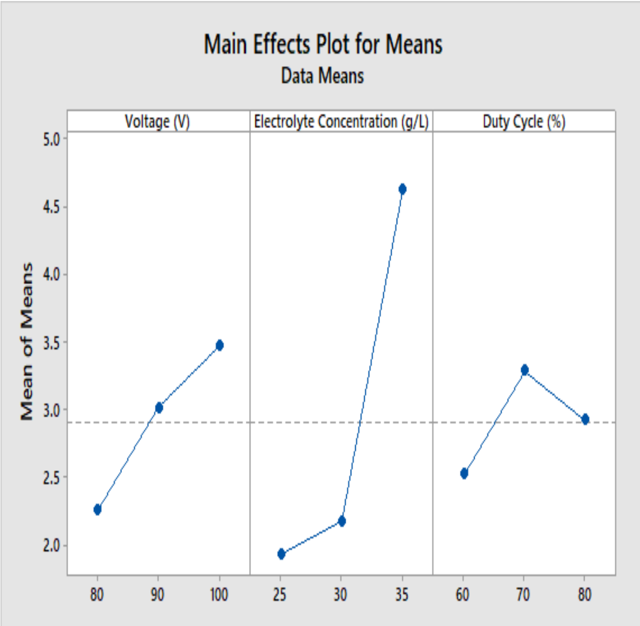


**Figure 3 Main effect plot for the means**

Figure 2. shows the main effect plot for the S/N ratio.Higher values of S/N ratio identify control factors setting that minimize the effect of noise factors. For material removal rate, S/N ratio is considered as large the better. From the figure2,it is clear that higher value occurred at voltage of 100 V, Electrolyte concentration of 35 g/L and at duty factor 70%. Figure 3 shows the main effect plot for means. It is clear from the figure 3 thathigher value of S/N ratio occurred at voltage 100V,Electrolyte concentration of 35 g/L and duty factor 70%. Table 4 and 5 is shows the response table for S/N ratio and response table for means. Response table shows the delta value and rank for the parameters based on the experimental results.

From the table 4 and 5, it is clear that electrolyte concentration is the major influencing factor followed by voltage and then duty factor.Based on the test results, plots and S/N ratio, it is clear that for parameter setting voltage at 100V, Electrolyte concentration at 35 g/L and at duty factor 70%maximum material removal rate is obtained.

**Table 4. Response table for S/N ratio**

| Level | Voltage (V) | Electrolyte concentration (g/L) | Duty factor (%) |
|---|---|---|---|
| 1 | 5.653 | 5.017 | 6.557 |
| 2 | 9.229 | 6.697 | 9.288 |
| 3 | 10.023 | 13.191 | 9.061 |
| Delta | 4.370 | 8.174 | 2.731 |
| Rank | 2 | 1 | 3 |

**Table 5.Response table for means**

| Level | Voltage (V) | Electrolyte concentration (g/L) | Duty factor (%) |
|---|---|---|---|
| 1 | 2.257 | 1.933 | 2.520 |
| 2 | 3.010 | 2.177 | 3.287 |
| 3 | 3.463 | 4.620 | 2.923 |
| Delta | 1.207 | 2.687 | 0.767 |
| Rank | 2 | 1 | 3 |

## V. CONCLUSION

ElectrochemicalDischarge Machining process is used to machine ceramic materials. In this project, Alumina Plate was produced successfully by compaction and sintering process.Alumina Plate was machined in ECDM process based the design of experiments made by Taguchi method. Material Removal Rate is obtained as output parameters after machining. Based on experimental results, Material removal rate increases linearly with respect to electrolyte concentration and voltage and duty cycle.Based on the response table, electrolyte concentration is the major influencing factor followed by voltage and then duty factor. Based on the main effect plot, the optimal process parameter to obtained maximum material removal rate was obtained.The optimal parameter setting obtained is voltage of 100V, Electrolyte concentration of 35 g/L and duty factor 70%.

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