Proceedings of 10th International Conference on Precision, Meso, Micro and Nano Engineering (COPEN 10)
December 07 – 09, 2017, Indian Institute of Technology Madras, Chennai – 600 036 INDIA

Electrochemical Discharge Micro-Machining of Glass for Different Types of Micro-channel

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Abstract

Since 1968 electrochemical discharge machining played a great role in the field of non-conventional machining area. Therefore, this paper includes the basic experimental results of micro-profile generation like micro-channel, micro-slot etc. The experimentations have been carried out on the silica glass by using a newly developed micro-ECDM set-up. This paper also deals with the effects of different parameters like applied voltage (V), electrolyte concentrations (wt%), pulse frequency and duty ratio on different machining performance characteristics such as machining rate (MR) as a form of material removal rate (MRR), Overcut (OC) from width of cut (WOC) , surface roughness (SR)(R_a) and heat affected area (HAZ) after micro-profile generation on electrically non-conducting glass and a comparative study has been performed for those machining criteria using direct as well as reverse polarity. From the parametric analyses it is observed that applied voltage, electrolyte concentration and duty ratio have more significant effects on machining rate as well as heat affected zone.

Keywords: Micro-ECDM, Reversed polarity, MR, WOC, HAZ, Surface Roughness (R_a), Micro-slot, Micro-profile, Micro-channel.

1. INTRODUCTION

Electrochemical Discharge Micro-machining process is involved to cut micro-channel as well as profile, micro-slot and micro-drilling on non-conducting materials. Bhattacharyya *et al.* [1] showed that the material removed by the combined effect of electrochemical (EC) reaction and electrical spark discharge (ESD) action. Sarkar et al. [2] illustrated that the quality of the micro-holes on advanced ceramics during micro-drilling mainly depended on the applied voltage and electrolyte concentration. Gupta *et al.* [3] illustrated that the pulse duration has a great effect to achieve better control on quality characteristics and aspect ratio of glass material machined by ECDM process. Hajian *et al*. [4] demonstrated that the machined surface will be smoother for the lower concentration of electrolyte and higher machining voltage, so the machining depth will increase using magnetic field. Saranya *et al.* [5] exposed the electrical and 2D machining characteristics of ECDM process using a dynamic cylindrical tool electrode. Mallick *et al.* [6] illustrated the effects of applied voltage, electrolyte concentration and inter electrode gap on material removal rate, machining depth, overcut and heat affected zone. Tang *et al*. [7] used side insulated tool with proper diamond coating to prevent the side wall discharge and achieved better surface integrity. This paper deals with the effects of different parameters like applied voltage (V), electrolyte concentrations (wt%), pulse frequency and duty ratio on material removal rate (MRR), Overcut (OC) surface roughness (SR) (R_a) and heat affected area (HAZ) after micro-profile generation on glass and a comparative study has been performed for those machining criteria using direct as well as reverse polarity for different types of μ-channels.

2. EXPERIMENTATION

To fulfil the objectives of this research work, the process parameters such as machining voltage (35-55V), duty ratio (45-65%), pulse frequency (200-1000Hz), electrolyte concentration (10-30wt%) with fixed inter-electrode gap (40mm) have been chosen. During experimentation stagnant NaOH electrolyte solution and stainless steel μ-tool of 250 μm diameter were used. Each experiment was conducted by varying one variable at a time within its range and keeping other parameters fixed at their lowest levels. The indigenously designed and developed set-up includes various sub-systems and is shown in figure 1. Feeding to the job is given by spring feed mechanism while tool does not move in downward direction during experiments but revolves around a template, which is design according to shape of the desired profile. Metler Toledo weighing balance, Leica measuring microscope. and Mitutoyo 178-561-02A Surface Roughness Tester were used for measuring different responses.

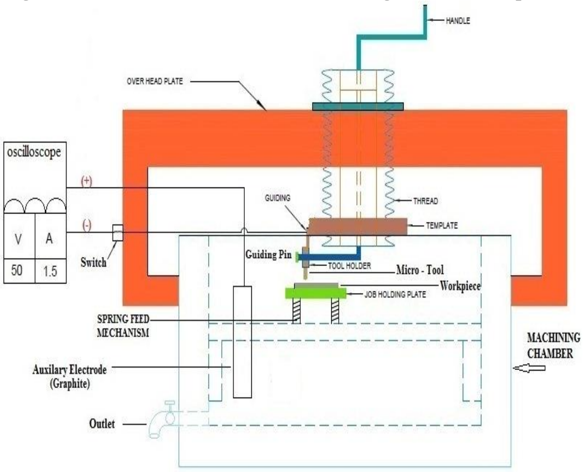


Fig. 1 Schematic diagram of μ-ECDM set-up

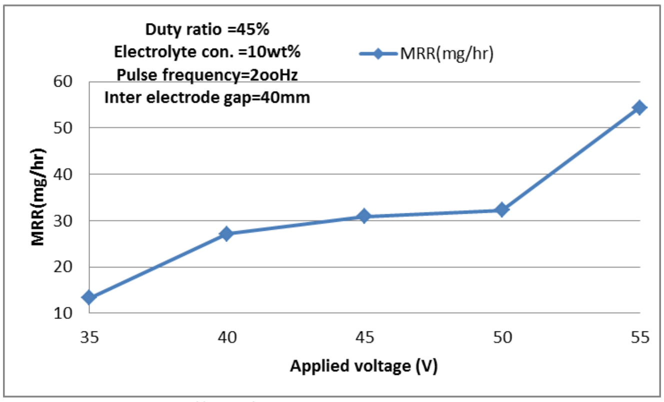
3. RESULTS AND DISCUSSION

3.1 Influences of Process Parameters on Material Removal Rate (MRR)

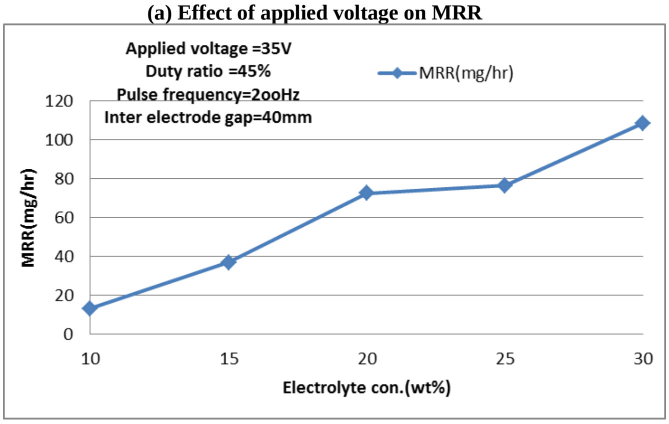
The influences of applied voltage, electrolyte concentration, pulse frequency and duty ratio on material removal rate for fixed inter-electrode gap (40mm) when micro-channel is cut on glass using NaOH electrolyte are shown in figure 2 (a) - (d) respectively. These figures show that the material removal rate for NaOH electrolyte solution increases with the increase of applied voltage, electrolyte concentration and duty ratio but decreases with increase of pulse frequency. Figure 2 (a) and (b) reveal that material removal rate is high for 55 V and 30 wt%

ISBN: 978-93-80689-28-9

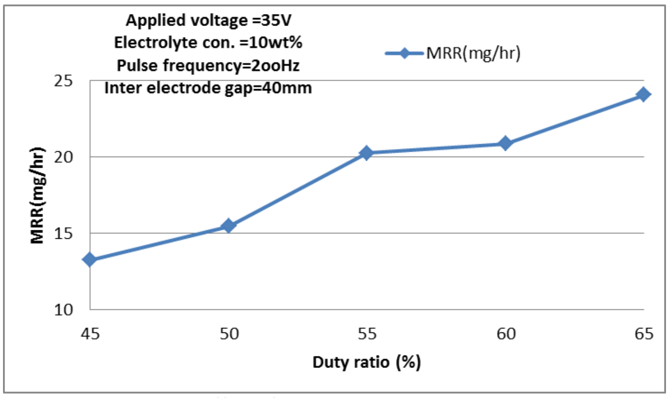
electrolyte concentration respectively. Also MRR increases with increase of duration of ON-time, which increases with duty factor. As the discharge duration increases, the removal rate increases since the temperature of the glass channel rises. MRR falls down with increase of pulse frequency because the duration of the discharge increases as the frequency decreases, even though the total time that voltage is applied stays the same. Figure 2 (c) shows that material removal rate will be almost same for the pulse frequency of 800 and 1000 Hz. At 65% duty ratio and 200 Hz frequency MRR is found to be higher as shown in figure 2 (c) and (d) respectively.



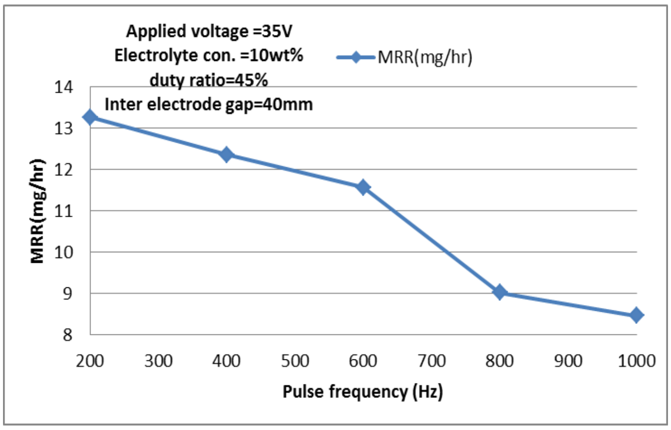
(a) Effect of applied voltage on MRR



(b) Effect of electrolyte concentration on MRR



(c) Effect of duty ratio on MRR

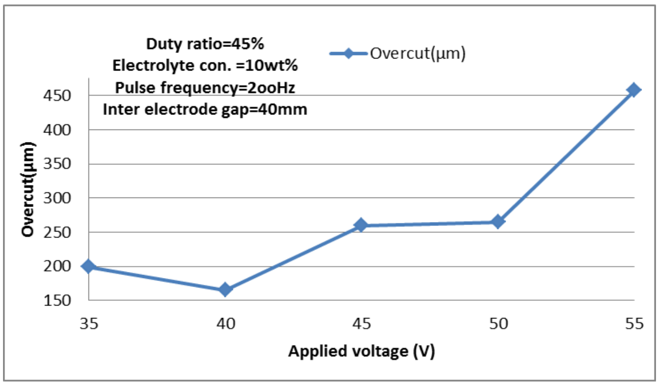


(d) Effect of pulse frequency on MRR

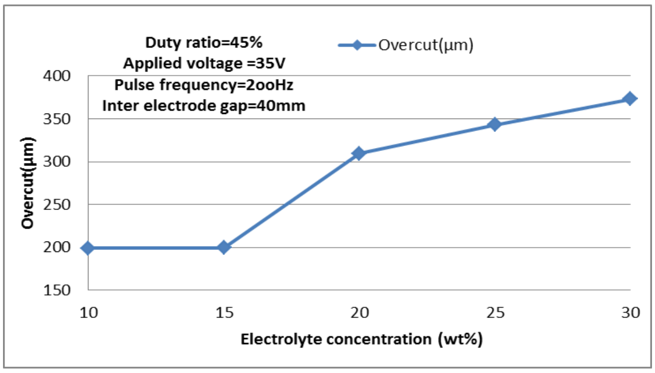
Fig. 2 (a) - (d) - Effects of different process parameters on Material Removal Rate (MRR)

3.2 Influences of Process Parameters on Overcut (OC)

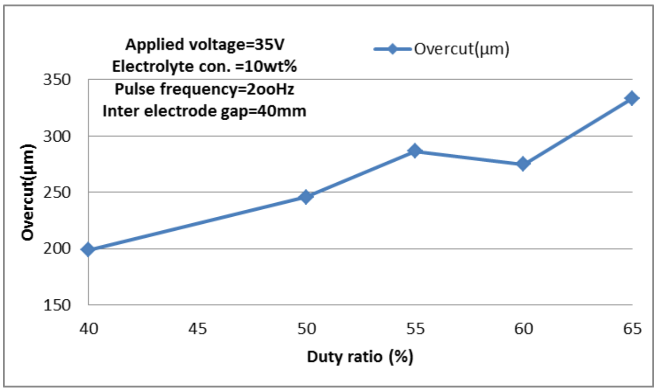
Overcut is an undesirable characteristic in case of machining operations. In every machining operation, the desirable condition is to minimise overcut or avoid overcut if possible. In the present work, overcut has also been observed with varying the input process parameters. Figs. 3 (a) and (b) exhibit the influences of applied voltage and electrolyte concentration respectively on overcut using NaOH as electrolyte. Generally, rate of sparking increases with the increase of both applied voltage and electrolyte concentration and consequently increases not only MRR but also width of cut due to side wall sparking from the tool electrode and thereby increases overcut. Figs. 3 (c) and (d) exhibit the variation of overcut with varying duty ratio and pulse frequency respectively using NaOH as electrolyte. Overcut increases with increase of duty ratio and decreases with increase of pulse frequency. One possible reason is that the discharge gets more powerful because the current density on the tools side surface increases.



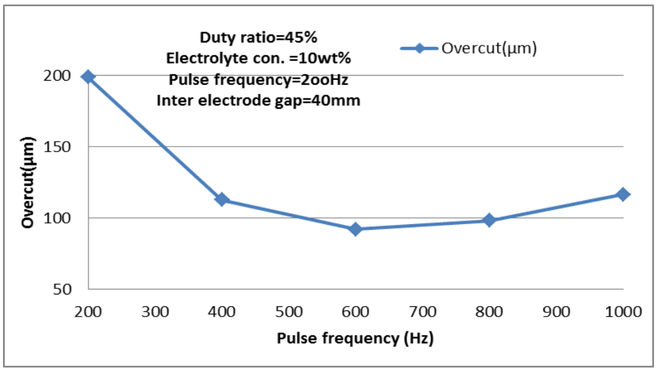
(a) Effect of applied voltage on OC



(b) Effect of electrolyte concentration on OC



(c) Effect of duty ratio on OC

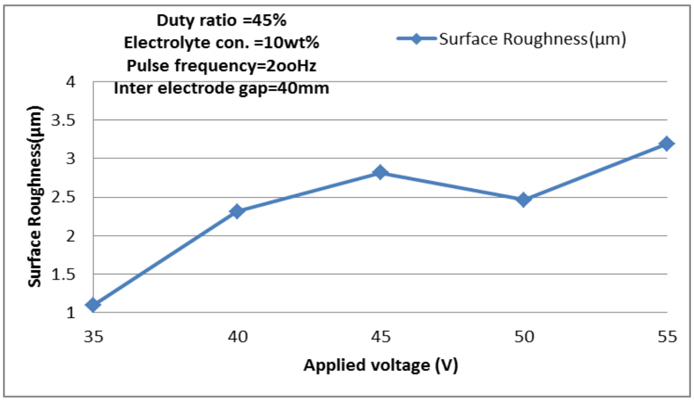


(d) Effect of pulse frequency on OC

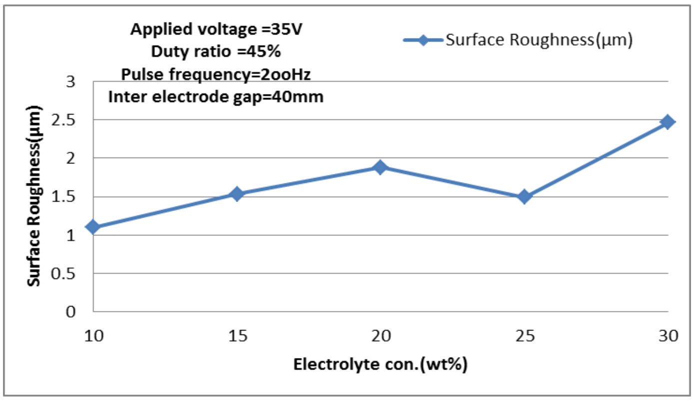
Fig. 3 (a) - (d) - Effects of different process parameters on Overcut (OC)

3.3 Influences of Process Parameters on Surface Roughness

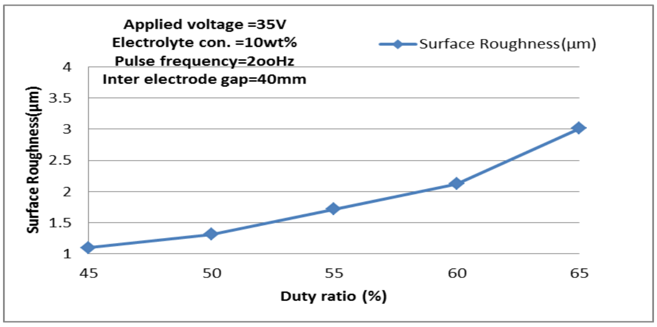
The influences of applied voltage, electrolyte concentration, duty ratio and pulse frequency on average surface roughness (R_a) for fixed inter-electrode gap are shown in figure 4 (a)-(d) respectively when micro-channel is cut on glass using NaOH as electrolyte. From the Figs. 4 (a), (b) and (c) it is clear that SR increases as voltage and duty ratio is increased due to increase in sparking rate but it decreases only at 50 volt, 25% electrolyte concentration and 55% duty ratio. Large amount of heat is produced into the machined channel during sparking and as a result, HAZ area increases and makes irregularities on the surface of the workpiece that increased surface roughness of the micro-channel. If the rate of sparking is continuous and stray sparking is less, better surface finish may be found. From the figure 4 (d) it is observed that if pulse frequency is increased, initially surface roughness is decreased because pulse on-time is decreased since the rate of sparking and stray sparking are reduced. But at higher pulse frequency, it is very difficult to control the continuous sparking that causes irregularities on the machining surface. So, after that surface roughness is increased.



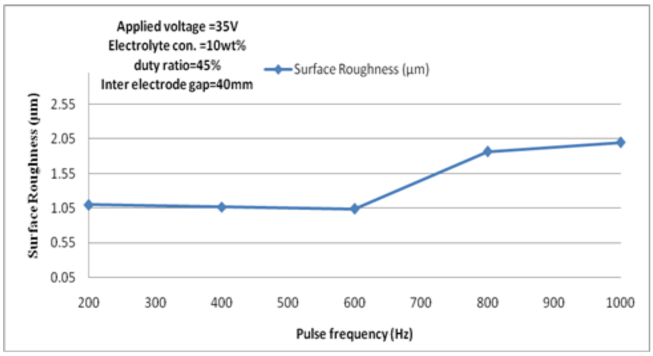
(a) Effect of applied voltage on Surface Roughness



(b) Effect of electrolyte concentration on Surface Roughness



(c) Effect of duty ratio on Surface Roughness



(d) Effect of pulse frequency on Surface Roughness

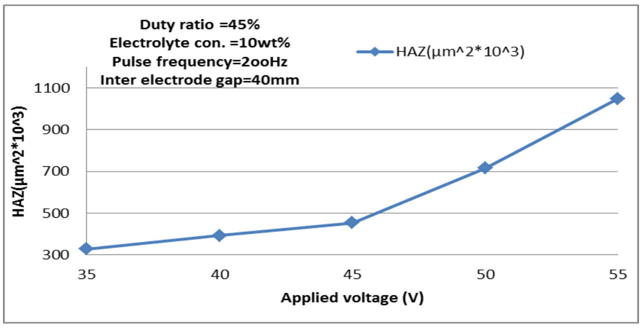
Fig. 4 (a) - (d) Effects of different process parameters on Surface Roughness

3.4 Influences of Process Parameters on Heat Affected Zone (HAZ)

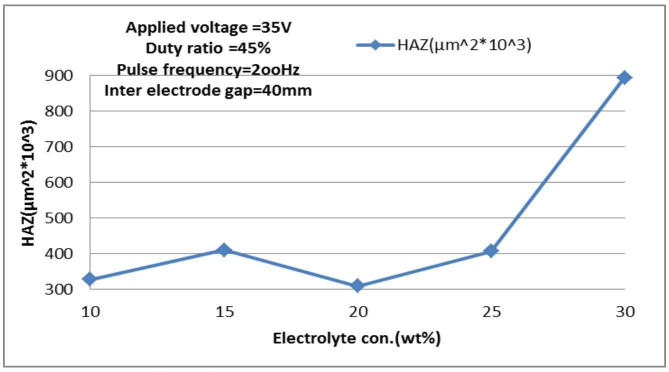
Figure 5 (a) and (b) show the influences of applied voltage and electrolyte concentration on heat affected zone (HAZ) area. In ECDM process a large amount of heat is generated during the machining of a glass material. A portion of this heat is radiated to atmosphere, some is lost to the electrolyte by convection and remainder is conducted to the work piece. The main reason behind the HAZ around the machined profile is due to the heat energy conducted to the work piece. It is observed from Fig. 5 (a) and 5 (b) that HAZ area increases almost gradually with increase of applied voltage and electrolyte concentration and it becomes higher at 55 V and 30 wt% electrolyte concentrations. Variations of HAZ area with pulse frequency and duty ratio are shown in Figure 5 (c) and (d) respectively. It is obvious from the figures that initially HAZ area increases and then it decreases with frequency whereas it increases with duty ratio after 55% of duty ratio.

3.5 Comparative Studies on MRR, OC, HAZ and R_a using Direct and Reverse Polarity

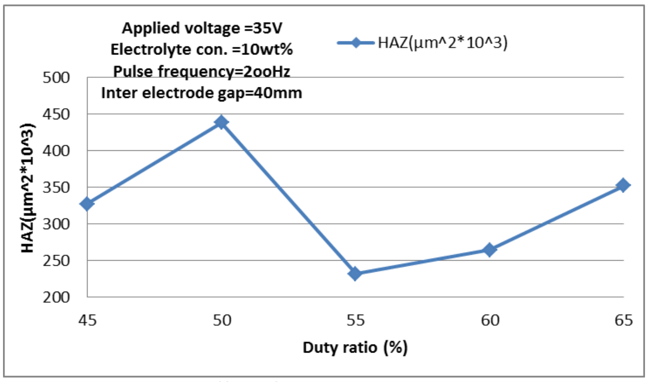
A comparative study for MRR, OC, HAZ and surface roughness has been carried out between direct polarity and reverse polarity using NaOH as electrolyte for fixed electrolyte concentration of 10 wt%, applied voltage of 35 V, pulse frequency of 200 Hz and duty ratio of 45 %. It is clear from Fig. 6 that MRR, OC, HAZ is very high in direct polarity than reverse polarity but surface roughness is high at reverse polarity and material removal is 2.25 times more at direct polarity than reverse polarity. Figure 7 shows types of different micro-channels cut on glass at 50Volt, 600Hz pulse frequency, 25wt% electrolyte concentration, 55% duty ratio. By this set-off experiment 1500µm machining depth is achieved. HAZ is found more for curved channel compared to straight and Y-shaped channels. Also, the width-of-cut of micro-channels is comparatively uniform for straight channel. This may be due to uniform sparking from the side wall of channel.



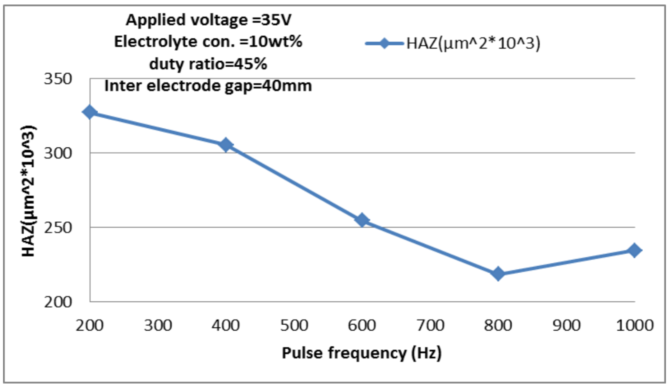
(a) Effect of applied voltage on HAZ



(b) Effect of electrolyte concentration on HAZ



(c) Effect of duty ratio on HAZ



(d) Effect of pulse frequency on HAZ

Fig. 5 (a)-(d) Effects of different process parameters on Heat Affected Zone (HAZ)

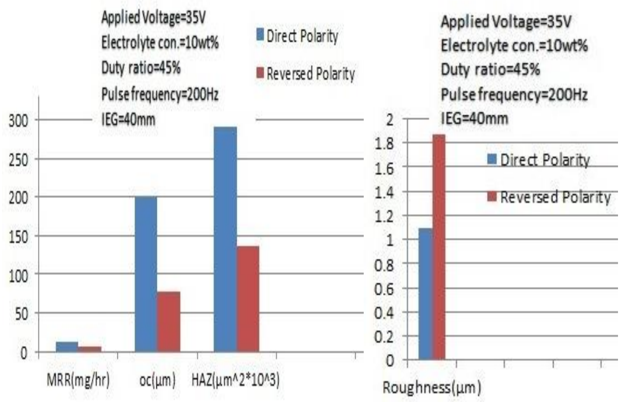
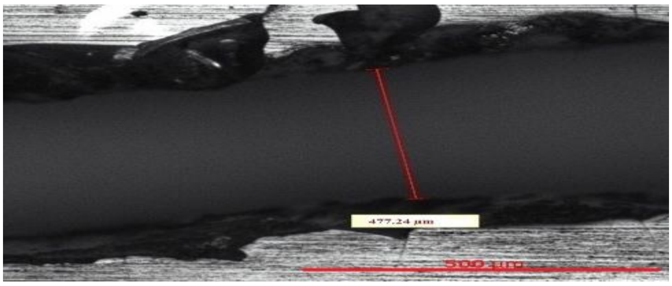
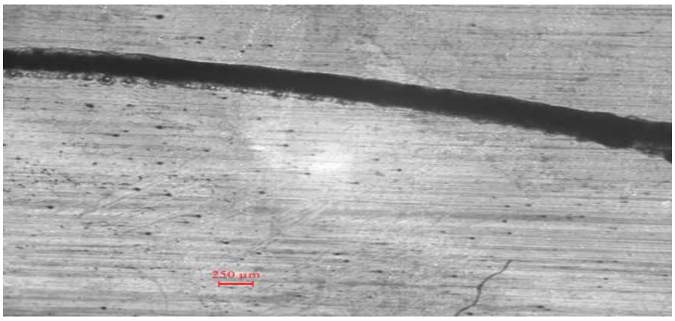


Fig.6 Comparative Studies on MRR, OC, HAZ and R_a using Direct and Reverse Polarity



(a) Optical microscopic image of micro-channel of 1500µm machining depth at 50Volt, 600Hz pulse frequency, 25wt% electrolyte concentration, 55% duty ratio



(b) Optical microscopic image of curved micro-channel cut at 50Volt, 600Hz pulse frequency, 25wt% electrolyte concentration, 55% duty ratio

(c) Photographic view of Y-shaped micro-channel cutting at 50Volt, 600Hz pulse frequency, 25wt% electrolyte concentration, 55% duty ratio

Fig. 7 (a)-(c) Different types of Micro-channel cut on Glass

4. CONCLUSIONS

From the present research work it is cleared that MRR increases with the increase of applied voltage, electrolyte concentration, duty ratio but decreases with pulse frequency when NaOH electrolyte is used for cutting different types of µ-channels on glass with micro-ECDM process. Overcut always increases with increase of applied voltage but it decreases with increase of pulse frequency up to 600Hz. HAZ area increases with increase of applied voltage and is lower at 55% duty ratio. Initially HAZ area decreases with increasing pulse frequency upto 800Hz. Surface roughness is increased when voltage, duty ratio and electrolyte concentration are increased and better surface finish is obtained at 50V, 600Hz, 45%, 25wt%. Direct polarity is found better for µ-channelling on glass.

References

[1] Bhattacharyya, B.; Doloi, B.; Sorkhel, S.K., "Experimental investigations into electrochemical discharge machining (ECDM) of non-conductive ceramic materials", *Journal of Materials Processing Technology*, **95**, (1999), 145-154.

[2] Sarkar B.R.; Doloi B.; Bhattacharyya B, "Experimental investigation into electrochemical discharge micro drilling on advanced ceramics", *International Journal of Manufacturing Technology and Management*, **13** (2/3/4), (2008) 214 -225.

[3] Gupta, P.K.; Dvivedi, A.; Kumar, P. "Effect of Pulse Duration on Quality Characteristics of Blind Hole Drilled in Glass by ECDM", *Materials and Manufacturing Processes*, **31**, (2016), 1740-1748.

[4] Hajian, M.; Razfar, M.R.; Movahed, S, "An experimental study on the effect of magnetic field orientations and electrolyte concentrations on ECDM milling performance of glass", *Precision Engg*., **45**, (2016) 322-331.

[5] Saranya, S.; Nair, A.; Ravi Sankar, A., "Experimental investigations on the electrical and 2D-machining characteristics of an electrochemical discharge machining (ECDM) process", *Microsystem Technologies*, **22**, (2016), 1-9.

[6] B. Mallick; B.R. Sarkar; B. Doloi; B. Bhattacharyya," Analysis on Electrochemical Discharge Machining during Micro-channel Cutting on Glass" *Int. J. of Precision Technology*, **7**, (2017), 1, 32-50.

[7] W.Tang, X.Kang and W. Zhao, "Enhancement of electrochemical discharge machining accuracy and surface integrity using side-insulated tool electrode with diamond coating" *Journal of Micromechanics and Micro engineering*, , **6**, 2017, 065013 (11pp).