Experimental Investigation on Electrochemical Discharge Machining of Zirconia

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1 Introduction

Nowadays, the manufacturing industries adopt non-traditional machining processes. It reduces the tool cost and also effectively machining high-strength materials without any thermal defects [1]. Electrochemical discharge machining (ECDM) is a non-traditional machining process that combined electrochemical machining (ECM) and electrical discharge machining (EDM) [2]. ECDM process uses NaOH as an electrolyte with voltage to machining the ceramics [3]. In this research work, the ECDM process uses various levels of NaOH electrolyte concentrates and voltage. High-strength and corrosive resistance materials are used to produce dental and medical instruments. Zirconia (ZrO_2) is widely used for the production of medical and dental instruments due to its high resistance to corrosion and high strength [4]. This experimental work uses zirconia as a working material, and ECDM is the process of machining the zirconia [5].

In ECDM, the parameters used to machine zirconia are electrolyte concentrate, electrolyte flow type or stagnate type, applied voltage, duty cycle and tool, inter-electrode gap (IEG), critical depth, etc. This work involves parameters such as electrolyte concentrations, applied voltage, and duty cycles in three levels and also uses the design of experiments [6] with response surface methodology for this work;

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ECM [7, 8] and EDM [9] processes also studied to achieve optimization of material removal rate (MRR) in ECDM having three process parameters such as electrolyte concentration, duty cycle, and applied voltage; [10] in this work, various process parameters are studied and predict that the electrolyte concentration is reducing the tool wear and increasing the MRR. In this research work, the electrolyte concentration is used to three levels to achieve maximum material removal rate; [11] in this work, they used the various design of experiments such as the Taguchi design and GA algorithm to optimize. In this work, we used response surface methodology for the design of experiments; [12] in this experimental work, they used to machine glass workpiece in ECDM with four parameters such as voltage, duty factor, electrolyte concentration, and temperature. They used response surface methodology to design experiments to conduct experiments, and they revealed that MRR increased in voltage and temperature. The electrolyte used in this work NaOH is kept stagnate instead of circulation which is one of the important machine setups in this process; [13] in this experiment, they prove that the better MRR is achieved where the electrolyte is stagnating position, so in our experiment, we kept the electrolyte stagnate [14] while machining.

2 Design of Experiment

The stainless steel tool is used to remove the material to make a hole in the zirconia plate. The tool is stationary and electrolytes kept stagnate condition. The material removal rate is observed under the impact of three distinguished parameters, such as applied voltage, duty cycle, and electrolytic concentration.

2.1 The Process Parameters

The process parameters ranges for the experiments are given below:

Electrode	Stainless Steel
Workpiece	Zirconia
Workpiece thickness	1 mm
Electrolyte	NaOH (with various concentrations)

2.2 Selection of Machining Parameters

For the machining of hard materials like ceramics, the following machining parameters voltage, electrolyte concentration, and duty cycle are the most influencing machining parameters in the ECDM and selected the above-mentioned parameters based on the literature work.

Table 1 Levels of process parameter

Name	Units	Low	High
Electrolyte concentration	%wt	15	25
Voltage	V	80	100
Duty cycle	%	50	70

2.3 Box–Behnken Design

To conduct the experiments, Box–Behnkan design from response surface methodology is selected.

Table 1 depicts the process parameters and the level of their value on experiments.

3 Experimental Work

3.1 Material for Workpiece

Zirconia (ZrO_2) is one of the strongest material as well as highly corrosive resistant. Table 1 depicts the mechanical properties of Zirconia (ZrO_2), and they studied zirconia is a material having tremendous properties such as high resist to indentation strength, high resist to wear, great thermal hardness, and more chemical durability, and also noted the zirconia material is strongly recommended to produce dental crowns and wear-resistant coating. Further, they observed from experiments that MRR is increasing due to increasing applied voltage and also noticed that overcut issues were also raised [15]. The objective of this research work is to maximize the MRR.

3.2 Electrochemical Discharge Machining (ECDM) Processing

The non-traditional machining processes are used to machining the hard and brittle material such as zirconia [16]. They used the ultrasonic machining process in their experimental work and revealed that higher voltage causes to tool wear [17] which utilize the ultrasonic machining process to machine the zirconia composite material and revealed the slurry with abrasives which are causes to damage the workpiece surface. In this work, the ECDM is used to avoid surface damage due to abrasive slurry. Figure 1 shows the experimental arrangement for the ECDM. This setup consists of a stepper motor, filter unit, tool holder, machining chamber, tool horizontal movement control handwheel, and programmed tool movement controller.

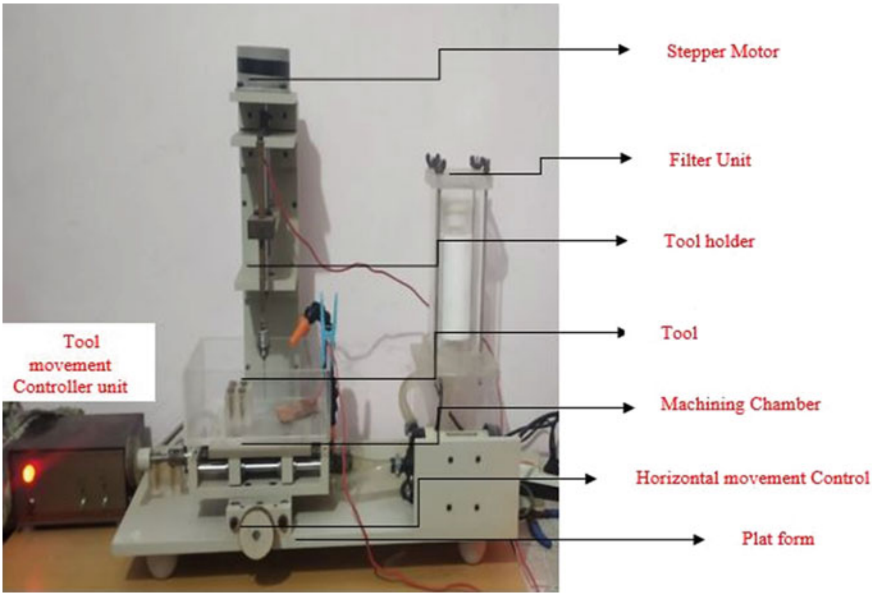

Fig. 1 ECDM machining setup

The workpiece is kept in the machining chamber, and beforehand, the machining chamber is filled with NaOH electrolyte up to cover the workpiece surface. The stainless steel tool is mounted with a tool holder. The workpiece is moving with the help of a handwheel in X- and Y-direction to drill the zirconia material.

Beforehand, the design of experiments (DOE) is used to conducting experiments. Response surface methodology is select to DOE in Box–Behnken model design using design-expert software.

4 Results and Discussion

Figure 2 shows the machining of the workpiece material into the machining chamber. The spark is produced between the workpiece and electrolyte. The Electrochemical Discharge Machining process beginning, electrolyte enclosed the tool gets debase by the reaction, produces gas bubbles, as a result, the bubbles release the pressure energy causes to material removal. The electrode gets wear and contaminates due to spark. Therefore, for each experiment, a new electrode is used with a fresh electrolytic concentration solution.

Table 2 shows the material removal rate of the machining of zirconia. The workpiece has been observed before and after machining to calculate the material removal rate.

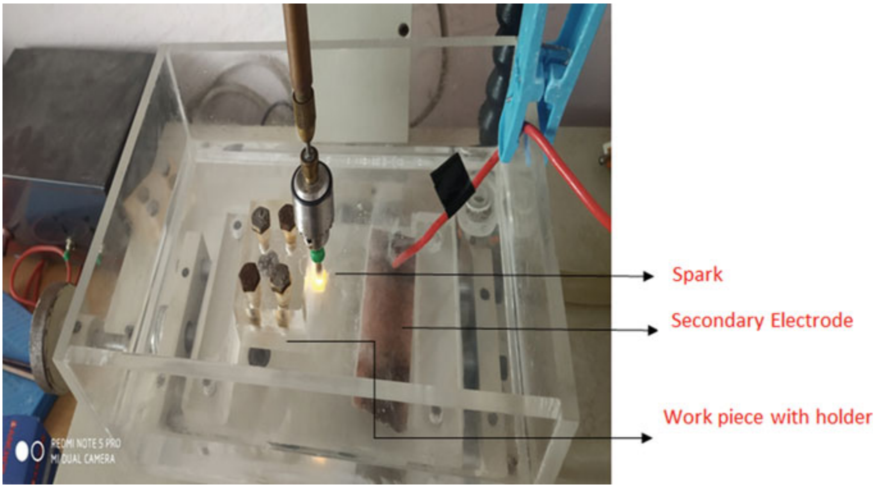

Fig. 2 Machining of workpiece

Table 2 Material removal rate (MRR)

Run	Electrolyte concentration (A)	Voltage (B)	Duty cycle (C)	MRR (µg/min)
1	20	90	60	238
2	20	90	60	237
3	20	90	60	238
4	15	90	50	210
5	25	80	60	249
6	20	100	70	245
7	25	90	70	263
8	15	100	60	234
9	20	90	60	236
10	20	80	70	239
11	15	80	60	214
12	25	100	60	276
13	20	80	50	227
14	15	90	70	226
15	20	90	60	237
16	20	100	50	242
17	25	90	50	247

4.1 *Observations During Experimentation (MRR)*

Time duration	30 min, (Each Cycle)
Tool	Stainless Steel
Tool diameter	1 mm

Regression equations obtained for the material removal rate is given below. This equation helps in the prediction and optimization of output variables concerning input variables.

$$\begin{aligned} \text{MRR} = {} & 237.2 + 18.875\,\text{A} + 8.5\,\text{B} + 5.875\,\text{C} + 1.75\,\text{AB} + 5.55958\,\text{e} \\ & - 16\text{AC} + -2.25\,\text{BC} + 2.15\,\text{A2} + 3.9\,\text{B2} + -2.85\,\text{C2} \end{aligned} \quad (1)$$

where A is electrolyte concentration, B is voltage, and C is duty cycle.

Table 2 shows the result of the material removal rate of zirconia in g/min. These table values are clearly indicating that zirconia is machined using ECDM with NaOH.

From the above table values, we clearly infer that experimental run no: 12 achieved more MRR than others, and in the 12th run, we used the parameters that are electrolyte concentration is 25% wt., the applied voltage is 100 V, and the duty cycle is 60%.

Figure 3 shows the parameter relations regarding the material removal rate. The graph shows that voltage gives a most influencing effect on material removal rate. Increases in voltage lead to increase in the rate of spark generation in the sparking area.

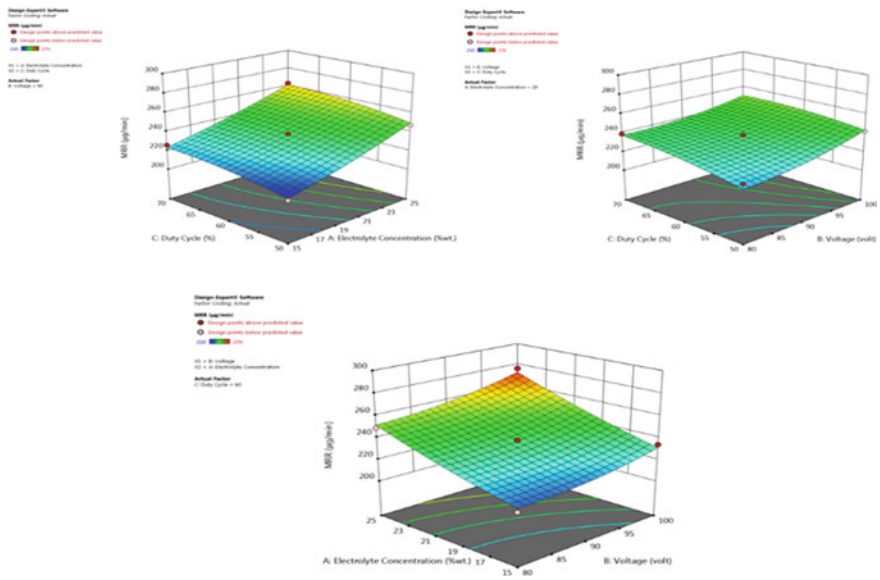

Fig. 3 Response surface plots for MRR

5 Conclusion

1. The electrochemical discharge machining (ECDM) technique is able to machine non-conductive materials like ceramics, glass, polymers, etc., in an effective manner. Based on experimental studies by the machining of zirconia, the following conclusions are drawn out:
2. From this experimental work, hard and brittle material like zirconia can be effectively machined without any fracture or thermal defects to the workpiece.
3. In this work, voltage plays a major role then followed by electrolyte concentration in the material removal rate of zirconia.
4. It was found that the maximum MRR is achieved when the voltage is and the electrolyte concentration in the peak, and the duty cycle was in the nominal stage.
5. In the future study can be carried out for radial overcut, roughness of machined area, and tool wear rate.

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