Experimental Investigations on Developed Electrochemical Spark Machining Set up during Machining of Alumina Ceramic Component

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ABSTRACT

Advance difficult to machine materials such as ceramics motivated researchers and engineers from manufacturing industries to develop newer methods of machining of such materials. Advanced machining processes such as electrical discharge machining and electrochemical machining are being effectively used in industries but for electrically conducting materials only. Ceramics such as alumina is electrically non conductive material and have superior properties and wide spread applications such as cutting tools, electrical and thermal insulators, turbine blades etc. Hence the machining of alumina ceramic material becomes very important. But due to electrically non conductive property of alumina, advance machining processes such as Electrochemical machining (ECM) and Electrical discharge machining (EDM) cannot be applied and other machining operations like ultrasonic machining and ion beam machining have their own limitations. So in the present research paper, a hybrid machining process, electrochemical spark machining (ECSM) setup was designed, fabricated and utilized for experimental investigations to find the suitability of developed set up for machining of non conductive alumina ceramic. The effect of various machining parameters such as DC supply voltage, electrolyte concentration, Pulse-on-time, pulse-off-time and inter electrode gap on different response characteristics such as material removal rate, overcut and taper generated during machining of hole was investigated and suitable range of the process parameters of the developed set up was determined.

Keywords: ECSM, machining parameters, material removal rate, overcut, taper

1. INTRODUCTION

Researchers and engineers from advanced manufacturing industries like automobile, aerospace and nuclear industries have developed a large number advanced materials like ceramics. Advanced ceramic materials, are gradually becoming very important for their superior properties such as high hardness, chemical resistance, low density, wear and corrosion resistance, high-temperature strength and high strength to weight ratio [1]. Alumina is a dominant ceramic material used in many applications ranging from refractory industry to wear and ballistic applications, low-tension and high-tension insulator and substrates for microelectronic applications. Alumina ceramics distinguish themselves from other materials by number of exceptional properties such as ability to withstand high temperatures up to 2000º C, corrosion resistance, high stiffness and hardness [2].

But machining of such advanced ceramics by well known conventional and some of non conventional machining processes are difficult because of cutting tool wear, micro crakes developed on the machined surface, low material removal rate (MRR), relatively poor surface quality etc. Advanced machining methods like electrochemical machining (ECM) and electric discharge machining

(EDM) provides good surface finish and machining tolerances but suffers from the drawback that these processes can't be used for machining of these advance materials because they are electrically non-conductive [3]. Machining of materials based on electrochemical spark phenomenon was first presented in 1968 by Kurafuji as 'electrochemical discharge drilling' for micro-holes in glass [4]. Machining with electrochemical discharge phenomena is possible only above the critical voltage, i.e. in the arc region. In this situation several processes may contribute to the machining mechanism [5]. Some of the similar works related to machining of materials by electrochemical spark phenomenon are presented here. Jain et al. [6] studied the electrochemically spark abrasive drilling (ECSAD) process and authors reported that improved performance in terms of material removal and machined depth can be observed while machining the ceramic materials by electrochemical spark machining with abrasive cutting tools. Peng and Liao [7] conducted experimental investigations on electrochemical discharge machining (ECDM) to slice the small size (10–30 mm diameter) optical glass and quartz bars. Skrabalak, et al. [8] studied the building of rules base for fuzzy-logic control of the ECDM process and presented a simplified model for estimation of current for electrochemical dissolution and electro discharge machining in ECDM process. Sarkar et al. [9] studied the parametric analysis on electrochemical discharge machining of silicon nitride ceramics and reported that applied voltage has more significant effect on MRR, ROC, HAZ during ECDM micro-drilling operation than other machining parameters such as electrolyte concentration and inter-electrode gap. Kim et al. [10] studied on electrochemical discharge machining (ECDM) and observed a drawback of ECDM is the heat-affected zone (HAZ) left on the micro-drilled hole surface. Bhondwe, at al [11] studied on electro-chemical spark machining (ECSM) and reported that MRR is found to be increased with increase in electrolyte concentration and duty factor. Cao et al. [12] demonstrated the capabilities of ECDM for micro-machining of glass by fabricating various micro-structures of features less than 100μm in size and 3D micro-structure. In order to improve the machining quality of 3D micro-structure on glass, authors investigated the effects of the parameters such as electrolyte concentration, pulse-on-time, pulse-off-time, supply voltage during milling processes. Manna and Narang [13] conducted the experimental investigation on the micro machining of electrically nonconductive e-glass–fibre–epoxy composite during machining by ECSM using specially designed square cross section micro hole brass tool and different diameter round-shaped micro tools made of IS-3748 steel. The influence of the fabricated ECSM parameters on the material removal rate and overcut on generated hole radius were investigated. Manna and Kundal [14] developed TW-ECSM setup and utilized the developed set up for experimental investigation for micro slicing of alumina ceramic. Authors investigated the parametric effects of TW-ECSM on material removal and spark gap width by taguchi design of experiment and found that the electrolyte concentration and DC supply voltage are the most significant parameters for material removal and spark gap width respectively. Behroozafar and Razfar [15] studied the wear of different tool materials such as tungsten, brass and steel during electrochemical discharge machining. Authors found that the voltage at which the tool wear starts depends upon the material of tool and its melting point.

From the review of literature, it is found that there is need of developing the efficient and accurate as well as cost effective machining techniques for machining the alumina and other such nonconductive ceramic materials. Keeping in view, a hybrid ECSM (Electrochemical Spark Machining) set-up has been designed and fabricated, and utilized to machine alumina ceramic material. Electrochemical Spark Machining (ECSM) or electrochemical discharge machining (ECDM) is also known as spark-assisted chemical engraving (SACE) is considered to be a hybrid machining method that has shown potential in machining of electrically non-conducting ceramic materials as explained by Wuthrich and Fascio (2005). In ECSM, material removal process is based on two phenomena: (i) electrochemical dissolution of the material and (ii) thermal erosion by electrical sparks that occur between the electrodes. The basic principle of electrochemical spark machining is shown in Fig.1.

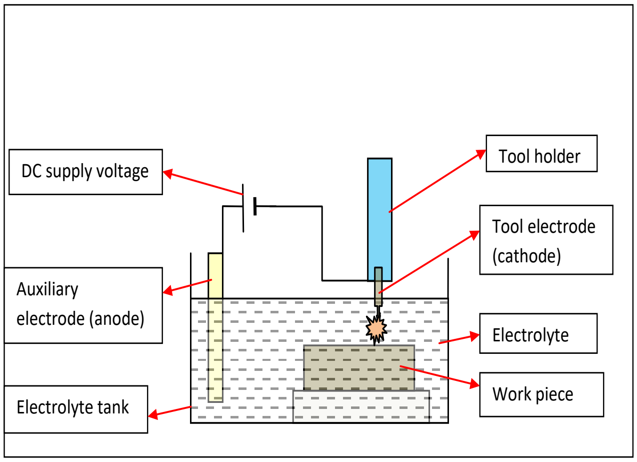

Fig. 1 Basic principle of ECSM

The work piece is dipped in an electrolytic solution (generally NaOH or KOH). A constant or pulsed DC supply voltage is applied between the tool electrode (i.e. cathode) and auxiliary electrode (i.e. anode). The tool-electrode is dipped a few millimeters in the electrolytic solution and the anode is in general a large flat plate whose surface area is about about 100 times larger than tool-electrode surface area. The polarity of tool-electrode is generally set s a cathode but the opposite polarity is also possible.

2. Design and Fabrication of ECSM Setup

This designed and fabricated ECSM set-up shown in Fig. 2 was used for experimentation to investigate the machining performance during machining of nonconductive alumina ceramic workpiece specimens. The specifications of designed and fabricated setup of ECSM are as follows:

- Size of machining chamber: 400 mm x 300 mm x 200 mm
- Maximum dimension of job that can be fitted in job holding fixture is 70 mm x 50 mm x 15mm
- Maximum inter electrode gap that can be possible to set is 120 mm
- Maximum movement in horizontal direction with the help of vice is 50 mm
- Main input power supply: single phase 220 V A.C.
- Power supply for machining: Pulsed D.C.
- Voltage range: DC, 0 to 120V
- Range of current: 0.5 to 5A.
- Pulse-on and pulse-off timings: can be set up in the steps of 1ms

Fig. 2 Designed and fabricated ECSM setup

3. Planning for Investigations

To identify the effect of fabricated ECSM parameters on the machining characteristics i.e. material removal rate, overcut and taper generated in machined hole, a series of experiments has been carried out using variation of machine parameter setting. The ECSM parameters considered for experimental investigations and their units are represented in Table 1.

Table 1 Parameters of the developed ECSM set-up and their units

S.No.	Symbol	Machining parameters	Units
1	A	Applied voltage	Volts
2	B	Electrolyte concentration	g/l
3	C	Pulse on time	ms
4	D	Pulse off time	ms
5	E	Inter electrode gap	mm

Other Experimental Conditions:

Electrolyte level : 2 to 3mm above the alumina ceramic workpiece specimens

Tool electrode material: Stainless steel

Tool electrode shape : Solid circular shape with 0.8 mm diameter

Auxiliary electrode : Cu plate of size 80 mm × 40mm × 3mm

Tool feed rate : 0.1mm/ min.

The NaOH was selected as electrolyte and solid circular stainless steel was selected as the tool electrode material for experiments. The material removal rates are determined by difference of weight of work-pieces before and after each micro hole. The weight of workpiece specimen before and after drilling was measured by Denver SI 234 electronic weighing machine of least count 0.0001g and material removal rate was determined utilized the relation equation 1.

$$MRR = \frac{\text{Wt.of specimen before machining} - \text{Wt. of specimen after machining}}{\text{Machining time}} \qquad \text{Eq. 1}$$

To check the radial overcut and taper of machined hole, a coordinate measuring machine (CMM) was used. CMM machine used was of Mitutoyo corporation, model BND-crysta C 7106. The maximum overcut and taper were calculated by using the equations 2 and 3 respectively.

$$\text{Overcut} = \frac{\text{Diameter at entry of hole} - \text{Diameter of tool}}{2} \qquad \text{Eq. 2}$$

$$\text{Taper per unit length}, X = \frac{\text{Diameter at hole entry} - \text{Diamter of hole exit}}{2 \times \text{depth of hole}} \qquad \text{Eq. 3}$$

$$Taper\ (degree) = \tan^{-1} X \qquad \text{Eq. 4}$$

4. Results and Discussion

The effect of fabricated ECSM set-up parameters on material removal rate, overcut and taper in holes during machining of nonconductive alumina ceramic workpiece specimen was investigated through different graphs. This investigation also helps to identify the effective range of process parameters. The experiments were performed by varying one parameter and keeping other parameters constant. The constant parameters were: electrolyte concentration = 120g/l, pulse on time (T_{on}) = 200 ms, pulse off time

(T_{off}) = 100 ms, inter electrode gap = 100 mm, tool feed rate = 0.1mm/min. and constant machining time = 30 min. The parameter DC supply voltage was varied from 10 to 110 V and feasibility experiments were carried out. Fig. 3 shows the variation of material removal rate with DC supply voltage during machining of non-conductive alumina ceramic workpiece specimen on fabricated ECSM set-up.

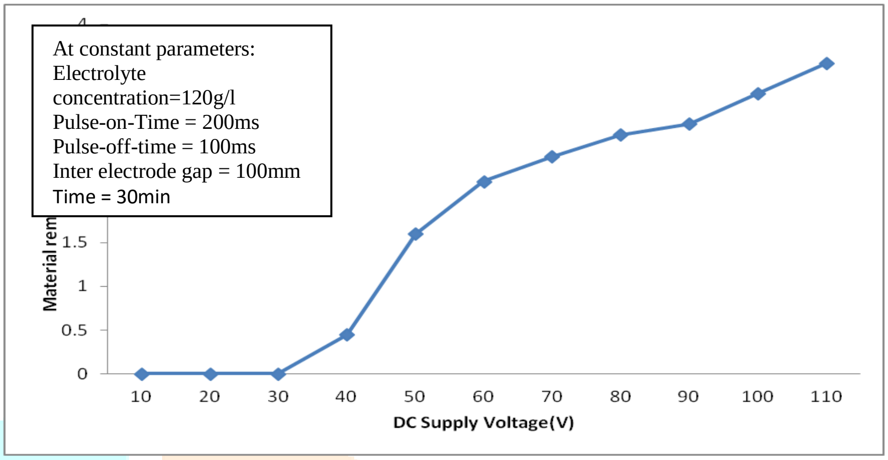

Fig. 3 Variation of material removal rate (MRR) with DC supply voltage (V)

From Fig. 3, it is clear that there was no machining i.e. no spark generation takes place during machining when machining operations were carried out at 10V to 40V DC supply voltage. Hence there were no material removals up to 40V supply. However, at 40V, spark generation was occurred without any material removal. When the supply voltage was further increased, there was increased in material removal (Fig.3).

Fig. 4 shows the variation of overcut (μm) with DC supply voltage (V). The machining operations were carried out with varying the parameter DC supply voltage (V) from 10 to 110V, keeping other parameters constant. The experiments were carried out at constant 120 g/l electrolyte concentration, 200ms pulse-on-time, 100ms pulse-off-time, inter electrode gap = 100 mm, tool feed rate = 0.1mm/min and constant machining time = 30 min. From Fig. 4, it is clear that initially there was no overcut because of no significant material removal takes place up to 40 V DC supply voltage. But beyond the 40 V DC supply voltage overcut start to increase with increase in DC supply voltage.

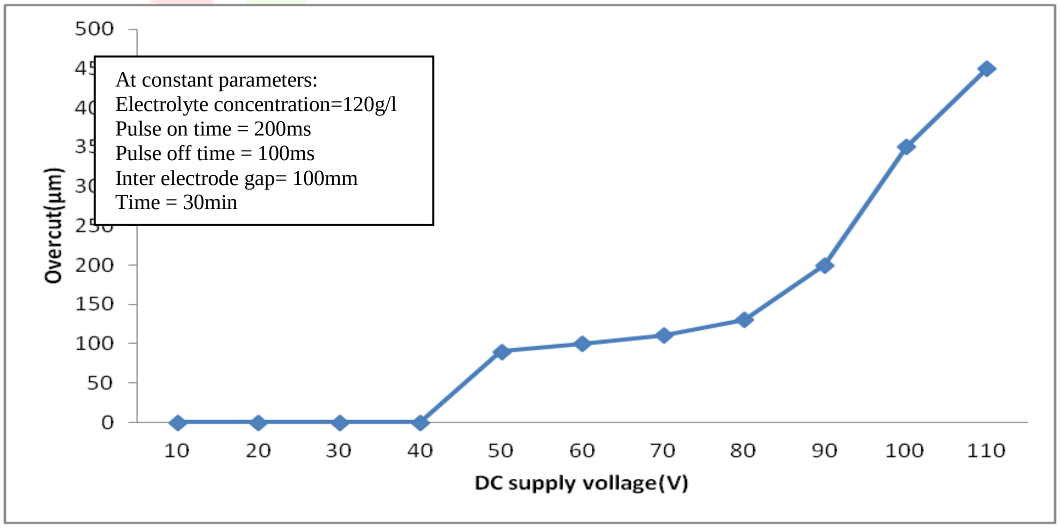

Fig. 4 Variations of overcut (μm) with DC supply voltage (V)

Fig. 5 shows the variation of taper with DC supply voltage during machining of non-conductive alumina ceramic workpiece specimen on fabricated ECSM set-up. The experiments were performed by varying one parameter and keeping other parameters constant. The constant parameters were: electrolyte concentration = 120g/l, pulse-on-time (T_{on}) = 200 ms, pulse-off-time (T_{off}) = 100 ms, inter electrode gap = 100 mm, tool feed rate = 0.1mm/min. and constant machining time = 30 min. The parameter DC supply voltage was varied from 10 to 110 V. From Fig. 5, it is clear that taper was very low at low supply voltage but it increases with increase in supply voltage. It is may be due to removal of more material by supplying high voltage during machining.

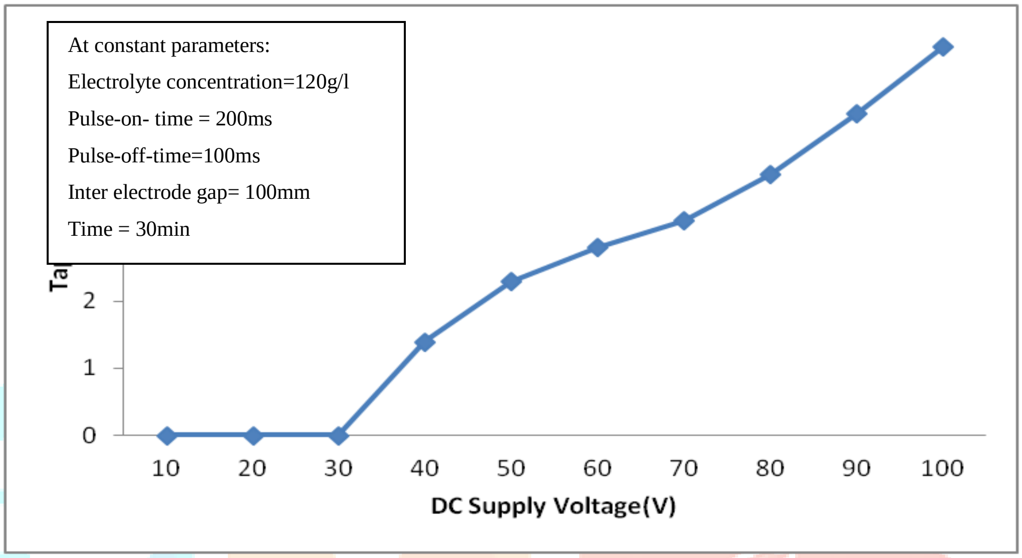

Fig. 5 Variations of taper (degree) with DC supply voltage (V)

Fig. 6 shows the variation of material removal rate (MRR) with pulse-on-time ($T_{on,}$ ms). This graph was drawn with the acquired results from the experiments carried out with varying the parameter pulse-on-time (Ton, ms) from 20 ms to 600 ms, keeping other parameters constant.

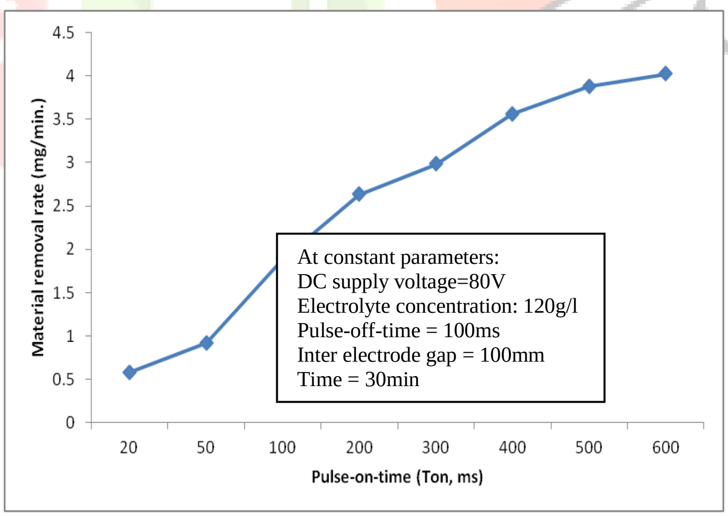

Fig. 6 Variation of material removal rate (MRR) with pulse-on-time ($T_{on,}$ ms)

The experiments were performed at constant 80V supply voltage, 120 g/l electrolyte concentration, pulse-off-time = 100 ms, inter electrode gap = 100 mm, tool feed rate = 0.1mm/min and continuous machining time = 30 min. From Fig. 6, it is clear that the material removal rate (MRR) is very low at low pulse-on-time but it increases with increase in pulse-on-time (Ton) up to a certain level i.e. 500ms. However, beyond that level there is no significant increment in MRR was identified.

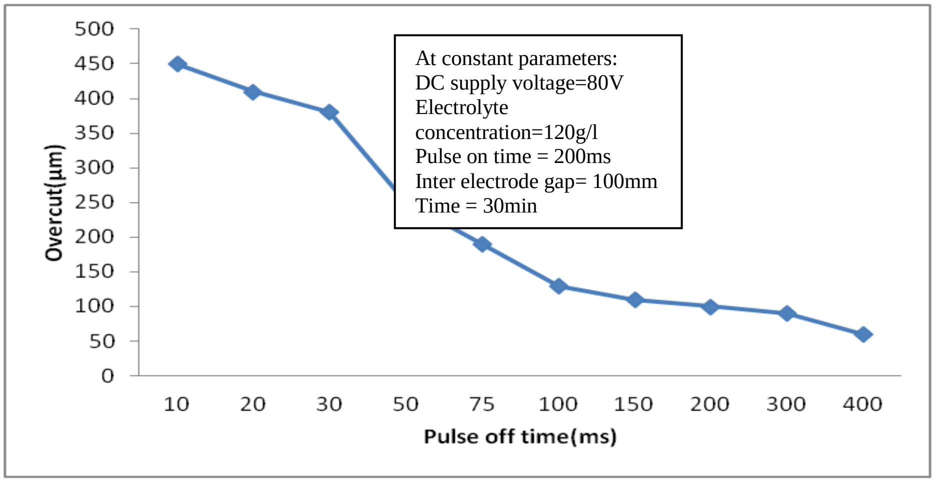

Fig.7 Variations in overcut (µm) with variation in pulse-off-time (T_{off})

Fig. 7 shows the variation in overcut (µm) with variation in pulse-off-time (T_{off}). This graph was drawn with the acquired results from the experiments carried out with varying the parameter pulse-off-time (Toff, ms) from 10 ms to 400 ms, keeping other parameters constant. The experiments were performed at constant 80V DC supply voltage, 120 g/l electrolyte concentration, pulse-on-time = 200ms, inter electrode gap = 100 mm, tool feed rate = 0.1mm/min and continuous machining time = 30 min. From Fig. 7, it is clear that the overcut is very high at low pulse-off-time but it decreases with increase in pulse-off-time (Ton). However at pulse-off-time beyond 300msec, the overcut was found is very low, it is due to the occurrence of very less material removal from the machining zone.

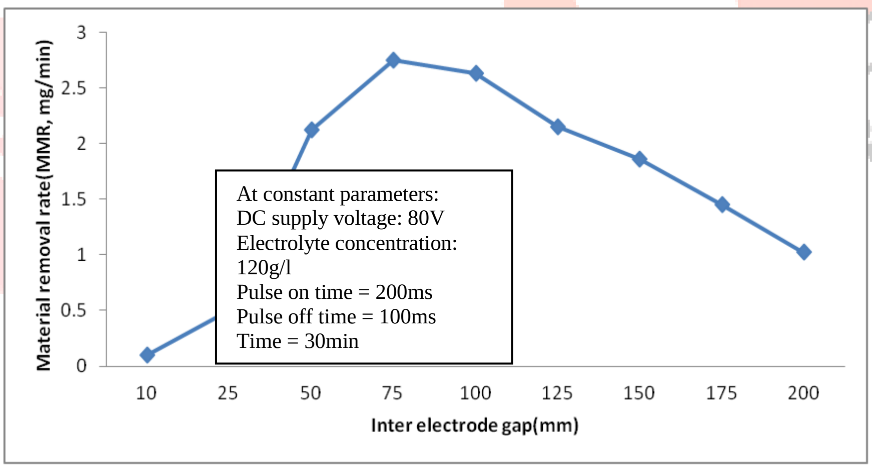

Fig. 8 Variation of material removal rate (MRR) with inter electrode gap (mm)

Fig. 8 shows the variation of material removal rate with variation of inter electrode gap (mm). This graph was drawn with the acquired results from the experiments carried out with varying the parameter inter electrode gap (IEG, mm) from 10 mm to 200 mm, keeping other parameters constant. The experiments were performed at constant 80V supply voltage, 120 g/l electrolyte concentration, pulse-on-time = 200 ms, pulse-off-time = 100 ms, tool feed rate = 0.1mm/min and for continuous machining time = 30 min. From Fig. 8, it is clear that the material removal rate (MRR) is very low at low inter electrode gap but it increases with increase in IEG (mm) up to a certain level. However, beyond that level there was again decrease in MRR was observed.

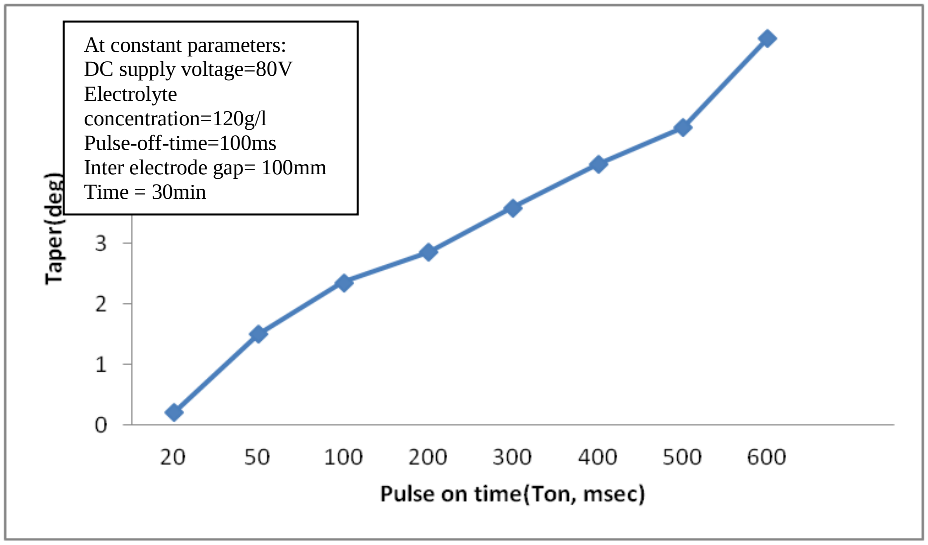

Fig.9 Variations of taper (degree) with pulse-on-time (T_{on})

Fig. 9 shows the variation in taper (degree) with variation in pulse-on-time (T_{on}). This graph was drawn with the acquired results from the experiments carried out with varying the parameter pulse-on-time (Ton, ms) from 20 ms to 600 ms, keeping other parameters constant. The experiments were performed at constant 80V DC supply voltage, 120 g/l electrolyte concentration, pulse-off-time = 100 ms, inter electrode gap = 100 mm, tool feed rate = 0.1mm/min and continuous machining time = 30 min. From Fig. 9, it is clear that the taper is very low at low pulse-on-time but it increases with increase in pulse-on-time (Ton). However at pulse-on-time beyond 500msec, the taper increases very rapidly, it is due to the occurrence of high material removes from the machining zone.

5. Conclusion

Based on the discussion and analysis of the experimental results during machining of non conductive alumina ceramic workpiece components on developed ECSM set-up, the important parameters along with their working range were identified. The identified parameters and their ranges are DC supply voltage 40V to 110 V, electrolyte concentration 40 g/l to 280 g/l, pulse-on-time 50 ms to 500 ms, pulse-off-time 50 ms to 300 ms, inter electrode gap 30 mm to 240 mm. The specified range of the machining parameters such as DC supply voltage, electrolyte concentration, pulse-on-time, pulse-off-time and inter electrode gap can be further utilized for the optimization of process parameters in order to machine the alumina ceramic components on developed ECSM setup.

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