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Experimental Investigation of the Effects of Electrode Shape on ECSM Performance during Machining of Alumina Ceramics

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ABSTRACT

Advanced ceramic material like alumina ceramic is continuously gaining the industrial acceptance in various applications such as cutting tools, electrical and thermal insulators, turbine blades, electronic devices etc. due to the superior properties of such ceramic. The alumina ceramic has different superior qualities such as high hardness, refractoriness, wear and corrosion resistance, high temperature withstands capability, low thermal coefficient of expansion etc. But machining of alumina ceramics is very difficult because of its brittleness and electrically nonconductive. Keeping in view, the present research work undertakes the machining study through design and fabrication of electrochemical spark machining (ECSM) set-up. Experiments were carried out with three different shapes of electrodes such as (i) solid circular shape of 0.8mm diameter (ii) hollow circular shape of 0.8mm external and 0.6mm internal diameter (iii) 0.8mm diameter solid circular tool with flutes i.e. drill type electrodes. The experimental results and SEM images of the machined holes revealed that the solid circular drill electrode is better electrode as compared to the others electrodes used for experiments for machining of hole on alumina ceramic workpiece specimens. The working range of different machining parameters was also identified on the basis of experimental results and analyzed the effects of ECSM set-up parameters on response characteristics.

***Keywords*--** ECSM, Electrode shape, Alumina, SEM images

I. INTRODUCTION

The electrically non-conducting advanced ceramic materials such as alumina are becoming increasingly popular in technologically advance industries such as aeronautics, automotive and nuclear industries because of their inert nature, high hardness, refractoriness, wear and corrosion resistance and high temperature strength [1]. But machining of such advanced ceramics by well known conventional and some of non conventional machining processes are difficult because of cutting tool wear, low material removal rate (MRR), relatively poor surface quality and micro cracks developed on the machined surface, it is due to high brittleness and electrically nonconductive of these materials. 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 [2, 3]. To meet the challenges in micro-machining domain and overcome the limitations of machining of nonconductive ceramics, different researchers have been attracted toward developing hybrid machining processes (HMPs), in which two or more processes are combined together for machining to enhance the advantages of constituent processes and hybrid machining processes can be effectively applied for machining of electrically nonconductive materials.

Electrochemical spark machining (ECSM) process can be employed for drilling of electrically non-conducting materials like alumina and borosilicate glass with good speed and accuracy [4]. ECSM is a process in which tool (i.e. cathode made of electrically conducting material) and workpiece i.e. anode (electrically non-conducting material like ceramics) are immersed in electrolyte. As anode is nonconductive thereby an auxiliary anode (usually used cupper plate at least 100 times more area over electrode) is used for machining of such nonconductive materials. Both the electrode and auxiliary anode are connected to the negative and positive terminals of the DC power supply. In this process, hydrogen bubbles are evolved at the cathode and the material removal is accomplished by establishing sparks across these bubbles in the vicinity of the work piece immersed in the electrolyte [5].

Machining of holes was one of the early applications of electrochemical discharge machining as explained by Kurafuji and Suda [6]. The ECSM can be used for machining of holes diameter ranges from 100 µm to 1000 µm, grinding, cutting and 3D micro structuring etc. Manna and Kundal [7] developed TW-ECSM set-up and utilized the developed set-up for experimental investigation for micro slicing of alumina ceramic. Authors investigated the parametric effects on material removal and spark gap width. Manna and Narang [8] explored the capabilities of ECSM by conducting the experimental investigation on the micro machining of electrically nonconductive e-glass–fibre–epoxy composite during electrochemical spark machining using specially designed square cross section with centrally 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. The shape of the tool has a strong influence on the geometry of the machined hole. Flat side wall shaped tool performed better as compared to cylindrical tools while machining the holes as reported by Eunice et al. [9]. Yang et al. [10] used spherical end shape tool i.e. electrode and claimed that the curved surface of the spherical tool reduces the contact area between the electrode and the workpiece, thus facilitating the flow of electrolyte to the electrode end and enables rapid formation of gas film, resulting generates better micro-hole. Wei et al. [11] presented the technique of electrochemical discharge machining (ECDM) gravity-feed drilling using micro-drills. They claimed that the micro-drilling tool can provides additional material removal by generating chips.

In view of the review of literature, it is clearly revealed that the electrode material and shape, and machining parameters such as DC supply voltage, electrolyte concentration, pulse-on-time, pulse-off-time and inter electrode gap have great influence on machining performance characteristics. However, some of the researchers worked on ECSM but still a lot of applied research in this area is required so as to explore the successful utilization of the process in the area of machining of non conductive ceramics. Keeping in view, the experiments were carried out to investigate the effect of tool electrode shape and other machining parameters on the performance characteristics i.e. material removal rate (MRR) and radial overcut during machining of alumina ceramic on developed ECSM set-up.

II. PLANNING AND EXPERIMENTATION

The experiments were carried out based on one factor at a time approach. The selection of parameters and their range (Table 1), and plan for experimentation were done based on the feasibility tests conducted on fabricated ECSM set-up. The three different shapes of stainless steel electrodes i.e. (i) solid circular shape of 0.8 mm diameter tool, (ii) hollow cylindrical shape of 0.8 mm external and 0.6 mm internal diameter tool and (iii) 0.8 mm diameter solid circular with flutes i.e. drill type electrode were selected for the experiments is shown in Fig. 1. The non conductive alumina ceramic and NaOH selected as workpiece specimens and electrolyte respectively. Fig. 2 shows the developed ECSM set-up used for machining of alumina ceramic.

Table1. ECSM machine parameters and their ranges selected for experiments

S. No.	Symbol	Machining parameters	Ranges	Units
1	A	DC supply voltage	40 to 110	V
2	B	Electrolyte concentration	40 to 280	g/l
3	C	Pulse-on-time ,T_{on}	50 to 500	ms
4	D	Pulse-off-time ,T_{off}	50 to 300	ms
5	E	Inter electrode gap	30 to 240	mm

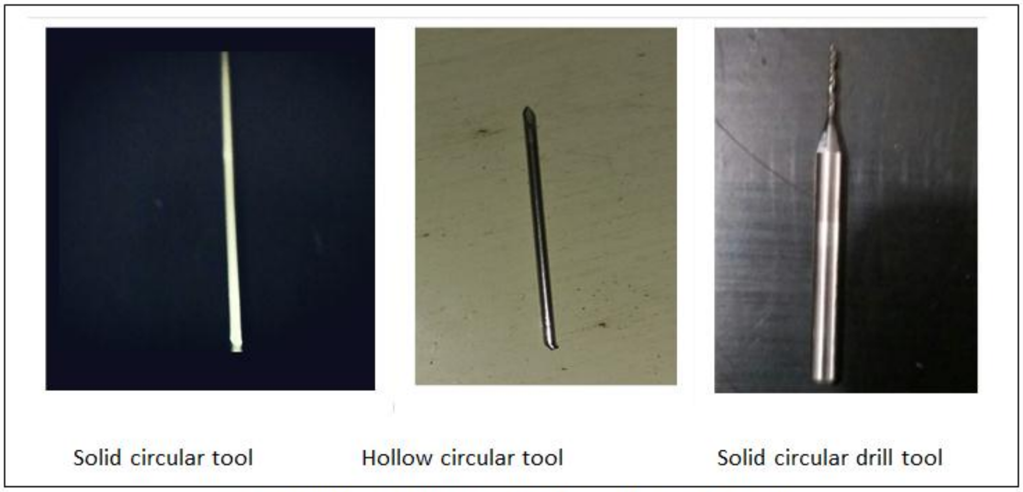

Fig. 1 Different shapes of tool i.e. electrodes used

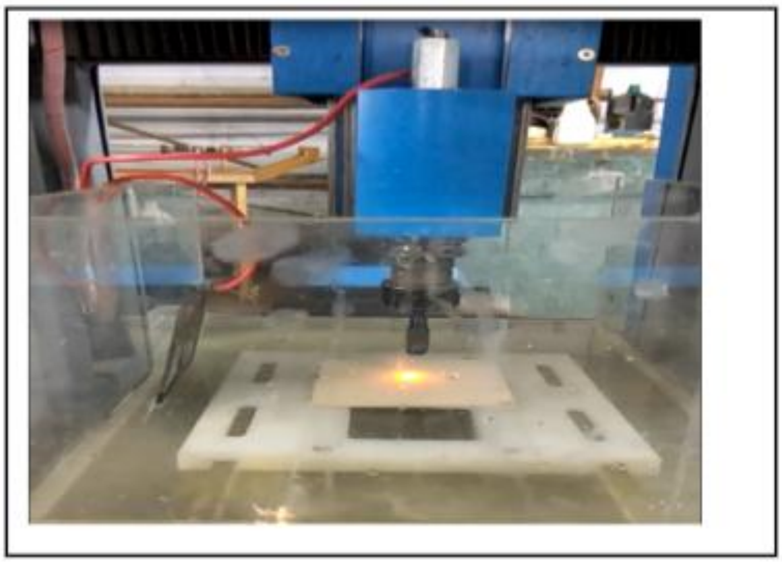

Fig. 2 Experiments carried out on developed ECSM set up

III. RESULTS AND DISCUSSION

As discussed earlier, experiments were carried out with the objective to study the effect of developed ECSM set-up parameters on machining response characteristic as well as to identify the best tool i.e. electrode shape for effective machining of alumina ceramic. The effect of various parameters on MRR and overcut during machining of alumina ceramic specimens with different shapes of electrodes were analyzed through various graphs, SEM images.

3.1 Effect of electrode shape and machining parameters on MRR

Fig.3 shows the variation of material removal rate (MRR) with DC supply voltage (V) during machining of electrically non conductive high-strength high-wear-resistant fabricated alumina (Al_2O_3) workpiece specimens on developed ECSM set-up. The experiments were carried out with variation of one factor keeping other constant. Fig. 3 graphs were drawn with utilized the acquired results from the experiments when experiments were carried out with varying supply voltage from 40V to 110V and at constant 150 g/l electrolyte concentration, 250 ms pulse-on-time ($T_{on,}$), 150 ms pulse-off-time ($T_{off,}$), 120 mm inter electrode gap, 0.1 mm/min tool feed rate, 0.3 l/min electrolyte flow rate and 30 min constant machining.

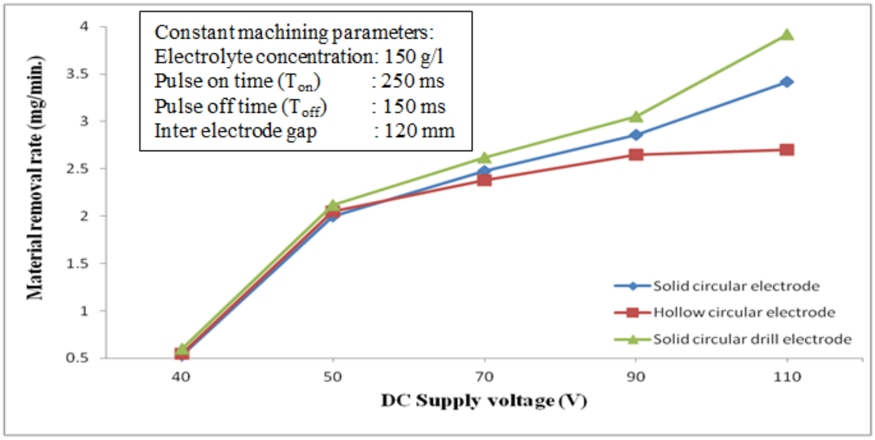

Fig. 3 Variation of MRR with DC supply voltage for different shapes of electrodes

From Fig. 3, it is clear that at lower values of DC supply voltages, the material removal rate was very low and almost same for three different shapes of tool electrodes used. But as the DC supply voltage was increased further, the MRR was also increased. This may be due to increase of DC supply voltage, the bubble formation increases which leads to increase the intensity of spark generation in the machining zone. It is also clear that the material removal rate is high for solid circular with flutes i.e. drill type electrode. The hollow circular electrode gives almost same MRR as solid circular electrode gives at low supply voltage.

Fig. 4 shows the variation of MRR with electrolyte concentration. From Fig 4, it is identified that the material removal rate increases with increase in electrolyte concentration. It is may be due to more ionic current generation in the machining zone at high value of electrolyte concentration. The same increasing trend was observed for all three shapes of electrodes, but material removal rate for the solid circular drill electrode was more as compared to other two shapes of electrodes. It is due to the availability and circulation of more electrolytes in the machining zone.

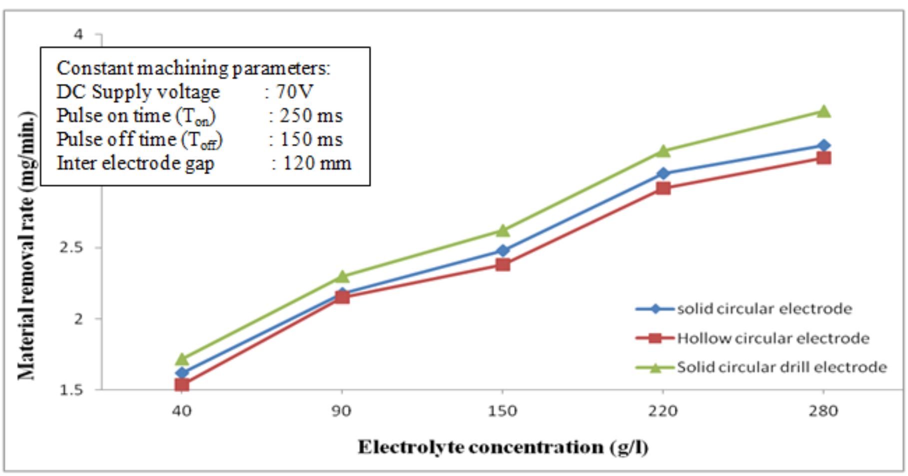

Fig. 4 Variation of MRR with electrolyte concentration for different shapes of electrodes

Fig. 5 shows variation of MRR with pulse-on-time ($T_{on,}$ ms). From Fig 5, it is found that the material removal rate increases with increase in pulse-on-time ($T_{on,}$ ms). When the small duration pulse was used for machining of alumina ceramic specimens, the spark was generated for the smaller period of time resulting into low material removal rate. As the pulse-on-time increases which increase the pulse duration time thereby spark generated for longer durations and hence the material removal rate increases. In case of circular tool with flutes, as the availability and circulation of electrolyte is more in the machining zone and spark is generated for longer durations at higher values of pulse-on-time, the material removal was more as compared to other two electrodes used for experiments. At high pulse-on-time, the MRR is sharply increases when machining operations were carried out with solid and hollow cylindrical shape electrodes.

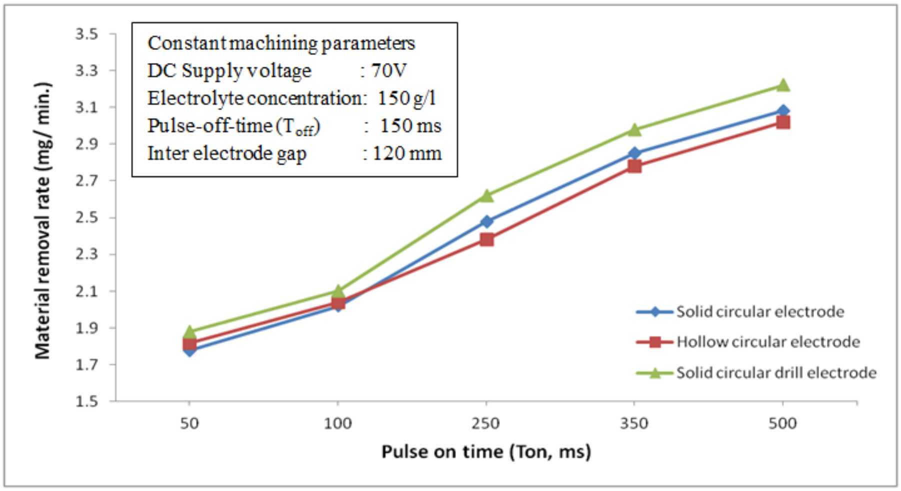

Fig. 5 Variation of MRR with pulse-on-time (T_{on}, ms) for different shapes of electrodes

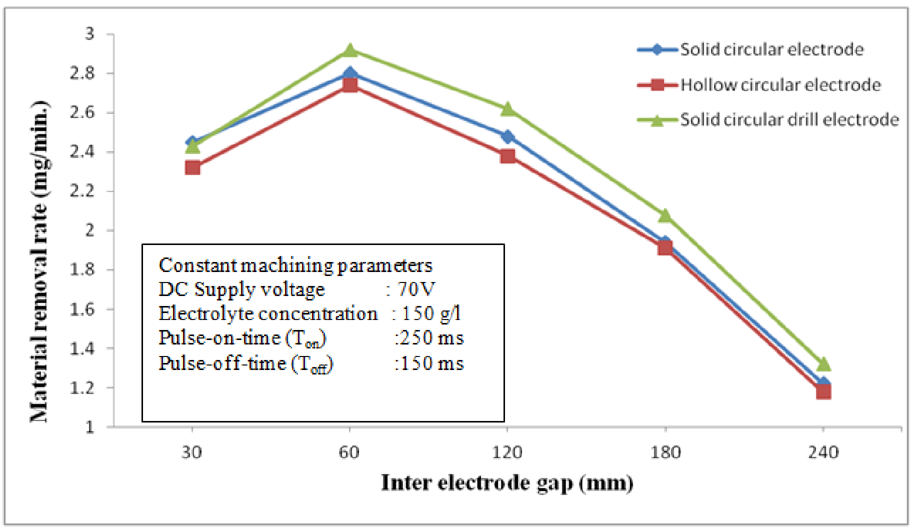

Fig. 6 Variation of MRR with inter electrode gap for different shapes of electrodes

Fig. 6 shows the variation of MRR with inter electrode gap during machining of electrically non conductive alumina (Al_2O_3) ceramic. From Fig. 6, it is clear that the variation of material removal rate (MRR, mg/min) with variation in inter electrode gap (IEG, mm) follows the similar fashion for all the three types of tool shapes of electrode. With increase of IEG from 30mm to 60mm, an increasing trend for MRR is identified but further increase in IEG i.e. beyond 60 mm IEG, the trend of MRR is declining in nature. As the inter electrode gap increases, it increases the resistance to current flow thereby decreases material removal rate. It is may be due to low electrochemical dissolution of material from the workpiece surface. The material removal rate at 60mm IEG was higher as compared to other setting values of IEG for all shapes of electrodes. However, the tool shape i.e. solid circular drill electrode was identified as best electrode for MRR (Fig.6)

3.2 Effect of electrode shape and machining parameters on overcut

Fig.7 shows the variation of overcut (µm) with DC supply voltage and it is depicted that the overcut increases with increase in DC supply voltage for all three shapes of electrodes. It is also clear that at lower value of applied voltage, the overcut was less for all the three shapes of electrodes. But the phenomenon of overcut becomes more predominant as value of applied voltage was increased. This may be due to the fact that at high DC supply voltage, the intensity of spark generation at the side walls of tool and in the machining zone are more, hence the more electrochemical dissolution takes place thereby increases overcut. But the value of overcut was low in case of solid circular with flutes electrode, it may be due to the formation of less bubbles and sparking at the tool tip and side walls of the tool.

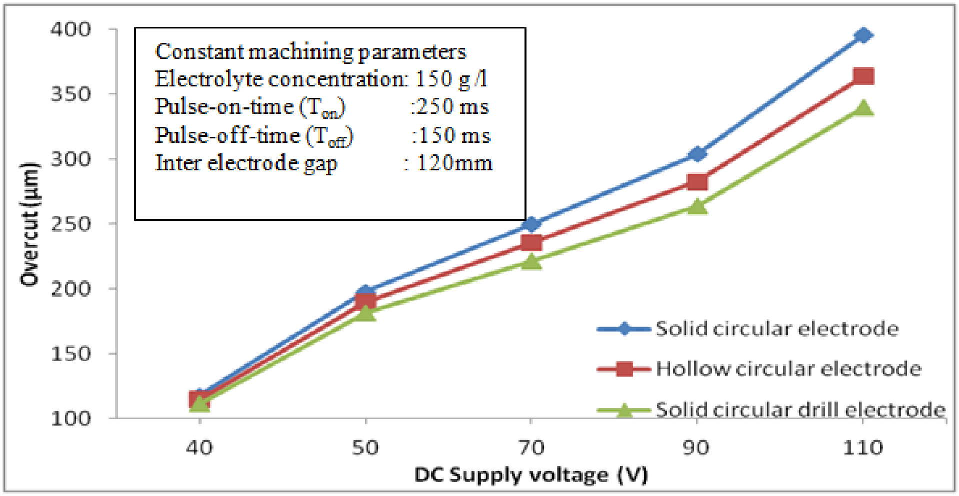

Fig. 7 Variation of overcut with DC supply voltage for different shapes of electrodes

It is clear from Fig.8 that overcut increases with increase in electrolyte concentration. With increase in electrolyte concentration, the charge carrier increases in the machining zone and hence the material also removes from the side walls of the holes already generated as a result increases overcut. Electrolyte concentration has an important effect for all three shapes of electrodes but overcut was found less in case of solid circular tool with flutes as compared to other shapes of electrodes at all levels of electrolyte concentrations.

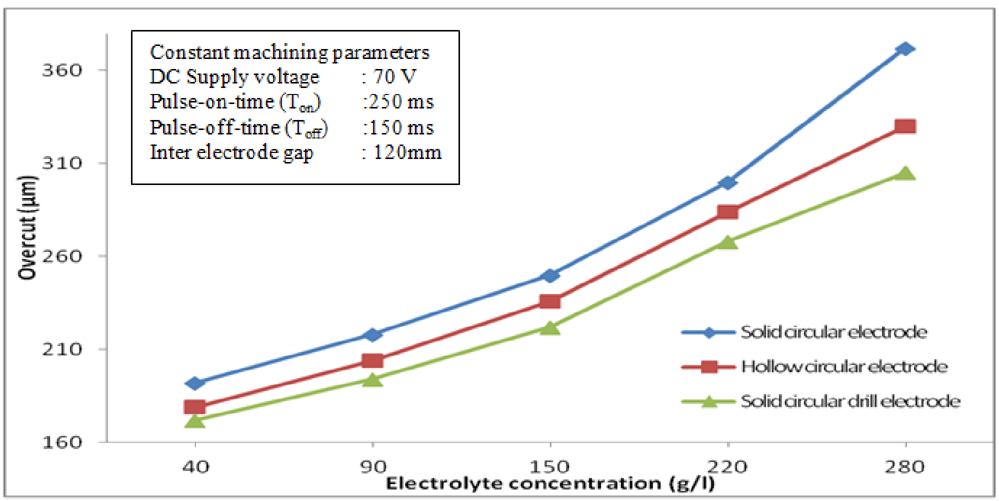

Fig. 8 Variation of overcut with electrolyte concentration for different shapes of electrodes

Fig. 9 shows the variation of overcut (µm) with pulse-off-time (T_{off}) and it is found that the overcut decreases with increase in pulse-off-time (T_{off}) for all three shapes of electrodes. With the increase of pulse off time, the current for the sparking in the machining zone is available for lesser durations resulting into less material removal from the entry of the hole as well as from the side walls of the machined hole thereby reduces overcut.

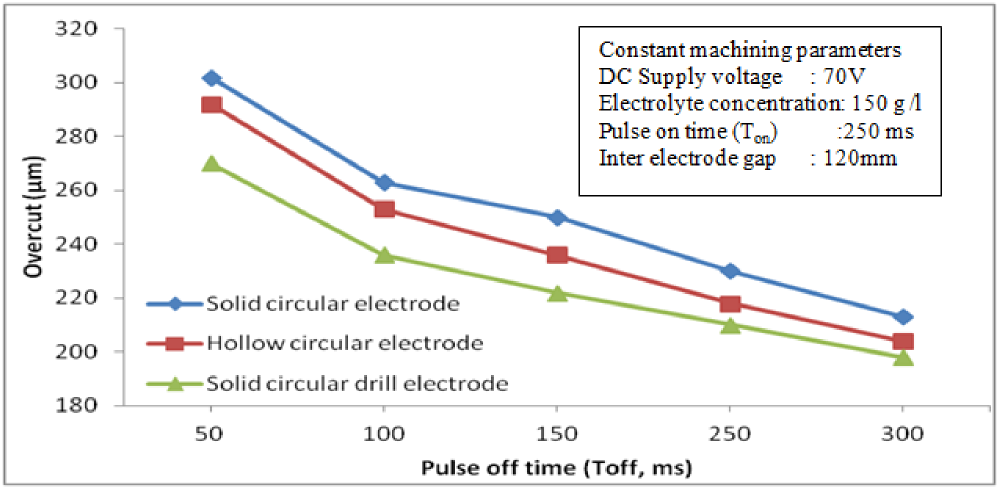

Fig. 9 Variation of overcut with pulse-off time (T_{off}) for different shapes of electrode

IV. ANALYSIS OF SEM IMAGES OF MACHINED HOLES

The SEM images of the machined holes were taken during experiments and analyzed for machined surface quality. Fig. 10 shows the SEM images of machined hole machined with solid circular drill electrode at 70 V DC supply voltage, 150 g/l electrolyte concentration, 250 ms pulse on time (T_{on}), 150 ms pulse off time (T_{off}) and 150 mm inter electrode gap. The machining quality was also improved in terms of hole diameter at entry and exit i.e. less overcut when machining was done with solid circular drill electrode over other electrodes.

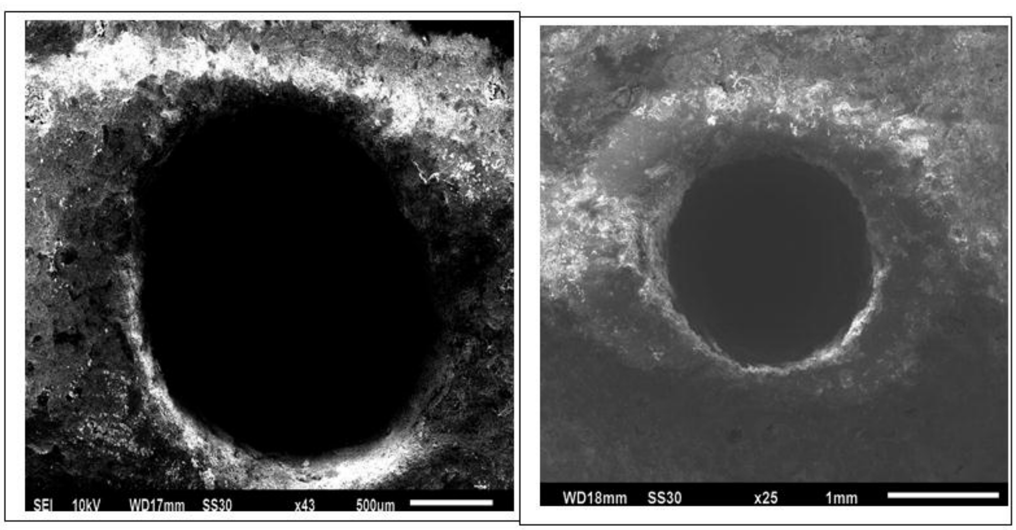

Fig. 5.10 SEM images of machined hole at 70V with (a) solid circular electrode (b) solid circular drill electrode.

V. CONCLUSION

The electrochemical spark machining process can be effectively used for machining of nonconductive alumina ceramic material. Based on the experimental results, SEM images and discussions, it is clear that the solid circular drill electrode is the best tool as compared to the other tools (i.e. electrodes used in the experiments) for machining of alumina ceramics. Solid circular drill electrode is recommended for machining of hole on alumina ceramic workpiece specimens. The high material removal rate is possible at high setting value of DC supply voltage, pulse-on-time, electrolyte concentration and moderate setting value of inter electrode gap. The overcut is comparatively low at high pulse-off-time and low DC supply voltage with low setting value of electrolyte concentration.

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