Machining of Carbon Fibre Reinforced Polymer Composite by Electrochemical Discharge Machining Process

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Abstract. Carbon Fibre Reinforced Polymer (CFRP) composite is highly applicable in aeronautics, defence and electronics industries application due to their better mechanical properties. Still, the micro-drilling of CFRP composite is challenge to research society due to its semi-conductive and fibrous nature. In this work, the author’s successfully drilled micro-holes in CFRP composite using Electrochemical Discharge Machining (ECDM) process. The experiments were designed on the basis of Taguchi’s method using L₉ orthogonal array. The experiments were carried out with process parameters such as electrolyte concentration, applied voltage, inter electrode gap and material removal rate as response characteristic. The surface characteristics of drilled hole were studied by Scanning Electron Microscope (SEM) micrograph. Additionally, the dominant effects of process parameters on MRR were evaluated using Analysis of Variance (ANOVA).

1. Introduction
In recent years, the Polymer Matrix Composites (PMC’s) have attained popularity in aeronautics, defence and other applications due to low weight, high strength and less thermal expansion [1]. The machining of PMC’s is challenge to research society due to different irregularities occurred while machining by traditional machining methods. With development of advance materials, the researchers tried to develop a process which can machine various materials without constraint to their properties. The Electrochemical Discharge Machining (ECDM) process has gained reputation in the machining of conductive and non-conductive materials irrespective to their properties [2]. ECDM process is firstly attempted to machining of glass by Karafuji [3]. Later on, ECDM process is successfully attempted to machining of composites [4], ceramics [5], steel plates [6] and super-alloys [7]. ECDM process is hybrid machining method which pools the process individualities of Electrochemical Machining (ECM) and Electrical Discharge Machining (EDM) [8]. The ECDM setup includes two electrode terminals i.e. tool electrode and auxiliary electrode alluded to as cathode and anode independently as showed up in Figure 1. During machining, the cathode is submerged up to couples of millimetres in electrolyte solution and anode electrode is arranged at few centimetres away from tool electrode tip. The material to be machined is positioned at vicinity of cathode and submerged in electrolyte. With initiation of DC supply, the hydrogen bubbles starts formed on tool electrode surface due to electrolysis. The high current density at cathode tip is stepped up generation rate of hydrogen bubbles and combines to form a gas film layer. The layer casing formed on tool electrode surface behaves as a dielectric and eliminates contact of electrolyte with cathode. When the applied electrode potential increases beyond the disruption strength of gas film, the discharge is produced at periphery and tip of
cathode electrode. The machining material in the vicinity of cathode electrode gets softening, vaporization and thermal spalling caused by spark energy [4].

In domain of composites, Liu et al. [9] conducted micro-machining of conductive composite material using grinding aided ECDM. They concluded that nature of material removal criterion in ECDM is equivalent to EDM i.e. spalling of debris. Manna and Narang [10] attempted micro-drilling of E-glass fibre epoxy composite by ECDM process. They concluded that, the machined surface characteristics were non-uniform due to imperfect machining of fibres. Antil et al. [11] effectively machined micro-holes in SiC reinforced PMC’s. They observed heat affected zone (HAZ) and micro cracks on machined surface by SEM micrographs. From the available literature, it is revealed that machining of various materials such as composites, ceramics, steel and super-alloys have been reported by different researchers. However, the machining of carbon fibre reinforced polymer composite (CFRP) by ECDM process is least reported. The principle point of this study is to examine the impact of process parameters such as applied voltage, electrolyte concentration and inter-electrode gap on response characteristic i.e. material removal rate (MRR). Additionally, to find out optimum parametric conditions for machining of CFRP composite using ECDM process.

2. Experimentation and Methodology
The material used for experimentation purpose is carbon fibre reinforced polymer composite (CFRP) is procured from Indigenous Ltd., Dehradun, India. The characteristics of material such as warp fibre-carbon fibre 3K 200tex, weft fibre-carbon fibre 3K 200tex. The weight distribution of carbon fibres in CFRP composite is 50% warp: 50% weft with an orientation of 0/900. The thickness of work piece material is 2mm. The micro-drilling of CFRP composite is carried out on developed ECDM set up. The machining parameters for experimentation were applied voltage (50-70V), electrolyte concentration (30-50%) and inter-electrode gap (60-80mm) with performance characteristic such as material removal rate (mg/min).The input parameters values for experimentation with their levels are shown in Table 1. The NaOH electrolyte is chosen among other electrolytes due to high popularity in ECDM process [8]. While machining, each experiment is carried out by first hand carbide tool drill bit of diameter 300µm. The experiments were performed by using Taguchi’s L9 Orthogonal array. The output response characteristics of nine alternative experiments are shown in Table 2. The material removal rate (MRR) in each experiment is calculated by weighing machining sample with reference to time.

| Sr. | Electrolyte | Applied Voltage | Inter Electrode Gap | MRR (mg/min) |
|-----|-------------|-----------------|---------------------|--------------|

![Figure1: Schematic of ECDM process](image)

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| Symbols | Process Parameters | Level 1 | Level 2 | Level 3 |
|---------|--------------------|---------|---------|---------|
| A       | Electrolyte        | 30      | 40      | 50      |
| B       | Applied Voltage    | 50      | 60      | 70      |
| C       | Inter-Electrode Gap| 60      | 70      | 80      |
### Table 3: Analysis of variance for MRR

| Source                     | Symbols | DF | SS   | MS   | P Value | Percentage contribution |
|----------------------------|---------|----|------|------|---------|-------------------------|
| Electrolyte Concentration  | A       | 2  | 0.011850 | 0.005925 | 0.076 | 31.82                   |
| Voltage                    | B       | 2  | 0.021791 | 0.010895 | 0.043 | 58.52                   |
| Inter-electrode Gap        | C       | 2  | 0.002618 | 0.001309 | 0.272 | 7.03                    |
| Error                      |         | 8  | 0.037235 |        |       |                         |

The SEM micrograph of machined hole on CFRP material at 150x magnification is shown in Figure 4. The SEM micrograph depicts drilling of through hole with complete cutting of fibres from surface of composite. Moreover, the periphery of hole is slightly non-uniform due to semi-conductive nature of CFRP composite. Apart from these, cracks and uneven surface produced on outer surface of drilled hole. This is because of limited supply of fresh electrolyte while machining. The supply of fresh electrolyte in machining regime produced continuous and sparking phenomenon. In future, the non-uniformity of machined surface can be addressed by incorporation of other techniques such as vibration assistance, tool electrode geometry etc. which promotes flushing of electrolyte in machining zone.
4. Conclusions
Based on experimental results in machining of CFRP composite by ECDM, the following conclusions were drawn:

- The ECDM process is effectively used for machining of polymer matrix composites irrespective to their properties.
- Based on Taguchi’s technique, the optimum parametric values for MRR are electrolyte concentration, applied voltage and inter-electrode gap are 50% (mass percent), 70V and 70mm respectively.
• The experimental investigation shows that MRR is directly related to voltage and electrolyte concentration of ECDM process, whereas the inter-electrode gap shows inverse trends.
• SEM micrograph depicts drilling of hole on CFRP with fibres removal on surface of composite by sparking phenomenon. However, the outer surface of drilled hole becomes less uniform due to cracks and uneven machined surface.

5. References
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