

Effect of Duty Ratio at Different Pulse Frequency during Hole Drilling in Ceramics Using Electrochemical Discharge Machining

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Abstract. The Electro Chemical Discharge Machining (ECDM) is a hybridization process of electro chemical and electric discharge machining, which is used for machining of hard, brittle and nonconductive materials. The present paper investigates the effect of duty ratio at different pulse frequency on the four process responses, i.e. material removal rate, depth of penetration, surface damage and heat affected zone of the hole drilled by ECDM. The requirements of a quality drilled hole are to have less surface damage and heat affected zone along with larger depth of penetration and material removal rate. The selected alumina ceramic (Al₂O₃) work piece material is widely used in hi-tech electrical apparatus. The results were characterized by optical microscope and analysed by using pulse wave forms of voltage with time. The results show that the effectiveness of pulse frequency varies according to the desired response characteristics. The research findings provide the most effective duty ratio for an improved quality of drilled hole in ceramics.

1 Introduction

Electro Chemical Discharge Machining (ECDM) was invented as 'electrical discharge drilling' in 1968 for producing micro holes in nonconductive materials such as glass, ceramic, etc. [1]. ECDM is a combination of the two non-conventional machining methods, namely; electro chemical machining (ECM) and electrical discharge machining (EDM) [2]. The common non-conventional methods used to fabricate the holes in nonconductive work pieces are abrasive jet machining and ultrasonic machining [3, 4]. However, the application of these processes are restricted due to poor material removal rate, high tool wear, poor surface finish and geometrical inaccuracy [4]. Therefore, ECDM is an alternative approach to machine the nonconductive work materials. The alumina ceramic is most widely used in high temperature electrical insulators and in other electrical applications due to higher strength, stiffness, high wear and corrosion resistance, high thermal stability and excellent insulation as compared to its counter materials. The subsequent section details some of the investigations conducted on variety of ceramics by various researchers.

It was investigated that material removal in ceramics occurred by etching of grains through high temperature electrolyte and melting [5]. Gas Filled Electro discharge Electro Chemical Machining (GFEECM) was developed to machine the ceramics [6]. The ECDM was used for drilling holes on non-conducting zirconium oxide ceramic components [7]. It was reported that effect of

tool tip with flat front and taper side wall provides the controlled and effective machining [8].

The literature revealed the need for accurate and precise machining of ceramics. In ECDM, the material is melted by thermal energy and removed by subsequent chemical etching [9, 10]. This thermal energy is transferred in the workpiece and creates the heat affected zone (HAZ). The HAZ results in cracks on the workpiece surface and distort the hole dimensions. The surface damage (SD) is unwanted material removal and losses the accuracy of drilled hole. Hence, reduction of the HAZ and SD with high material removal rate (MRR) and depth of penetration (DOP) are desirable to produce more accurate holes in ceramics. The HAZ was reduced in a pulse voltage supply, because the hole drilling takes place during the pulse-on-time of the cycle and the material cools during the pulse-off-time [11]. The present article investigates the results of increasing duty ratio at different pulse frequency on the MRR, DOP, SD and HAZ at desirable points of interest. From the results, a favourable machining condition with minimum SD and HAZ along with maximum MRR and DOP was reported.

2 Experimental Procedure

An experimental setup was developed in the laboratory [12]. The applied voltage was 65 V using DC pulse power supply. Rectangular pulse waves with a specific pulse width were supplied. The number of pulse cycles per unit time is pulse frequency. The ratio of 'pulse on

time' to total pulse cycle time (sum of pulse on time and pulse off time) is termed as duty ratio [11]. The voltage wave forms of pulses were recorded by Digital Storage Oscilloscope (DSO). The pulse frequencies are classified in four sets (in multiple of frequency from 1000 Hz to 1 Hz) according to pulse width as given in Table 1.

Table 1. Sets of Duty ratio According to Pulse Width and Pulse Frequency

Set	Pulse width		Pulse Frequency [Hz]	Duty ratio [%]
	Pulse on time [ms]	Pulse off time [ms]		
I (X1000 Hz)	0.1	0.1-0.04-0.01	5000-7000-9000	50-70-90
II (X100 Hz)	1	1-0.42-0.11	500-700-900	50-70-90
III (X10 Hz)	10	10-4.28-1.11	50-70-90	50-70-90
IV (X1 Hz)	100	100-42.85-11.11	5-7-9	50-70-90

The NaOH electrolyte with 20% wt/v concentration was used in the experiment at room temperature. A cylindrical stainless steel tool with diameter of 700 μm was used. The auxiliary electrode made of graphite was kept at a distance of 40 mm from tool. The workpiece was a 9 mm thick alumina ceramic (Al₂O₃) material.

The schematic of a drilled blind hole produced by ECDM is shown in Fig. 1. After drilling of the ceramic workpiece, the diameters of the top side of hole were measured as HAZ and SD using an optical microscope at 20X magnification. The HAZ was calculated as the difference in diameters of HAZ and SD, while the SD was the obtained by subtracting the tool diameter from diameter of SD. The DOP was measured by a dial gauge (Mitutoyo). Three specimen were drilled at constant parametric setting. Each experiment was performed for 5 minutes and average results of responses are presented herein.

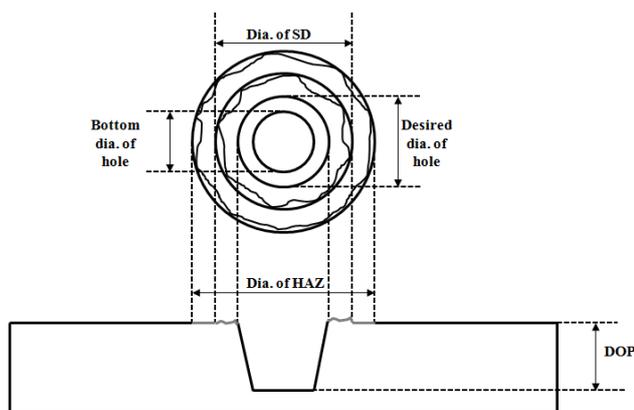


Figure 1. Schematic of the Drilled Hole

3 Result and Discussion

Effect of duty ratio was experimentally investigated on ceramic work material at four sets of pulse frequency. The experimental results revealed that the magnitude of all response characteristics i. e. MRR, DOP, SD and HAZ increased with the increase in duty ratio as shown in Figure 2 (a), (b), (c), and (d).

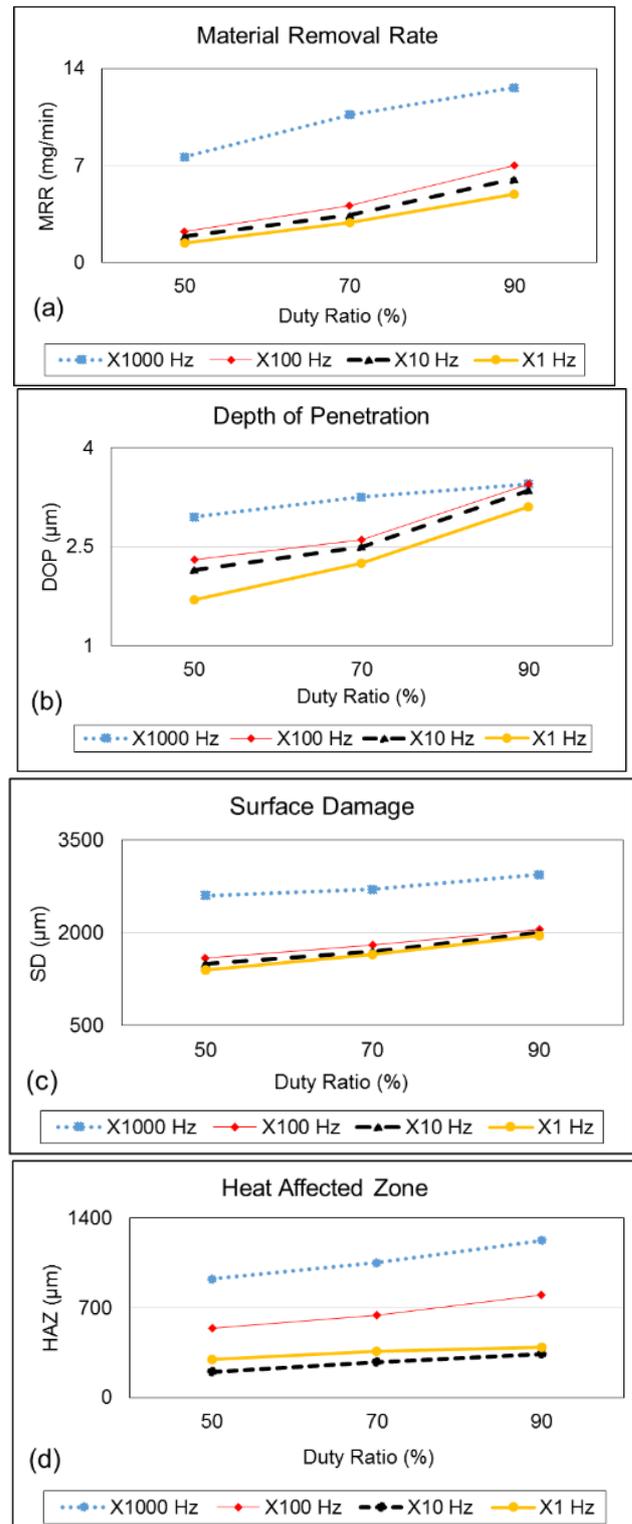


Figure 2. Effect of Duty Ratio at Different Pulse Frequency on Responses

The reason attributed is that the increase in duty ratio, increases the proportion of voltage applied time (pulse on time). Therefore, duration of thermal energy supply increased with increase in duty ratio. The maximum MRR, DOP, SD and HAZ were observed at 90% duty ratio in set I as shown in Fig. 2 (a to d)). It is evidenced to the high switching frequency as observed from pulse wave form in Fig. 3 (a) and side discharge [12, 13]. The minimum SD was at 50 % duty ratio, which is almost equal in set II, III and IV (Figure 2-c). It occurs because the effect of pulse off time and pulse on time is equal at this point. It means both pulse width plays equal role as shown in Fig. 3 (b). But HAZ was higher in set-IV as compared to set III at 50% duty ratio. It seems that longer pulse off time allows to flow the heat in the workpiece during pulse on time sufficiently in set-IV, while in set-III, the pulse off starts to play its role before the pulse on tries to propagate in the workpiece. The hole drilled with minimum HAZ with microscopic image and pulse wave form are shown in Fig. 3 (b).

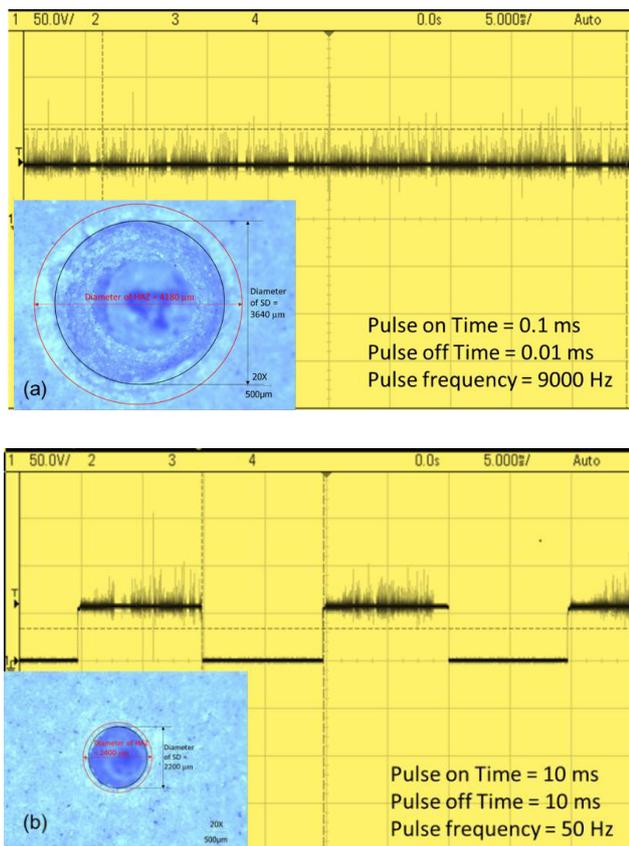


Figure 3. Pulse Wave Forms and Drilled Hole (a) at Maximum MRR Condition (b) at Minimum HAZ Condition

4 Conclusion

The holes were drilled at various pulse frequencies. The pulse width decides the frequency in a pulse power supply. All the response characteristics were found increased with increase in duty ratio. However, in order to get accurate and more precise holes with minimum SD and HAZ, compromise is required with MRR and DOP. Therefore, it is concluded that frequencies in multiples of

X10 Hz are recommended for minimum HAZ and SD, while the frequency in multiples of X1000 Hz is preferable for maximum MRR and DOP for drilling of holes in alumina ceramic work material. Results of frequencies in multiples of X100 Hz, X10 Hz and X1Hz are very close for the MRR, DOP and SD.

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