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An experimental investigation during Electro Chemical Discharge Machining of e-glass fibre reinforced polymer composite

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Abstract

This paper reports the experimentally investigated results during electrochemical discharge machining (ECDM) of e-glass fibre reinforced polymer composite. The effect of ECDM input parameters such as DC voltage, electrolyte concentration and gap between tool electrode (cathode) and auxiliary electrode (anode) i.e. inter electrode gap on material removal rate (MRR) were analyzed through different graphs. Taguchi method based design of experiment, $L_9(3^4)$ orthogonal array, analysis of variance (ANOVA), signal to noise ratio (dB) were employed to carry out the experiments, identify the significant parameters and optimize the input parameters respectively for various responses. Test results show that the DC voltage and electrolyte concentration are most influential parameters on MRR. The optimal parametric combination for high MRR was found at 75 V dc supply voltage, 85 g/l electrolyte concentration and 140 mm gap between cathode and auxiliary anode with brass tool electrode. The surface characteristics of the machined hole and tool electrode were analyzed by scanning electron microscope (SEM) and explained in the paper.

***Keywords**:* ECDM, e-glass fibre reinforced polymer composite, MRR, Taguchi method, SEM.

Introduction

At present the advance materials like e-glass fibre reinforced polymer composites are considered to be one of the important materials in manufacturing industries because of their use and scope. These materials have very attractive properties and specially used in aerospace, defense, automobile, medical etc. industries where high strength to weight ratio, high temperature, high corrosion resistance, high impact, less weight materials etc properties are essential. Glass fiber reinforced plastic (GFRP) has high strength/weight ratio and superior over monolithic materials, thus it can be used as a light construction materials with high strength. E-glass fibre is difficult to machine by conventional machining because fibre not cut properly rather fussing and delamination. Use of other nonconventional machining methods like EDM, ECM and W-EDM are mostly used for machining of conductive materials [1]. To overcome these problems, a hybrid machining process e.g. electrochemical discharge machining (ECDM) is selected for experimental investigation. The ECDM process is a combination of EDM and ECM processes. The basic principle of this process is explained through Fig. 1, where tool which is act as a cathode and auxiliary electrode act as an anode both submerged in an electrolyte solution. The auxiliary anode and cathode is connected to the positive and negative terminals of the DC power supply respectively. When DC supply voltage crossed beyond certain limit the formation of the hydrogen bubble generated near the vicinity of the tool electrode (cathode) and around the anode oxygen bubbles are formed. When applied voltage reaches to the critical voltage (depend upon the workpiece material and concentration of electrolyte) electric discharge taking place around the tool surface. Material removed from the workpiece with combined action of electrical discharge and chemical dissolution by reaction [2]. This process is known as hybrid process and well known as electrochemical discharge machining (ECDM). This process is develop to machine nonconductive materials i.e. plastics and ceramics. While machining the ceramic at moderate DC supply voltage the sufficient electrical spark and dissolution metals takes place from the workpiece surface [3]. This process is a low cost process over other non conventional hybrid machining processes; this process can be used in the small industries [4]. The widely adopted application of ECDM is drilling [3]. It is also used to make micro channels on the workpiece. K. Furutani. [5] claimed that the ECDM process effectively used for machining of cylindrical parts. In ECDM, thermal effects and chemical etching are vital parameters which play an important role on output characteristics. Material removal rate is directly connected with electrolyte concentration in which soda lime used as a workpiece material by Bhowndwe et al. [6]. Basak and Ghosh [7] explained an analytical calculation, which can support the thermal mechanism and proposed the discharge carries about 2000 J/cm2 and for a time period of 0.1 ms. Kulkarni et al. [8] estimated that 77.98% of the energy is being utilized to warm up the electrolyte and tool electrode and 2-6% is used for the workpiece to heat up during the whole course of action. Yang et al. [9] done several experiment to explain and clarify the chemical engraving or etching effects. The different parameters and their ranges like pulse on time (10-15 ms) and electrolyte concentration (15.20 g/l) were studied on MRR by Bhattacharyya and Munda [10]. Sarkar et al. [11] claimed that the maximum material removal rate was 1.2 mg/hr achieved when parameter setting varies between 50V to 70V pulsed DC supply voltage with stainless steel electrode of diameter 400μm during machining of silicon nitride ceramic by ECDM. Jana and ziki [12] claimed that the temperature of electrode is equal to the electrolyte temperature which is about 500°C and this temperature can be controlled by pulsed voltage supply. From literature review, it is apparent that still a lot of applied researches on ECDM process are required to explore and utilize the process successful for machining of electrically non-conductive materials. The main aim of the present work is to analyze the effects of input parameters of the developed ECDM set-up on machining responses while machining e-glass fibre reinforced polymer composite .In this study, Taguchi method, L9 (34) orthogonal array, ANOVA and S/N ratio were employed to carry out the experiments on developed set-up and to identify the significant parameters on machining responses as well as optimization of ECDM input parameters for efficient machining of e-glass fibre reinforced polymer composite

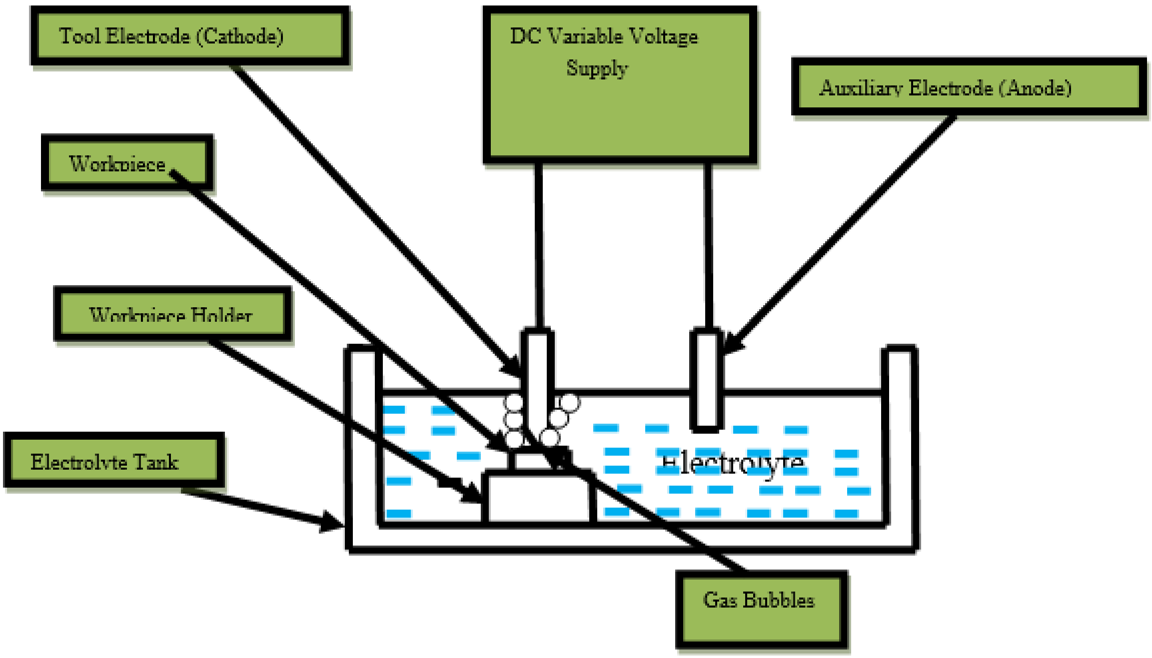

Figure 1. Basic diagram of Electrochemical Discharge Machining (ECDM) Process

Design and Fabrication of ECDM set-up

Fabricated ECDM setup has some of the important equipments such as (a) Electrolyte tank (b) Work piece holder (c) Pulse DC voltage generator (d) Electrode feed motion control. To supply the variable DC voltage ranges from 1V to 110V, a DC generator is used to convert 220V AC supply into variable DC supply. A feed motion control was used to control the feed motion of electrode with the help of stepper motor which operates at 18V, for this a step down transformer was also used which convert 220V to 18V. For the tool electrode motion in z axis a programmable logic control (automatic) which operates on a particular circuit was designed. To measure the gap between the electrode and auxillary anode, a scale is place beside the electrolyte chamber. Fig. 2 shows the schematic diagram and actual fabricated ECDM set-up. This fabricated ECDM set-up was used to machine the different diameters holes on e-glass fibre reinforced polymer composite with electrodes made of different materials.

Experimental Planning

Table 1 represents the properties of e-glass fibre reinforced polymer composite used as workpiece material for experimental investigation. The selected input parameters and their ranges used for conducting experiments are listed in Table-2. Taguchi method [13], L_9 (3^4) orthogonal array was employed for carrying out the experiments.

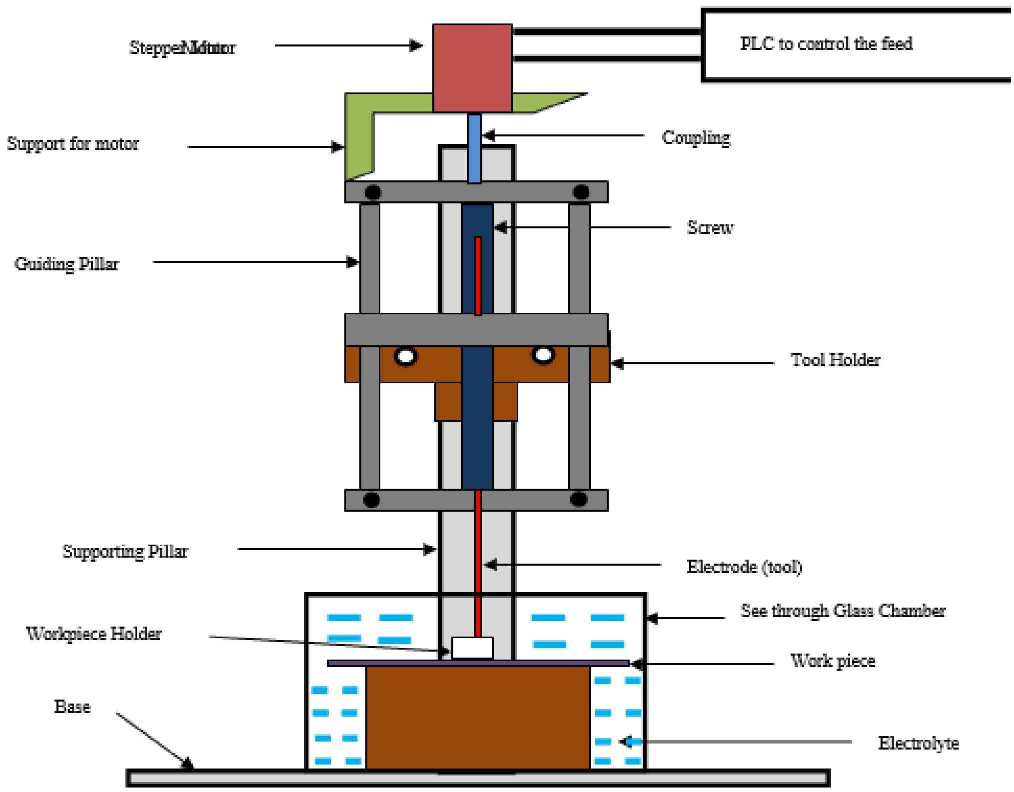

Figure 2. Diagram of the developed electrochemical discharge machining setup

Table 1. Composition of e-glass fibre reinforced polymer composite

Element	SiO_2	Al_2O_3	CaO
Wt.%	54%	15%	12%

The parameters chosen were DC voltage (A), electrolyte concentration (B) and gap between tool electrode (cathode) and auxiliary electrode (anode) i.e. inter electrode gap (C).

The value of MRR was determined by measuring the workpiece weight before machining (W_1) and workpiece weight after machining (W_2).

$$MRR = \frac{\text{workpiece weight before machining} - \text{workpiece weight after machining}}{\text{Machining Time}} = \frac{W_1 - W_2}{T}$$

Table 2. Input parameters and their ranges

	Labels	Input Parameters	Units	Level 1	Level 2	Level 3
variable	A	D.C. supply voltage	V	65	70	75
	B	Electrolyte concentration	g/l	75	80	85
	C	Inter electrode gap i.e Gap between tool electrode(cathode) and auxiliary electrode (anode)	mm	100	140	180
Constant		Auxiliary electrode material	Copper plate			
		Machining Time	45min			
		Work-piece material	e-glass fibre reinforced polymer composite			
		Tool electrode material	Brass			

Taguchi method is broadly used tool for professional experimental design and analysis as it advocates in developing a robust manufacturing system which is insensitive to the machine and environmental variation [14].

EXPERIMENTAL RESULTS AND DISCUSSIONS

The total twenty seven experiments were carried out for which each experiment was carried out with three replications and the mean values of the MRR were taken for further investigation. The two different types of electrolytes i.e. NaOH and KOH were used and carried out the experiments. Table 3 represents the L_9 (3^4) orthogonal array and experimental results for both the cases i.e. machining with NaOH and KOH electrolytes.

Table 3 : L_9 (3^4) orthogonal array and experimental results

Exp No	Applied Voltage(V)	Electrolyte Concentration(g/l)	Inter electrode Gap(mm)	For NaOH		For KOH	
	A	B	C	MRR(mg/min)	S/N ratio	MRR(mg/min)	S/N ratio
1	65	75	100	1.00	0.01	1.76	4.94
2	65	80	140	1.33	2.49	2.09	6.43
3	65	85	180	1.24	1.90	2.01	6.06
4	70	75	140	1.45	3.26	2.22	6.93
5	70	80	180	1.59	4.02	2.35	7.43
6	70	85	100	1.98	5.96	2.75	8.79
7	75	75	180	1.68	4.53	2.45	7.78
8	75	80	100	2.42	7.69	3.19	10.07
9	75	85	140	2.67	8.54	3.44	10.73

Case1: When NaOH used as an electrolyte.

The effects of the input parameters i.e. D.C. voltage, electrolyte concentration and gap between tool electrode (cathode) and auxiliary electrode (anode) i.e. inter electrode gap on MRR were analyzed through graphs. The graphs were drawn with utilized the results acquired during experiments on developed ECDM with NaOH electrolyte and brass electrode. Fig. 3 shows the effect of set voltages on MRR (mg/min). This result was attain from a particular set of machining condition i.e. at 85 g/l NaOH electrolyte concentration, 140mm inter electrode gap with varying DC supply voltage for continuous 45 min machining. From Fig. 3, it is clear that rise in the MRR with increase in DC voltage. It may be due to increase of current drawn side by side increase of supply voltage during machining. It obeys the basic theory of material dissolution from anode according to Faraday's laws of electrolysis. As the first law of Faraday's states that "the amount of chemical charges (W) produced i.e. dissolved is proportional to the amount of charge (Q) passed through the electrolyte". Which can be expressed as W α Q, if Q = (I. t), then, W α I, Where, I = machining current (A), t = time (s), W = material removed i.e. dissolution of fibre from work-piece (mg).

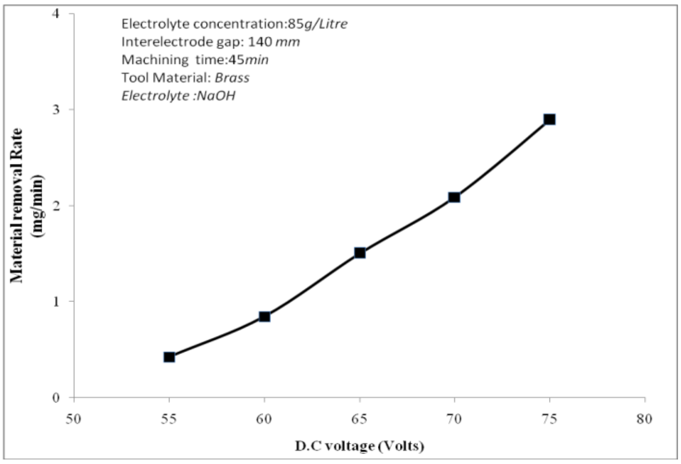

Figure 3. Variation in MRR with DC supply voltage

Fig. 4 depicts the effect of electrolyte concentration on MRR. This result attain from particular set of machining condition i.e. 70 V supply voltage, gap between anode and cathode 140mm and varied NaOH electrolyte concentration for continuous 45 min drilling in e-glass fibre reinforced polymer composite. From Fig. 4, it is clear that rise in MRR with increase in electrolyte concentration. It may be due rise in the current density with increase in the electrolyte concentration causes stronger spark produces in between the tool and the workpiece which enhances MRR.

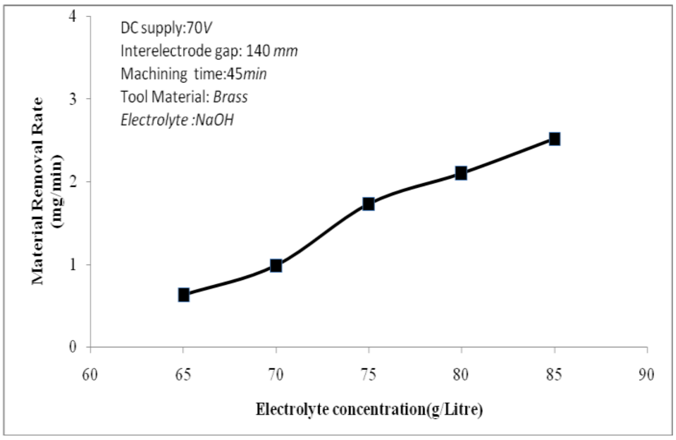

Figure 4. Variation in MRR with Electrolyte concentration

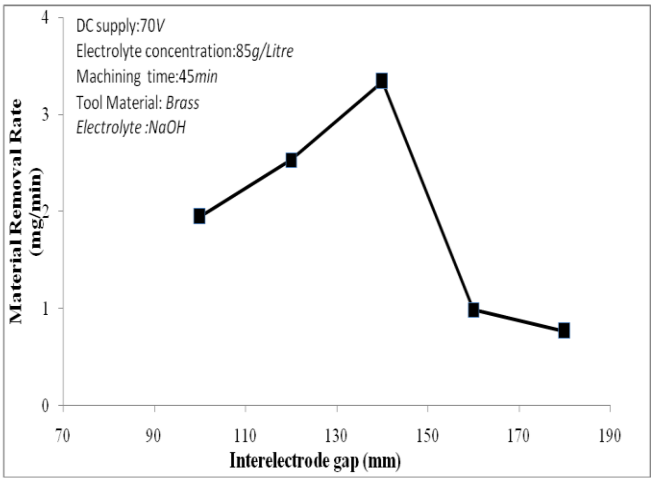

Figure 5. Variation in MRR with Inter electrode gap

Fig.5 shows the effect of gap between tool electrode (cathode) and auxiliary electrode (anode) i.e. inter electrode gap on MRR at machining condition i.e. 70 V supply voltage, 85g/l NaOH electrolyte concentration and varied inter electrode gap for continuous 45 min machining of e glass fibre reinforced polymer composite. It is clear from Fig. 5 that the initially with increase in the gap between the two electrodes up to 140mm material removal rate increases, it is because of gas formation limited. As the inter electrode gap increases from 140mm to 180mm the material removal rate decreases, thereby decreases the material removal rate.

Utilized the acquired results, the analysis of variance (ANOVA) Table 4 was constructed, which shows the parameter, DC supply voltage has highest effect i.e. 73.41% contribution on MRR followed by electron concentration (21.88%). The inter electrode gap had relatively lesser effect (4.65%) on MRR.

Table 4. ANOVA for MRR

Source	**DF**	**Sum of squares**	**Mean of squares**	**F ratio**	**P value**	**Contribution**
Voltage(A)	2	44.6798	22.3399	1606.04	.001	73.41%
Electrolyte concentration(B)	2	13.3154	6.6577	478.63	.002	21.88%
Inter-electrode gap (C)	2	2.8316	1.4158	101.78	.010	4.65%
Error	2	0.0278	0.0139			0.06%
Total	8	60.8547				100%

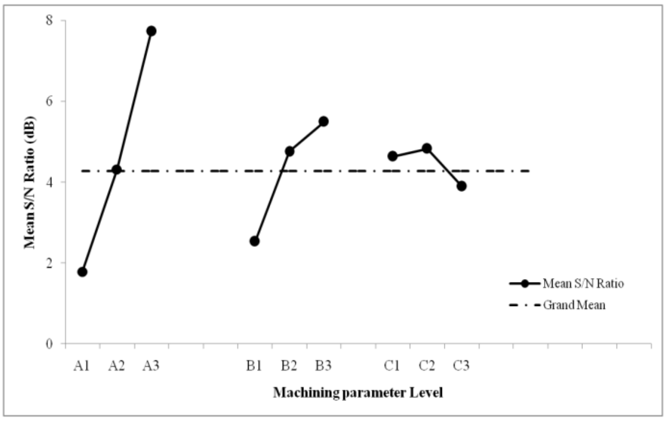

Figure 6. S/N ratio (dB) for MRR (mg/min)

Fig. 6 shows the S/N ratio (dB) for MRR. This S/N ration was determined based on the results acquired during machining with NaOH electrolyte. From Fig.6, it is clear that optimal parametric setting by their factor level for MRR is $A_3B_3C_2$ i.e. at 75 V supply voltage, 85g/l electrolyte concentration and 140 mm inter electrode gap.

(b) When KOH used as an electrolyte.

The effects of the different parameters i.e. D.C. supply voltage, electrolyte concentration and Inter electrode gap i.e Gap between tool electrode(cathode) and auxiliary electrode (anode) on MRR were analyzed through graphs. The graphs were drawn with utilized the results acquired during experiments on developed ECDM with KOH electrolyte and brass electrode. Fig. 7 shows the variation in MRR (mg/min) with dc voltage. This result was attain from a particular set of machining condition i.e. at 85 g/l KOH electrolyte concentration, 140mm inter electrode gap with varying DC supply voltage for continuous 45 min machining. From Fig. 7, it is clear that rise in MRR with increase in dc voltage. It is due to the conductivity and mobility of potassium exceeds that of sodium. Therefore material removal rate faster in potassium ion than in sodium ion.

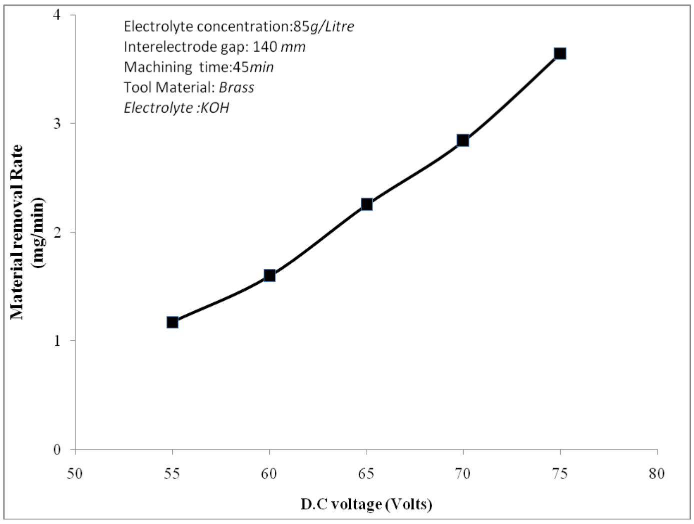

Figure 7. Variation in MRR with DC supply voltage

Fig. 8 shows the effect of electrolyte concentration on material removal rate. The result attain from particular set of machining condition i.e. 70 V supply voltage, 140mm gap between two electrode and varied KOH electrolyte concentration for continuous 45 min machining of e glass fibre reinforced polymer composite. From Fig. 8, it is clear that rise in MRR with increase in electrolyte concentration. It is due to the transfer efficiency of potassium is superior, which increase the chemical reaction of potassium ions as the concentration increases.

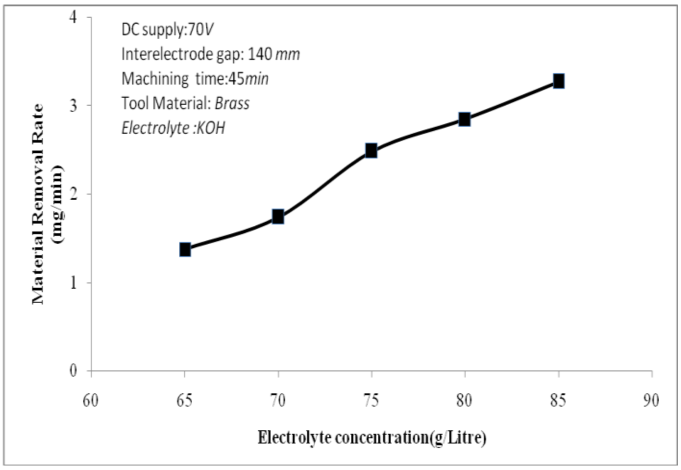

Figure 8. Variation in MRR with Electrolyte concentration

Fig.9 depicts the effect of inter electrode gap on MRR at set machining condition i.e. 70 V supply voltage, 85g/l NaOH electrolyte concentration and varied inter electrode gap for continuous 45 min machining of e glass fibre reinforced polymer composite. It is clear from Fig. 9 that the initially increase in the gap between the two electrodes i.e.upto 120mm the material removal rate increases, it is because in potassium much faster rate of discharges taking place as compared to sodium at less gap between the electrodes then further increase in the gap between the two electrodes from 120mm to 180mm the material removal rate decreases, thereby decreases the material removal rate.

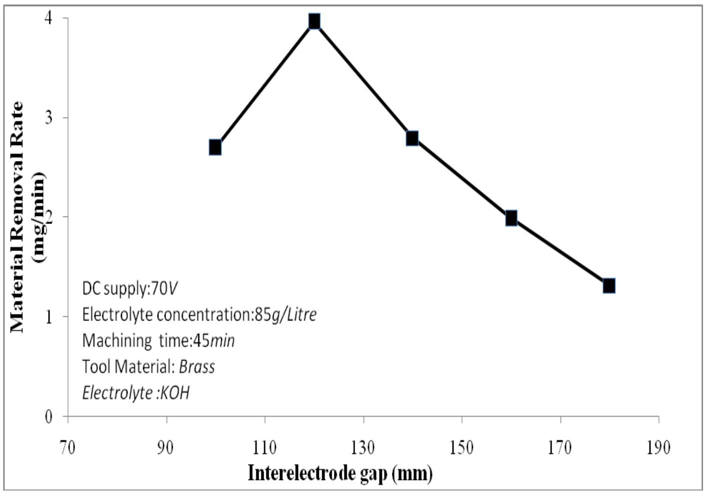

Figure 9. Variation in MRR with Inter-electrode gap

Utilized the acquired results, the analysis of variance (ANOVA) Table 5 was constructed, which shows the parameter, DC supply voltage has highest effect i.e. 72.51% contribution on MRR followed by electron concentration (21.88%). The inter electrode gap had relatively lesser effect (5.58%) on MRR.

Table 5: ANOVA for MRR

Source	DF	Sum of squares	Mean of squares	F ratio	P value	Contribution
Voltage(A)	2	20.70	10.35	11576.01	0.002	72.51%
Electrolyte concentration (B)	2	6.25	3.12	3494.24	0.003	21.88%
Inter-electrode gap (C)	2	1.59	0.79	892.33	0.015	5.58%
Error	2	0.0018	0.0009			0.03%
Total	8	28.55				100%

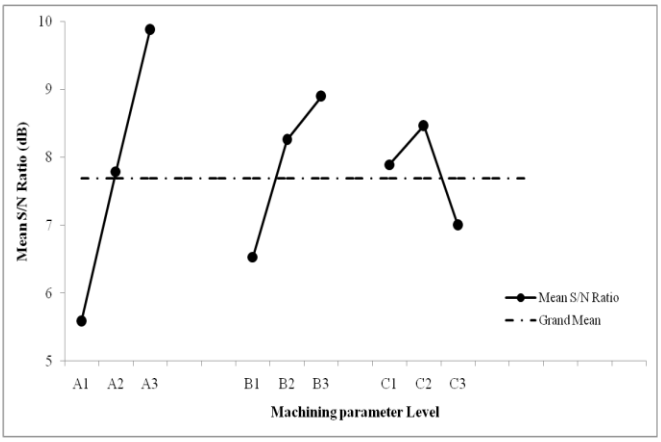

Figure 10. S/N ratio (dB) for MRR(mg/min)

Fig. 10 shows the S/N ratio (dB) for material removal rate. This S/N ration was determined based on the results acquired during machining with KOH electrolyte. It is clear from the Fig.10 that the optimal parametric setting by their factor level for MRR is $A_3B_3C_2$ i.e. at 75 V supply voltage, 85g/l electrolyte concentration and 140 mm inter electrode gap.

RESULTS THROUGH SEM

The Fig. 11 shows the SEM images of machined hole on e-glass fiber epoxy composite work piece specimen at 75V DC voltage, 75g/l electrolyte concentration, 180mm gap between the two electrodes i.e. tool electrode and auxiliary electrode with 300µm diameter brass tool electrode. It is clear from the figure-11 that multiple thermal cracks of the material found in the machine hole, it may be due to the high thermal energy per sparks was produced at 75V. Further it is also clear that upper edges of the machined hole is not heated properly to be melted or engraved which result heat affected zone starts growing. Along the depth, fibre was not cut properly due to insufficient supply of the electrolyte at the tool head, as a result sparks produces at the upper part of the tool thereby increases diameter and destroyed the shape of hole.

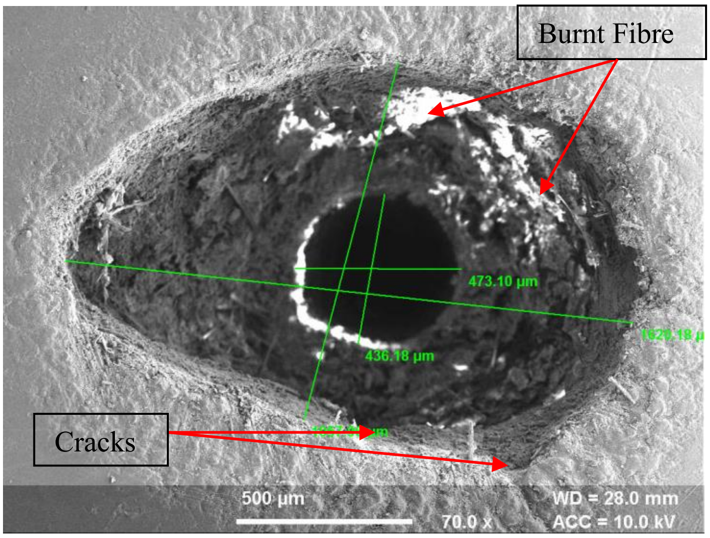

Figure 11. SEM of through hole

Fig. 12 shows the wear on the brass tool was found on the edges and on the sides. It is due to the increase in current density and at high DC supply voltage sparking effect more on the tool thereby scattered more energy to workpiece through edges. It was also found that some micro particles stick and seen on the face of the tool electrode due to the melting of the e glass fibre reinforced polymer composite. Some fine pores are also appeared in the SEM micrographs.

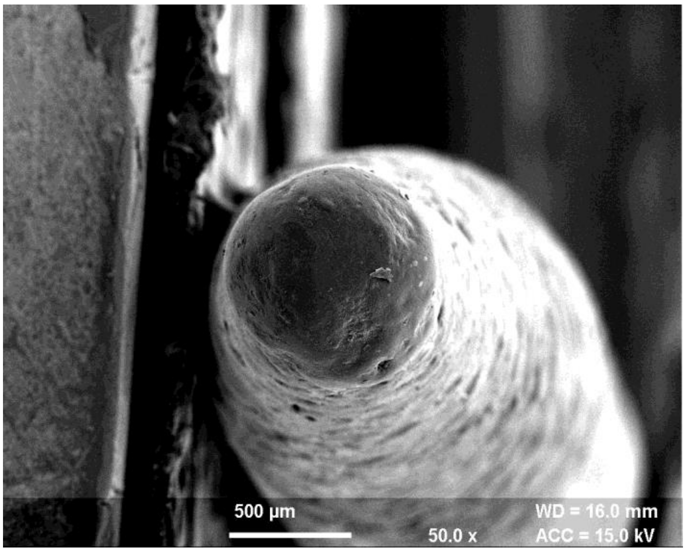

Figure 12 SEM of Micro Tool

CONCLUSION

The performance of the developed ECDM set-up during machining of e glass fibre reinforced polymer composite was discussed. The numbers of experiments were conceded according to Taguchi method and acquired results were analyzed by using Minitab 17 software. The experiments were carried out for generation of holes on e-glass fibre reinforced polymer composite with NaOH and KOH electrolytes for analyzing the response characteristic i.e. MRR. Three selected input parameters are DC voltage, electrolyte concentration and gap between tool electrode (cathode) and auxiliary electrode (anode) i.e. inter electrode gap. Based on the results and discussions, the following points are conclusions and drawn as follows:

(i) The fabricated ECDM machining set-up can be used for drilling in e-glass fibre reinforced polymer composite.

(ii) MRR increases with the increase in DC voltage as well as electrolyte concentration. The most influential input parameter was identified as DC voltage with 73.41% contribution for MRR.

(iii) The application of KOH as an electrolyte gives better results for MRR as compared to NaOH. However, tool wear was observed when KOH used as an electrolyte.

(iv) SEM image of the electrode i.e. tool shows some micro crater occurs on the tool face and tool wear at the edges of the brass tool used for experiments.

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