TOOL WEAR PREDICTION IN DRILLING OF GFRP LAMINATES
USING NEURO FUZZY MODELLING

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Abstract

Recently the use of GFRP materials in engineering application has increased due to their omni potential properties such as high strength to weight ratio and high specific stiffness. As structural materials, fastening of GFRP structures cannot be avoided. The fastening efficiency is largely dependent on the quality of machined holes. Due to the anisotropic and non-homogenous structure of GFRP, there exist an extensive tool wear to the drill bit. The excessive tool wear make the drilling process very expensive as only limited number of holes can be drilled with one particular drill bit. High temperature, vibration and noise generated during drilling were some of the factors responsible for tool wear during drilling various GFRP laminates. Hence it is necessary to find out the optimized drilling condition which minimizes the drill temperature, vibration and noise to minimize drill wear during drilling GFRP laminates.

Mechanical properties of unidirectional laminates are very different from those random laminates. Hence the study of directionality of the reinforcement has a significant effect during drilling. The work presented here focuses on finding suitable drilling condition which minimizes temperature, vibration and noise on GFRP laminates such as unidirectional, bidirectional, woven and woven cross. Based on taguchi L16 Orthogonal Array, drilling experiments were conducted on a CNC drilling machine for different type of GFRP laminates. Input parameter used in the experiments for various drilling conditions were spindle speed, feed and point angle.

A modelling algorithm, Adaptive Neuro Fuzzy Inference System (ANFIS) is used to find flank wear in drilling process.

Keywords: Adaptive Neuro Fuzzy Inference System, Drill temperature, GFRP laminates, Noise, Vibration.
1 Introduction

GFRP’s are a very important engineering material. For composite matrix and reinforcement systems, the reinforcement type and orientation will in most instances be the dominant contributor to properties. Reinforcement forms for the various matrix systems are classified as uni directional, bi directional, woven and woven cross.\(^{1-8}\) In uni directional fiber orientation in which all of the major fibres run in one direction whereas for bi-directional the fiber run in two or more direction. Whereas woven fabrics are formed by interlacing two sets of threads, the warp and the woof interlaced at right angles to create a single layer. The fabrics integrity is maintained by the mechanical interlocking of fibers. woven reinforcement are particularly useful for constructing shapes with double curvature since they can readily be draped over quite complex formers, unlike uni directional prepegs which may wrinkle because of their anisotropy. Woven cross fiber creates a little criss-cross pattern when all those tiny fibers are actually woven together.\(^{9-16}\)

Given the growing importance of GFRP’s in industry and manufacturing much research has been conducted to understand the negative side effects of drilling GFRP’s laminates. But this work has been done in a very fragmented manner, concentrating on temperature, vibration and Noise during drilling process. Machining of laminate composite depends on the direction of fiber and matrix and their effects on machining process. Important requirement for thermoplastic matrices which are to be used in high performance composite is thermal stability. Chemical decomposition brought on by elevated temperature affect the mechanical and all other properties of the polymer matrix. Weinert et al. \cite{1} studied the effects of temperature on tool life during drilling FRPs in dry machining and wet machining condition and found that tool temperature increases with increase in both cutting speed and feed and tool wear is distinctively more in dry machining than in wet machining.\(^{16-18}\)

According to Maninder Singh et al. \cite{2} FRP composites have low thermal conductivity and heat capacity. This affects the energy balance between the tool and workpiece ensuing in high temperatures at the flank area of the drill bit. These thermal loads affect the machined surface, cutting forces and tool life.\(^{19-21}\)

Wilson et al. \cite{3} have experimentally measured the temperature for uni directional and cross ply laminates of carbon fiber reinforced plastic and analysed the properties in both
longitudinal and transverse direction. The behaviour of glass fiber and polyester in compression and also mechanical properties of CFRP uni directional laminates at low temperature were studied by Dutia and schutz et al. [24,25] respectively. Both of them found that the Strength and modulus of the composites increases with decreasing temperature.

Palanikumar et al. [26] studies on machining characteristics of glass fiber reinforced polymer composites and found that increase in feed rate increased the heat generation and hence tool wear, which resulted in the higher tool wear. The increase in feed rate also increase the chatter and it produces incomplete machining at a faster traverse, which leads to more tool wear and hence low feed rates are selected and is between 0.10 and 0.50 mm/rev.

According to Komanduri et al. [27] the high abrasiveness of GFRP fibres result in loss of sharpness of cutting edges of the tool. This loss of sharpness affects the integrity of the holes drilled, increases production costs, power consumption and the productivity of the drilling tool. Blunt edges not only reduce the life of the tool but results in excessive chatter and poor surface finishes including overheating of the tool and a requirement for more power and thrust whilst drilling.

Amit Kumar Tanwer et al. [28] stated that in tensile as well as compression test unidirectional oriented glass fiber composites have large value of all the properties such as Ultimate force, yield force, compressive strength, tensile strength, elongation than bidirectional. Vibration and Noise are found to be primarily dependent on fibre orientation and operating conditions and tool geometry have less influence. Ramkumar et al. [29] stated that in conventional drilling of GFRP, force fluctuation has been observed during drilling, since the drill encounters two different materials, whereas in case of superimposed vibration, no such severe fluctuation in force is observed. The severe force fluctuation observed in the case of conventional drilling may be the cause for damage around the drilled holes. This damage increases progressively with the increase in thrust force.

Ramulu et al. [30] stated that the cutting forces produced in the machining of fiber reinforced plastic are influenced by the orientation of the fiber. The tool which generates the smaller force is expected to be more effective in cutting. The measured vibration signal was related to the drilling parameters and the state of the tool. It has been reported by lee that only force and acceleration signals in the feed direction are significant, signals in the other
directions not revealing any useful information. Arul et al. [31] stated that, the defects in the drilling of composites are due to thrust forces experienced by the work material. The parametric influence on cutting force was experimentally evaluated.

Langella et al. [32] presented a mechanistic model for predicting thrust force and torque when drilling composite materials which allows a focused approach to the description of the most appropriate drill geometry and cutting parameters.

Rajpal Singh et al. [33] predicted the effective thermal conductivity (ETC) using the volume fraction and thermal conductivities of different fillers filled in polymer matrices.

Lim et al. [34] stated that vibratory system formed due to the effect of machining operation. Vibrations are often unfavourable to the work piece, cutting tool and machine tool. Increase in cutting forces often results in flank wear to the drill bit and work piece will be degraded.

Vikrant Gupta et al. [35] developed a modelling algorithm using ANFIS to predict the effective thermal conductivity of different fibers in the polymer matrix. Anastasios P et al. [16] studied Adaptive neuro-fuzzy inference system in modelling fatigue life of multidirectional composite laminates. Xu Lei et al. [36] used the dynamic mechanical analysis and vibration test to reveal the dynamic behaviours of specimen. The effect of woven structure was discussed and the resultant analysis was done.

It is eminent fact that high temperatures, vibration and noise formed during drilling laminates are the cause of unsatisfactory cutting tool life. Therefore, the most suitable drilling parameters have to be selected to minimize wear during drilling laminates. Studies about various laminates are not discussed so far. So this study will be useful to find the influence of temperature, vibration and noise on various laminates and to predict the optimized cutting condition during drilling various laminates.

Drilling Temperature was measured with PFA Teflon-coated K type thermocouples with a diameter of 115µm, vibration signal measured with accelerometer and noise measured with microphone were the output parameter used for the investigation. Experiments were carried out using 10mm diameter drill bit with various point angles 90° 120° 130° 140° to find out the effect of flank wear of the drill bit on drilling various laminates.
The effect of tool wear on the various parameters has been analyzed by ANFIS. From the observed results it was found that the predicted output tool wear is almost very close to the actual output obtained in the experimental work. ANFIS model is validated with minimum error, less than 5% which is experimentally reasonable. ANFIS improves the system accuracy and eliminates the limitation in statistical modelling. This research would have served its purpose if it aids in minimizing drill wear and damages caused to various GFRP’s laminates whilst drilling.

2 Experimental setup

The drilling test were carried out on Hass CNCMILL USA model CNC milling machine with maximum torque 104 Nm@12000 rpm, maximum power rating 20 HP. Figure 1 represents the experimental setup.

![CNC milling machine and measurement setup](image)

**Figure 1 CNC milling machine and measurement setup**

2.1 Cutting tools

Four uncoated carbide drill bits with a diameter of 10mm were utilized in drilling GFRP laminates. The dimensional properties of the drilling tool are as follows: tool overhang 47mm, point angle 90° 120° 130° 140° 130˚ and Shank type is cylindrical. A total of 4 uncoated carbide drills were used and the performance of each drill bit was examined and monitored for sixteen condition of various feed rate, spindle speed and point angle.
2.2 Specimen preparation

In these experiments, the various GFRP laminates such as woven roving, unidirectional, bidirectional and woven cross matrix specimen with dimensions 90 x 200 x 8 mm prepared through hand moulding technique and used as work piece. High strength E-Glass Mat was used as reinforcement in epoxy resin with araldite as hardener and processed to a room temperature for approx 3hrs to fabricate GFRP. The prepared laminates are an E-glass/epoxy with a fiber volume fraction of 50% with a young’s modulus of 35Gpa and a tensile strength of 60Mpa. The various laminates used in this study for investigation was shown in figure 2.

![Figure 2 Different arrangement of GFRP orientation](image)

2.3 Drilling test

An experiment was conducted on Hass CNC MILL USA Model computer numerical control (CNC) milling machine (presented in figure 1) with a maximum torque of 104Nm at 1200 rpm, a maximum power rating of 20Hp, drill trials were conducted under four different cutting conditions. The range of cutting condition for GFRP drilling was recommended by the ASM machining data. They are listed in table 1. The orthogonal array selected was L16 (4^4). A total of 16 experiments were carried out considering speed, feed, point angle and laminates.
for drilling. Each experiment has been repeated for four times and the temperature, vibration, noise were recorded for each experiment.

Table 1 Four Levels of Testing the Experiment

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Factors</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
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<td>30</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>S</td>
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<td>500</td>
<td>750</td>
<td>1000</td>
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<td>θ</td>
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<td>120</td>
<td>130</td>
<td>140</td>
</tr>
<tr>
<td>L</td>
<td>laminates</td>
<td>WC1</td>
<td>WOVEN2</td>
<td>BD3</td>
<td>UD4</td>
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</table>

2.4 Temperature Measurement

In this study, drill temperature was measured with PFA Teflon-coated K type thermocouples with a diameter of 115 μm. The range of thermocouple is 0–500 °C, and its response time is 10 μs. OMB-PDQ 30 analog input expansion module with a sampling rate of 2MHZ is connected with thermocouple output and interfaced with computer for investigation. The thermocouple was fixed and positioned above the workpiece as shown in Figure 1. The drilling temperature values are stored in laptop for further analyses.

2.5 Vibration measurement and Noise absorption

Vibration and noise during drilling the composite material were measured using Kistler 8636C50 piezo electric accelerometer and microphone. The accelerometer amplitude range 500g peak and frequency range 1 to 2000Hz and the microphone frequency range is 100–10000Hz, and minimum sensitivity to noise ratio 58dB. The data acquired from the accelerometer mounted on the fixture are stored in laptop for further analyses using DEWESOFT.

2.6 Flank wear measurement
Maximizing the tool life by drilling through optimum drilling condition was the ultimate objective of the present work. Flank wear was produced by the friction between the GFRP laminates and the end flanks of the tool. This wear type was measured by using profile projector.

3 Results and Discussion

The Experimental results of Temperature, Vibration and Noise of each sample are shown in table 2.

Table 2 Temperature, Vibration and Noise absorption values for each Experiment

<table>
<thead>
<tr>
<th>EX. NO</th>
<th>SPINDLE SPEED (rpm)</th>
<th>FEED RATE (mm/min)</th>
<th>POINT ANGLE (degree)</th>
<th>LAMINATES</th>
<th>TEMPERATURE (ºc)</th>
<th>VIBRATION (g)</th>
<th>NOISE (dBL)</th>
<th>TOOL WEAR (mm)</th>
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<td>25</td>
<td>90</td>
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<td>120</td>
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<td>9</td>
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<td>23.155</td>
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<td>10</td>
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<td>26.138</td>
<td>78.16</td>
<td>0.0369</td>
</tr>
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</table>
3.1 Experimental observation

The experimental results of temperature, vibration and noise obtained during drilling various GFRP laminates at different cutting condition are shown in table 2.

From the experiment we found that the minimum temperature for unidirectional composite was 44.139°C where as for bi directional, woven and woven cross the minimum temperature obtained was 52.463°C, 46.789°C and 51.531°C respectively. In the same way minimum vibration for unidirectional composite was 23.155g whereas for bi directional, woven and woven cross minimum vibration was 25.451g, 23.955g 25.132g respectively. Similarly minimum noise obtained during drilling uni directional GFRP laminates was 0.52dbl whereas for bi directional, woven and woven cross the minimum noise obtained 72.44dbl, 71.79dbl and 78.12dbl. This shows that during drilling various laminates minimum temperature, vibration and noise was obtained in uni directional laminates compared to other laminates.

The influence of temperature on unidirectional composite was 79% whereas for bidirectional, woven and woven cross was more than 80%. This shows the % influence of temperature was less in unidirectional laminates compared to bidirectional, woven and woven cross. Similar observation was found in vibration and noise.

The percentage of wear occurs in unidirectional composite is 29% whereas for bidirectional, woven and woven cross was 49%, 39% and 33% respectively. This implies that wear obtained during drilling unidirectional composite was less compared with other three laminates (bidirectional, woven, woven cross).

Optimum cutting condition for minimizing Drill Temperature and vibration

- The optimum cutting condition which minimizes the drill temperature and vibration during drilling uni directional GFRP laminates is speed 750rpm, feed 25mm/min and point angle 130°.
- The optimum cutting condition for bi directional GFRP laminates is 750rpm, feed 30mm/min and point angle 140°.
• Woven GFRP laminates the optimum cutting condition is 1000rpm, feed 25mm/min and point angle 140°
• Spindle speed 1000rpm, feed 30mm/min and point angle 130° was the optimum cutting condition for woven cross GFRP laminates.

Optimum cutting condition for minimizing noise

• From the experiment we found that the optimum cutting condition which minimizes the noise during drilling Uni directional GFRP laminates is spindle speed 250rpm, feed 40mm/min and point angle 140°.
• Similarly for bi directional GFRP laminates the optimum cutting condition was spindle speed 250rpm, feed 35mm/min and point angle 130°.
• The optimum cutting condition for woven GFRP laminates is spindle speed 250rpm, feed 30mm/min and point angle 120°
• For woven cross GFRP laminates the optimum cutting condition 250rpm, feed 25mm/min and point angle 90°.

3.2 Discussion

From above table 2 it was found that the minimum temperature, vibration and noise for unidirectional composite was less when compared for woven, bidirectional and woven cross. This is due to the orientation of composite in one direction. Whereas for woven, bidirectional and woven cross the orientations of fibers are in longitudinal and transverse direction. During drilling this laminates, the interactions between the tool and fibers will be more. This increases the temperature in woven, bidirectional and woven cross composites. The temperature increase in woven cross is more when compared to woven due to the orientation fibers at different angle.

Similarly it was found that vibration was more in woven, bidirectional and woven cross composites compared to unidirectional composite. This is due to the twisting of the laminates by the perpendicular arrangement of the warp and weft threads. From the literature we found that the strength, stiffness & damping co-efficient of unidirectional composites was more compared to other laminates. In general fibers in a one dimensional form are characterised by flexibility, fineness and high ratio of length to thickness due to orientation of composite in
one direction. Continuous fibers have long aspect ratio and normally have preferred orientation.

4 ANFIS modelling on tool wear

Adaptive Neuro-fuzzy inference system is a fuzzy inference system implemented in the framework of an adaptive neural network.

ANFIS is more powerful than the simple fuzzy logic algorithm and neural networks. Since it provides a method for fuzzy modelling to learn information about the data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. The architecture of ANFIS for flank wear is shown in Figure 3.

Figure 3    ANFIS Architecture

The seven inputs with one output and their final fuzzy membership functions are shown in this figure 3. A total of 84 network nodes and 12 fuzzy rules were used to build the fuzzy inference system.

A triangular – shaped membership functions were used to train ANFIS because it achieved the lowest training error as shown in the training curve of Figure 4. Seven triangular-shaped membership functions were used for inputs of spindle speed, feed rate, point angle, laminates, temperature, vibration, noise. The input values are normalized by the mark signal and
submitted for ANFIS training.

4.1 ANFIS training error curve

ANFIS predictions of tool wear starts by obtaining the data set (input-output data pairs) for training. The data set is used to find the initial premise parameters for the fuzzy membership functions by equally spacing each membership function. The values of the premise parameters are fixed, so the overall predicted tool wear, can be expressed as a linear combination of consequent parameters. Then, the output of ANFIS in Figure 4 shows the predicted tool wear.

![Figure 4 Trained output data for ANFIS](image)

4.2 Validation of Neuro Fuzzy Model of Flank Wear

The wear testing on a new carbide drill bit with same specification is conducted. The flank wear in every stages are noted. Then the obtained parameters are submitted for validation in ANFIS as shown in table 3. Figure 5 shows the FIS model of ANFIS.

Each validation data point (spindle speed, feed rate, point angle, laminates, temperature, vibration and noise) was fed into the system, and then the predicted tool wear values were plotted with the actual experimental values of tool wear as shown in Figure 6. This figure 6 shows that the predicted values are a close match to the actual ones.
No of Inputs : 7 (Exclude Machining time)

FIS : Mandani Sub clustering

Algorithm : Hybrid

Total number of Input Membership Functions: 84 (7 inputs X 12 each)

Total number of Output Membership Functions: 12

Membership Function: Gaussian Membership Function

Figure 5 FIS MODEL

Figure 6 ANFIS Validation diagram
Table 3 Validation of results

<table>
<thead>
<tr>
<th>EXN O</th>
<th>SPINDLE SPEED (rpm)</th>
<th>FEED RATE (mm/min)</th>
<th>POINT ANGLE (degree)</th>
<th>LAMINATES</th>
<th>TEMPERATURE (ºc)</th>
<th>VIBRATION (g)</th>
<th>NOISE (dB)</th>
<th>Tool wear (mm)</th>
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</table>

Actual values measured from the Profilometer and the output of FIS is shown in Table 3.

To validate the experimental values, tool wear values was measured for arbitrary cutting condition and validated with ANFIS modelling. It was found from the figure 6 percentage of error within 5% for tool wear. Since the % error was very less ANFIS was best suitable for modelling the evaluation of tool wear. The instrument errors in measurement system and uncertainty of machining parameters produce uneven rate of change in tool wear. This may be the reason for the error, which is experimentally reasonable.

5 Conclusions

Tool abrasion reduces their work life considerably. Blunted tools results in excessive power consumption, increase in production costs, excessive noise whilst drilling and a compromise in the integrity of the composite materials. In the present work a comparison of tool wear characteristics on drilling various laminates were studied. Drilling experiment was conducted by changing the spindle speed (rpm), feed rate (mm/min) and point angle (degree). The
ANFIS model developed for the validation of flank wear model is carried out with 5% error which is experimentally reasonable, because of its complex nomenclature.

Based on the experimental results the following conclusion can be drawn from drilling of various GFRP laminates.

- The spindle speed should be in the range of 62% from the rated speed in order to obtained minimum wear during drilling various GFRP laminates.
- The feed rate set should be in the range of 25-30mm/min and point angle must be in the range of 130-140° to obtained less wear during drilling GFRP laminates.
- The influence of temperature, vibration and noise in unidirectional composite was very less compared to other laminates.
- The percentage influence of temperature in unidirectional composite was 79% whereas the percentage influence of vibration and noise was 86% and 87% respectively. This shows the influence of vibration and noise was more in drill wear when compared to temperature. Similar observation was found in bidirectional, woven and woven cross.
- The percentage of wear obtained during drilling unidirectional laminates was very less compared to other laminates. This shows the significance of unidirectional laminates over other laminates.
- The investigation of drilling process has shown that unidirectional laminates was the best suited laminates.
- The statistical or analytical methods have certain limitations for non linear systems, and for online application. The ANFIS solves the stated problems. The model developed by neuro fuzzy system shows that the presented system can be used in real time with minimum error.
6 Reference

36. Lakshmi C., Ponnavaikko M., Sundararajan M., Improved kernel common vector method for face recognition varying in background conditions, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), V-6026 LNCS, PP-175-186, 2010