An Experimental Investigation on Designed and Fabricated WECSM Setup during Micro Slicing of e-glass Fibre Epoxy Composite

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ABSTRACT

The e-glass fibre epoxy composite is a non-conductive ceramic material hence it is difficult to machine by any well known non-conventional machining methods like electrical discharge machining, wire electrical discharge machining etc. This material can be machined with conventional machining but compromise with accuracy, surface texture even not possible to micro slicing etc. Keeping in view, a hybrid machining technique which is combination of both electro chemical machining (ECM) and wire electric discharge machining (WEDM) is used to machine such material. This paper presents the results during machining of e-glass fibre epoxy composite on a designed and fabricated wire electrochemical spark machining (WECSM) setup. The numbers of experiments have been carried out to investigate the effect of different parameters of fabricated WECSM setup on machining performance characteristics such as material removal and spark gap width. Test results reveals that the width of micro slicing was very small e.g.127 µm. The practical research analysis and test results present in this paper will provide new guidelines to the manufacturing engineers and upcoming researchers.

Keywords: Hybrid machining, WECSM, e-glass fibre epoxy composite, Micro slicing.

1 Introduction

Advanced glass fibre composites and ceramics having good strength, light weight, flexibility in shape and sizes, good corrosion as well as creep resistance and high thermal shock resistance than that of monolithic metals. Advanced fibre glass reinforced composite materials can be used in place of steel, aluminium alloy and other monolithic materials. Advanced glass fibre composites and ceramics have wide range of applications due to their high performance properties particularly in the corrosive areas such as chemical storage and processing, water and wastewater storage or processing, aeronautical and defense, building construction, electrical and electrical utility, marine industry etc. But advanced e-glass fibre epoxy composite is an electrically non conductive material which is very difficult to machine by any well known nonconventional machining processes. Hence, it is essential to develop an efficient and accurate machining method for processing of e-glass fibre epoxy composite materials. For effective machining of non-conductive e-glass fibre epoxy composite materials Wire Electro Chemical Spark Machining (WECSM) setup has been designed and fabricated. The fabricated WECSM Setup has been utilized to machine e-glass fibre epoxy composite. Utilized the experimental results and through different graphs analyzed the effect of various parameters of the developed WECSM setup on the machining performance characteristics.

In the WECSM process, the material removal takes place due to the combined effects of electrochemical (EC) reaction and electrical spark discharge (ESD) action. The material to be machined is dipped in the electrolyte and placed very near to the cathode. In this study a brass wire electrode is used for experimental investigation. A constant DC voltage is applied between the wire tool cathode and the counter electrode known as auxiliary electrode. The counter electrode used is a flat plate made of copper of size 100 x 80 x 2 mm thick. When the applied voltage above a certain range hydrogen gas bubbles are formed at wire cathode and oxygen bubbles at the auxiliary electrode. It has been observed that if the two electrodes are of different sizes then beyond a certain value of applied voltage, electric sparks appear at the electrode-electrolyte interface on the smaller electrode and the cell current drops. As voltage is increased, current density rapidly increases too. The density and the mean radius of the bubbles increase and bubbles finally coalesce into a gas film around the tool-electrode. A brass wire is traveling continuously and functioning as an electrode during machining operation.
From the review of literature, it is found that few research publications on electrochemical and traveling wire electrochemical spark machining are available, however; still a lot of applied research in the above field is required to explore the successful utilizations of the process for effective machining of nonconductive ceramics and composites materials. Some of the published research are reviewed and explained in brief here. Basak and Ghosh (1996) concluded that a substantial increment in the material removal rate can be achieved by introducing an additional inductance. Gautam and Jain (1998) investigated on electrochemical spark discharge process using various tool kinematics to enhance the process capabilities. Jain, et al. (2002) concluded that electrochemical spark machining with abrasive cutting tools can be improved the performance related to machining of electrically non conducting materials, alumina and borosilicate glass. Kulkarni, et al. (2002) conducted an experimental study on discharge mechanism in electrochemical discharge machining. In the particular study, authors have attempted to identify the mechanism through experimental observations of time-varying current in the circuit. Based on these observations the basic mechanism of temperature rise and material removal was proposed. Medilleyegedara, et al. (2004) studied and analyzed the electro chemical discharge machining (ECDM) process and concluded that ECDM process has advantageous over ECM or EDM because of higher machining rate. Manna and Bhattacharyya (2006) studied a dual response approach for parametric optimization of CNC wire cut EDM during machining of particulate reinforced aluminium silicon carbide metal matrix composite (PRAI/SiC-MMC). They used Taguchi method for experimental design and the significant factors were identified for machining performance characteristics during WEDM of PRAI/SiC-MMC. Mohen and Shan (2005) reviewed of electro chemical micro-to-micro-hole drilling processes and concluded that advanced hole-drilling process like jet-electrochemical drilling can be accepted in producing large number of quality holes in difficult to machine materials. Different authors such as Kulkarni and Jain (2007), Hwa and Ling (2007), Singh et al (1996), Manna and Khas (2009), Manna and Narang (2012) performed experiments on micro EDM and electrochemical spark machining processes; they explained the effects of various parameters on response characteristics.

2 Experimentation Planning

A wire electro chemical spark discharge machining (WECSM) setup has been designed and fabricated for experimental investigation. Utilized fabricated WECSM setup different micro slicing tests are performed on electrically nonconductive high corrosive resistant and light weight e-glass fibre epoxy composite material. Table 1 represents the details of fabricated WECSM setup, tool (wire electrode), work-piece and electrolyte used for experimentation. Material removal (MR) is obtained from the difference of weight between work-piece weight before and after slicing of each operation. Contech (Instrument) Electronic Balance of resolution 0.1 mg is used to weight the work-pieces before and after each run. The SEM photographs are taken to analyze the surface texture of the machined surface. The micro slicing time is recorded by using a digital stop watch of accuracy 0.1 s.

Table 1: Details of experimental conditions

<table>
<thead>
<tr>
<th>Machine Used</th>
<th>Designed and Fabricated WECSM setup</th>
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<tbody>
<tr>
<td>Electrolyte used</td>
<td>Sodium Hydroxide (NaOH)</td>
</tr>
<tr>
<td>NaOH and natural water concentration</td>
<td>(i) 50 g/l; (ii) 100 g/l; (iii) 150 g/l; (iv) 200 g/l</td>
</tr>
<tr>
<td>Work-piece material</td>
<td>Electrically non-conductive e-glass fibre epoxy composite</td>
</tr>
<tr>
<td>Work-piece thickness</td>
<td>2 mm</td>
</tr>
<tr>
<td>Tool used</td>
<td>Brass wire of diameter 200 µm</td>
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</table>

3 Designed and Fabrication of WECSM Setup

A semiconductor base rectifier converter cum regulator is used to convert 220 volts A.C into D.C supply in the range of 10 volt to 110 volt. Positive (+ve) terminal of the converter cum regulator is connected to an auxiliary copper plate which in due course functioning as an auxiliary anode otherwise it is known as auxiliary electrode. Negative (−ve) terminal of the converter cum regulator is connected to the tool i.e. wire electrode which in turn functioning as a cathode. An electrolytic tank is used to hold the electrolyte during machining. A scale fixed along the electrolyte tank wall which is used to check the gap between auxiliary Cu plate and traveling wire electrode. An auxiliary copper plate is hanged on a wooden bar in such a way so that the certain portion of the auxiliary Cu plate must be immersed in the electrolyte lying with electrolytic tank. There is a provision to move the nonconductive wooden bar along the sides of the electrolytic tank to vary the gap between auxiliary anode and traveling wire cathode. Again another step down transformer and a regulator is also used to step down the supply voltage and regulates the same with variation of 6 to 12 volts to operate a stepper motor which gives the rotary motion to the wire take up unit. A D.C. supply power of 12 V is utilized for operating another stepper motor which rolls the wire
around a pulley fixed on the main frame is shown in
Figure1.

Figure 1 Fabricated WECSM setup

A special gearing and screw arrangement is used which gives upward and downward movement of the work-piece holder during cutting. It is operated by a 24 volt D.C. motor. The upward and downward motion is achieved by changing the input terminals of the motor.

4. Results and Discussions

A series of experiments has been carried out with variation of different parametric setting value and the results are utilized for further analysis. Different graphs have been plotted to analyze the effect of various parameters of fabricated WECSM setup on the machining characteristics e.g. material removal, spark gap width. Different scanning electron micrographs (SEM) show the characteristics of the generated spark gap width during WECSM operation.

4.1 Effect of Parameters on Material Removal (mg)

Figure 2 shows the effect of wire speed on material removal (MR, mg). From Figure 2, it is clear that the material removal (MR, mg) increases with increase in wire speed. Wire speed has an important effect on material removal. It may be due to traveling of fresh wire quickly across the cutting zone and generates higher number of spark discharge. Higher number of spark discharge generates more craters per unit time enhance increase the material removal rate. Maximum material removal is observed at 0.35 m/min of wire speed. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 min machining and at constant 40V supply voltage, 100 g/l electrolyte concentration, 110 mm gap between tool and anode and 1.4A supply current with variation of wire speed from 0.15 m/min to 0.35 m/min.

Figure 2 Effect of wire speed on MR

Figure 3 shows the effect of supply current on material removal (MR, mg). From Figure 3, it is clear that material removal (MR, mg) increases with increase in supply current. Maximum material removal is observed at 2.2A of supply current. It is due to increase of supply current that increases charge density. Further increases formation of craters around the tool and work-piece material by increasing of charge density. This graph is plotted based on the results obtained during slicing of e-glass fibre epoxy composite with continuous 90 min machining and at constant 40V supply voltage, 100 g/l

Figure 3 Effect of supply current on MR
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electrolyte concentration, 0.15 m/min wire speed, 110 mm of gap between tool and auxiliary anode and variation of supply current from 1.4 to 2.2 A.

concentration, 0.15 m/min wire speed, 110 mm gap between anode and cathode and 1.6 A supply current.

Figure 4 Effect of wire speed on spark gap width

4.2 Effect of Parameters on Spark Gap Width (µm)

Figure 4 shows the effect of wire speed on spark gap width (Wg, µm). From Figure 4, it is clear that the spark gap width (Wg, µm) increases with increase in wire speed. Parameter, wire speed has smaller effect while machining at low cutting speed but its effect increases with increase in wire speed. It may be due to fresh wire coming quickly across the slicing of e-glass fibre epoxy composite and it discharges stronger spark which helps to broken the gas bubbles and formation of more number of crater per unit time that’s why the material removal increases with increase in wire speed. Maximum material removal is observed at 0.35 m/min of wire speed.

Figure 5 shows the effect of supply current on spark gap width (Wg, µm). From Figure 5, it is clear that the spark gap width (Wg, µm) increases with increase in supply current. Maximum spark gap width is observed at 2.2 mm of supply current. It may be due to increase of supply current which increases density of charge and thereby increases formation of cutters around the tool.

Figure 6 shows a SEM photograph of a micro slice section of e-glass fibre epoxy composite work-piece sliced by fabricated wire electro chemical spark machining (WECSM) setup. The actual condition of the micro cutting surface is shown in Figure 6. This SEM photograph is an experimental result with parameters setting at 70V D.C supply voltage, 200 g/l electrolyte concentration, 0.15 m/min wire speed, 110 mm gap between anode and cathode and 1.6 A supply current.

The micro slicing shown in Figure 6 is the result of continuous 30 minutes machining with 200 µm diameter brass wire electrode at 0.15 m/min cutting speed. However, the surface finish is very poor; it may be due to high DC supply voltage and electrolyte concentration. This may also due to not proper flashing of electrolyte during machining and hence fibres are remaining in the form of fins and fibres as it is at the micro slice part on e-glass fibre epoxy composite work-piece.

Figure 7 shows a SEM photograph of a micro slice section of e-glass fiber epoxy composite work-piece sliced by fabricated wire electro chemical spark machining setup. This SEM graph shows the actual condition of the micro cutting surface. The micro slicing shown in Figure 7 is the result of continuous 40 minutes
machining with 200 μm diameter brass wire electrode at 0.25 m/min cutting speed. From SEM graph Figure 7, it is clear that micro slicing proceeds in uniform pattern. From Figure 7, it is also observed that the surface of the micro slicing is showing continuous burrs and fins. Overall slicing surface finish is poor at micron level. Slicing width at the entry is 238 μm but after 40 min of continuous cutting micro width is only 127 μm at the blind part of slicing (Figure 7). It’s proved that slicing is about to conical. Some fins and burrs are also observed during cutting in either sides of the sliced surface. It’s may be due to the irregular and insufficient flow of electrolyte.

Figure 8 shows a SEM photograph of a micro slice section of e-glass fiber epoxy composite work-piece sliced by fabricated wire electro chemical spark machining (WECSM) setup. The SEM graph shows the actual condition of the micro cutting surface. The micro slicing shown in Figure 8, is the result of continuous 50 minutes machining with 200 μm diameter brass wire electrode at 0.25 m/min cutting speed. From SEM photograph Figure 8, it is clear that micro slicing proceeds perfectly straight in nature. From Figure 8, it is also clear that the surface of the micro slicing is showing far better than surface produced are shown in Figure 6 and Figure 7. Slicing width at the entry is 316 μm but after 50 min of continuous cutting micro width is only 195 μm (Figure 8). Some fins and burrs are also observed at the beginning of cutting in either sides of the sliced surface. However, the overall surface finish is good; it may be due to higher concentration and regular as well as sufficient flow of electrolyte during machining. During micro slicing it is also observed that some gas bubbles and foam are generated which later on making a barrier to flow of electrons and decrease the chemically dissolution strength of the electrolyte and hence reduces material removal rate.

5. Optimization of Fabricated WECSM parameter

Taguchi method based L_{16} (4^5) orthogonal array is used for experimental investigation. Table 2 represents fabricated WECSM setup parameters considered for detail experimentation and optimization of parameters.

<table>
<thead>
<tr>
<th>Parameters, their symbols and units</th>
<th>Parametric Levels</th>
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<tbody>
<tr>
<td>A: DC supply voltage (Volt)</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>B: Electrolyte concentration (g/l)</td>
<td>50 100 150 200</td>
</tr>
<tr>
<td>C: Wire speed (m/min)</td>
<td>0.15 0.2 0.25 0.3</td>
</tr>
<tr>
<td>D: Gap between tool and anode (mm)</td>
<td>50 80 110 140</td>
</tr>
<tr>
<td>E: Supply current (amp)</td>
<td>1.4 1.6 1.8 2.0</td>
</tr>
</tbody>
</table>

Utilized the results S/N ratio (dB) has been calculated. The ANOVA for MR has been done (not presented in the paper) and DC supply voltage is identified as most significant parameter on material removal with 65.33 % contribution. Figure 9 show the S/N ratio (dB) graphs for MR. From Figure 9, it is concluded that the optimal parametric combination for higher MR is A_4B_4C_4D_1E_3.

Figure 10 shows the combined effect of D.C. supply voltage and wire speed on material removal (MR, mg). From 3-D graph Figure 10, it is clear that the
material removal increases with increase in DC supply voltage and wire speed.

![Graph showing S/N Ratio for material removal (MR, mg)](image)

**Figure 9** S/N Ratio for material removal (MR, mg)

![Graph showing effect of D.C. supply voltage and wire speed on MR, (mg)](image)

**Figure 10** effect of D.C. supply voltage and wire speed on MR, (mg)

### 6 Conclusions

Based on the experimental results during slicing of electrically non-conductive e-glass fibre epoxy composite on fabricated wire electro chemical spark machining (WECSM) setup the following conclusions are drawn as below:

- The developed WECSM setup can be effectively used for machining of non conductive e-glass fibre epoxy composite.
- From SEM graph, it is concluded that at the beginning of micro cutting the width of the micro slice is slightly more than the wire diameter but after few minutes of cutting the width of the micro slice decreases along the depth of cut. The surface of the micro slicing is irregular and poor if experiments are performed without plan.
- Fins and scattered along the cutting surfaces are observed that may be due to the adhering of small particles scattered from the work-piece surface during cutting. It is due to improper and insufficient flow rate of electrolyte during machining. The burrs are also noticed along the surface of micro cutting. However, from the experimental results, it is clear that the very fine micro slicing is possible. The generation of high surface texture also can be possible by optimization of machining parameters.

### References