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Effect of High-Speed Tool Rotation on Electrochemical Discharge Engraving

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Abstract

Composites and glass have been used in different fields of engineering like micro-electro mechanical system (MEMS), aerospace industry and biomedical applications. Composites and glass material are generally machined by using different nontraditional machining methods like laser beam machining (LBM), abrasive jet machining (AJM) and ultrasonic machining (USM). Electrochemical discharge machining (ECDM) is another promising technique to machine a glass and composite material. Electrochemical discharge machining (ECDM) is a hybrid machining process. In the present work, high-speed ECDM engraving on composite and glass material is conducted and the results of this machining process are presented. A conically shaped tungsten carbide tool of diameter 500μm has been used for experimentation and KOH is used as an electrolyte solution. The process parameters like voltage, electrolyte concentration, tool rotation speed and feed rate are studied in this experimental study. The work focuses on improvement of the material removal rate (MRR) and to reduce the overcut by using high speed of tool rotation and feed rate. This work also discusses the design and development of the experimental set-up for ECDM engraving process with high-speed rotation of the tool electrode. It was observed that material removal rate increased with increase in voltage and electrolyte concentration, tool rotation speed and feed rate.

Keywords: Electrochemical discharge machining, high speed, Engraving, Material removal rate, over cut.

1. INTRODUCTION

For machining non-conducting materials different non-traditional machining processes are used. Laser beam machining (LBM), Abrasive jet machining (AJM) and Ultrasonic machining (USM) are the most popular methods used for machining of non-conducting materials like glass, composites and ceramics. Mallick*et al.* [1] studied the micro channel cutting on glass material using ECDM. They observed that machining depth decreases and surface roughness improves when pulse frequency increased. Cao *et al.* [2] conducted ECDM for machining micro-structure on the glass material. In a study it is observed cracks are appeared at the edge of micro channels when the tool touched with the work piece. Jain and Priyadarshini [3] used electro chemical spark machining for fabrication of micro channel in ceramics. It is observed that with increasing applied voltage; MRR, width of micro-channel and width of heat affected zone increases but depth of micro channel remain constant. Kulkarni*et al.* [4] discussed design and development of the experimental setup for micro channel making. They were making micro-channel by using negative replica of the polydimethysiloxane (PDMS). Ziki*et al.* [5] [6] investigated effect of tool travel speed in engraving process. It is reported that channel depth decreases as the speed of tool increases. They have also used different tool materials and observed thermal expansion in engraving. No thermal expansion is observed with tungsten carbide tool. Kumar and Yadav [7] used electrochemical spark phenomena for grinding process on composite. Grinding wheel speed 20rpm used for material removal and surface finish improvement. Jui *et al.* [8] observed that the low electrolyte concentration can reduce overcut by 20%, which leads to high aspect ratio of micro holes. It is also observed that at lower electrolyte concentration tool wear and hole taper decreases. Sarda*et al.* [9] used a tool vibration for improving material removal rate and reducing radial overcut. They found that material removal rate increases from 0.24mg/min to 0.34 mg/min when frequency is increases from 19kHz to 20kHz. Dong *et al.* [10] showed the possibility of high speed electrochemical discharge drilling (HSECDD) on beryllium copper alloy. It is found that HSECDD shows the better material removal rate than electro discharge machining (EDM). Huang *et al.* [11] explored very high speed rotating tool for the drilling micro hole. It is observed that axial tool wear rate decreased with increased speed tool rotation. Many researchers have tried to improve the material removal rate, surface finish and reduce the over cut, tool wear rate but there is still scope to explore the ECDM further. Aim of this research work is to improve the material removal rate and reduce to overcut using high speed of tool rotation in engraving process on glass and composite.

2. DEVELOPMENT OF HIGH SPEED-ECDM SETUP

The rectangular shaped machining chamber of size 150mm×100mm×30mm was used for the experimentation. The fixture for holding the work-piece is fitted in the machining chamber. This fixture and machining chamber is made up of acrylic material. To hold the auxiliary electrode one cantilever sheet is attached on the machining chamber. The auxiliary electrode is made up with copper and diameter of this is 10mm. The DC power supply systems were used for the experimentation. The specially designed variable transformer, range between 10V to 110V and current 3Amp were used. This transformer converts main AC power supply to low voltage DC power supply. Tool electrode is connected with negative charge and auxiliary electrode is connected with positive charge.

3. EXPERIMENTAL RESULT AND DISCUSSION

Table 1 shows the details of work piece material and specifications of different components used for experimental testing during this work.

Figure 1 and Figure 2 shows the schematic view and experimental setup for this research work, in Figure 2 auxiliary electrode, tool electrode and other component of experimental setup during machining process can be observed.

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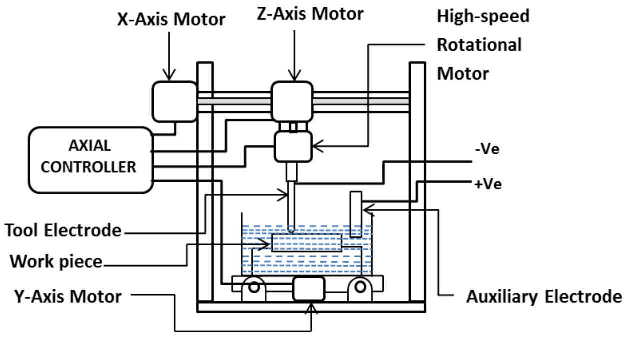

Fig.1. Schematic view of High Speed ECDM

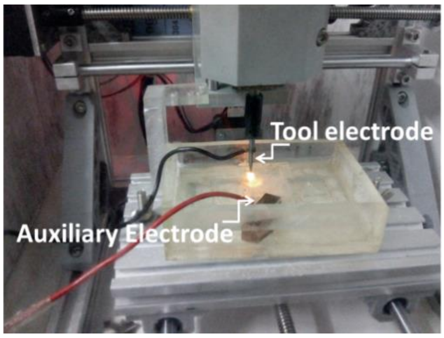

Fig.2. Experimental setup of High Speed ECDM

Table 1: Detailsfor the experimentation

Work piece material	Carbon-epoxy composite and Soda lime glass
Tool electrode	Tungsten carbide
Auxiliary electrode	Copper
Tool diameter	Ø500µm
Electrolyte solution	KOH

Table 2: Process condition for the experimentation

Voltage	(X_1)	40V to 60V
Electrolyte conc.	(X_2)	10% to 30%
Tool rotation speed	(X_3)	600rpm to 1000rpm
Feed rate	(X_4)	0.1mm/s to 0.3mm/s

During this research work different variants of process conditions are used for experimentation. These variants are listed in Table 2; experiments were performed on two work piece materials namelycarbon-epoxy compositeand soda lime glass. The process parameters used in this study are voltage, electrolyte concentration, tool rotation speed and feed rate. The effect of electrochemical discharge engraving on both materials (carbon-epoxy composite and soda lime glass) are compared in terms of material removal rate and overcut. All the experiments were conducted for 6 minute with the constant rotation of tool. The experimental result obtained from the machining process is presented.

3.1 Effect of high speed tool rotation on material removal rate

The comparison of the MRR for soda lime glass and carbon-epoxy composite with respect to different process parameters is presented in Table 3 from this table it is clear that MRR of soda lime glass is comparatively higher than carbon-epoxy composite.

Table3: Comparison of MRR for Soda lime glass and carbon-epoxy composite

Process parameters					MRR
V	%	rpm	mm	Work piece material	mg/min
40	30	1000	0.3	Soda lime glass	1.2913
				Carbon-epoxy composite	1.1811
50	20	1000	0.1	Soda lime glass	1.2889
				Carbon-epoxy composite	1.1112
60	10	1000	0.2	Soda lime glass	1.2209
				Carbon-epoxy composite	1.1201
60	30	800	0.1	Soda lime glass	1.2554
				Carbon-epoxy composite	1.1427

The Minitab 17 was used to analyze the experimental results and the following regression equation was obtained. This equation shows the rotation of tool electrode has the most significant effect on material removal followed by voltage and electrolyte concentration. The regression analysis equation of material removal rate for soda lime glass and carbon-epoxy composite can be expressed in equation 1 and 2 respectively.

$$MRR_{\text{Soda lime glass}} = -2.357 + 0.0274\,X_1 + 0.0256\,X_2 + 0.0016\,X_3 - 0.178\,X_4 \quad (1)$$

$$MRR_{\text{Carbon-epoxy composite}} = -2.189 + 0.0251\,X_1 + 0.0224\,X_2 + 0.0015X_3 - 0.063X_4 \quad (2)$$

These regression analyses show the effect of different process parameters on the material removal rate of soda lime glass and carbon epoxy composite respectively.

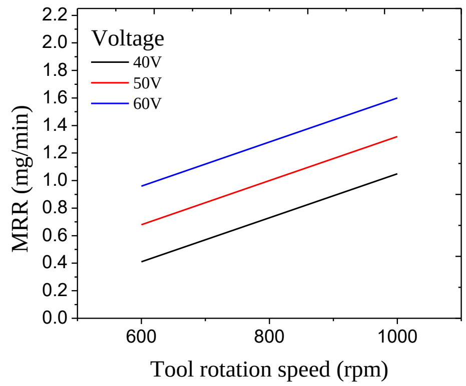

Fig. 3a

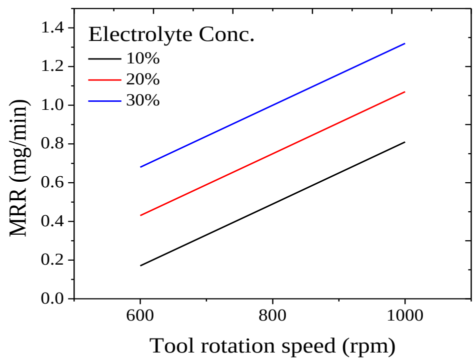

Fig. 3b

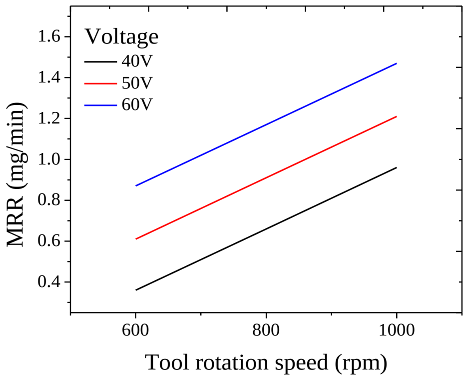

Fig. 3c

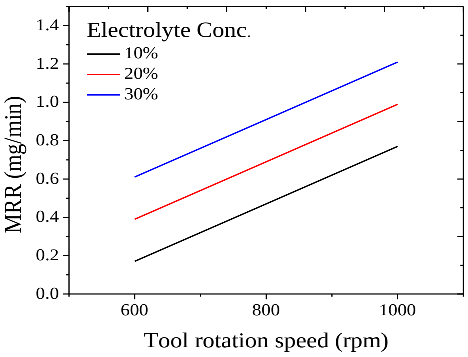

Fig. 3d

Fig.3. Effects of tool rotation speed on material removal rate (MRR) at constant feed rate =0.3
(a) Different voltages, electrolyte conc. =30, soda lime glass
(b) Different electrolyte conc., voltage=50, soda lime glass
(c) Different voltages, electrolyte conc. =30, Carbon-epoxy composite
(d) Different electrolyte conc., voltage=50, Carbon-epoxy composite

Above Figure 3 shows the effect of tool rotation speed on material removal rate with change in electrolyte concentration and voltages. Figure 3a and Figure 3c shows that with increase in applied voltage the material removal rate increases for both soda lime glass and carbon-epoxy composite material. Figure 3b and Figure 3d shows that with increasing in electrolyte concentration material removal rate increases. High critical voltage causes high erosion of the material which increases material removal rate of work material. And at high concentration of electrolyte chemical etching is higher which contributes to the MRR due to which at high concentration of electrolyte MRR increases.

3.2 Effect of high speed tool rotation on overcut

Following Figure 4 shows that the overcut is high at lower feed rate and it reduces with increased feed rate. A Figure 5 show that the over cut is high low tool rotation speed and it decreases with increasing tool rotation speed and feed rate. The results shown in Figure 4 and 5 are observed at 60V supply and 30% KOH electrolyte concentration. The tendency of overcut with increase in feed rate can be observed from Figure 6 for carbon-epoxy composite as well as soda lime glass. Figure6 shows that as feed rate increases the overcut observed in work piece decreases.

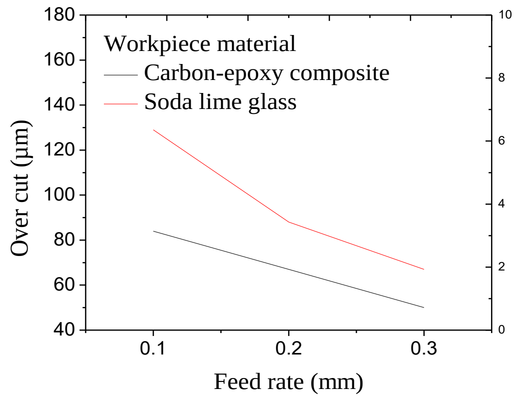

Fig.4. Overcut at different feed rate

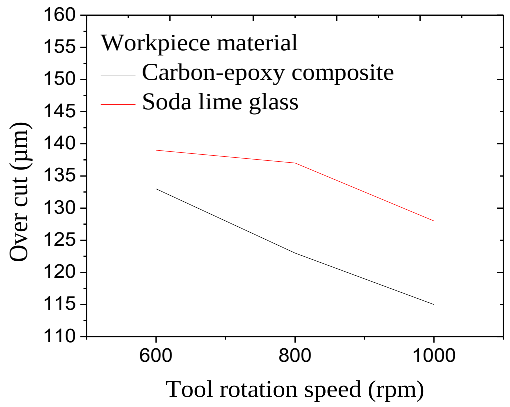

Fig.5. Overcut at different tool rotation speed

At low feed rate, tool moves slowly which gives more time to heat to be conducted into the work piece body this conducted heat causes the overcut as well as heat affected zones and at high feed rate and tool rotation speed tool moves fast hence it cuts the workpiece and advances, this reduce overcut.

Due to this phenomenon the overcut is reduces at high tool rotation speed and feed rate. this phenomenon does not give chance for overcutting the Figure 6 also shows that tendency of overcut is higher in case of soda lime glass than carbon-epoxy composite as carbon-epoxy composite is hard material it resist the erosion of its material due to heat conduction. Similarly increase in tool rotation speed lead to low overcut, this is due to fact that at slow tool rotation, more heat will conducted into work piece material and speed of tool rotation increases heat conduction and overcut with it reduces.

The heat affected zone occurred due to conduction of heat on work piece can be observed into Figure 5, this heat affected zone increases with increase in applied voltage and decrease in feed rate as more heat will be available to conduct at high voltage and more time will be available for heat conduction at low feed rate. At low feed rate tool moves slowly hence more heat will be conducted into the work piece which results into increased size of heat affected zones.

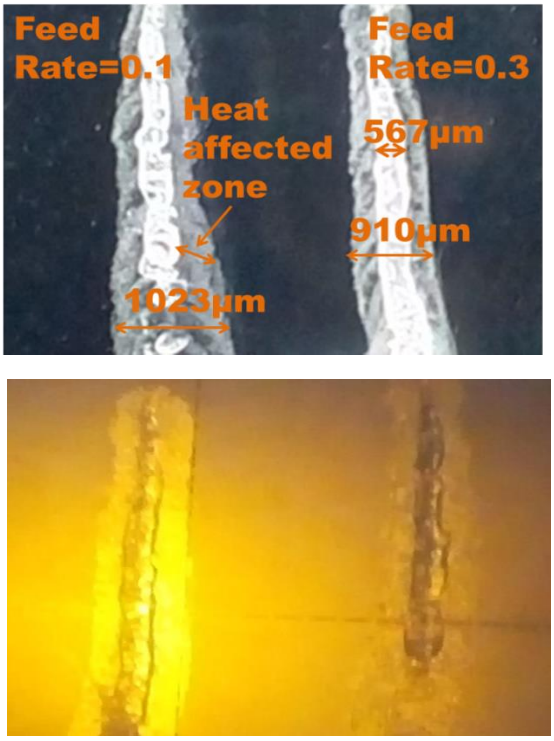

Fig.6. Formation of heat affected zone and overcut at different feed rate (Soda lime glass) (Scale 1:1, Magnification 1:20) (Feed rate =0.1, width of channel=1023μm) (Feed rate=0.3, width of channel 910μm)

4. CONCLUSION

It can be concluded from the findings of this research works that with increasing tool rotation speed the material removal rate increases for both soda lime glass and carbon-epoxy composite. Hence for drilling or engraving processes high speed tool rotation can be preferred over the low speed or steady tools to reduce the machining time. It is also observed that with increase in feed rate and tool rotation speed overcut in the material decreases which shows that with high speed of rotation and feed rate accurate machining can be achieved. Finding of this work shows that ECDM engraving at high speed tool rotation increases accuracy and material removal rate compared to the steady tool ECDM engraving.

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