Optimization Of Machining Parameter In Drilling Of Coir-Bagasse Natural Fiber Reinforced Polymer Composites

M.Saravanan Kumar, S.Bharani Kumar, S.Joe Patrick Gnanaraj, R.Prabaharan, P.Ebenezer Sathish Paul

Abstract: Natural fiber reinforced polymer composites competing with the glass fiber reinforced polymer composites in many applications in various aspects. Machining of polymer based composites is differing from metal machining because of their anisotropic nature. Drilling operation is often required for structural joining/assembly of the composite materials. This present research investigates the effects of drilling parameter by drilling the holes on hybrid coir-bagasse reinforced polyester composites. Feed rate, spindle speed, drill diameter, and point angle are taken as input parameter. The parameters such as thrust force, torque and the quality of the hole by measuring delamination will be evaluated. Taguchi based grey relational analysis is employed in optimizing the drilling parameters. Analysis of variance is used to find the most significant parameter.

Index Terms: bagasse, coir, delamination, grey relational analysis, optimization, point angle, thrust force

1 INTRODUCTION

To obtain high specific strength and high specific modulus, composite materials evolved as a better replacement over the conventional materials. Fiber reinforced polymer composite materials are having wide range of applications in aerospace, automobile and house appliances. Synthetic fiber reinforced polymers (Glass, Carbon, Aramid etc) often possesses problems in various aspects like re-use or re-cycling, bio degradability that makes researchers to find alternative materials. In recent years, attempts have been made to use natural fibers as reinforcement in polymer composites. The source of natural fiber can be from animal/plants [1]. Natural fiber based hybrid composites possess increased fatigue life, better fracture toughness which cannot be achieved by single fiber reinforced composites [2]. The Present work is focused on drilling of natural fiber reinforced polymer composites. The following content is about the previous work done by the researchers. In drilling of fiber reinforced polymer composites, consideration should be made on parameters such as tool materials and geometry, feed rate and cutting speed. These parameters influence the thrust force and torque which will affect the quality of the drilled holes [3]. A mathematical model was developed for predicting the thrust force and torque in drilling of rosselle/sisal hybrid composite material based on artificial neural network (ANN) and regression models (RM). HSS twist drill was employed for drilling operation. The input variables are feed rate, cutting speed and drill bit diameter. Thrust force, torque was measured as response variables. Experimental values were compared with empirical model response values developed by an ANN and RM. The study revealed that the ANN model is effective than RM model in prediction of response variables in drilling of rosselle/sisal hybrid composites. [4]. The effect of process parameters on thrust force, torque and tool wear in drilling of coir fiber reinforced polyester composites.

The drilling experiments were planned using Box-Behnken design. From the observed values the mathematical relationship developed to correlating the input process variable and its corresponding responses. Confirmation experiments were conducted to validate the mathematical model and the percentage of error was calculated. Nelder-Mead and Genetic Algorithm techniques were employed to optimize the input parameters. [5]. A drilling operation was carried out on glass and sisal fiber reinforced epoxy composites by varying the feed rate and tools (Twist and Brad). Tensile and flexural tests were done for material characterization. Drilled plates were also tested for bearing and open-hole resistance. The results indicated that thrust force in sisal/epoxy plates were lower compared to the glass epoxy plates. Delamination extension and thrust force is more at higher feed rates. [6]. The effects of solid and hollow drill point geometry on drilling of sisal fiber reinforced polypropylene composite laminates were studied. The experiments were carried out for different drill geometry by varying the cutting speed and feed rates. The results indicate that more thrust force is developed for solid (twist) drill. For a trepanning drill, thrust force is almost half of force developed at the twist drill. Increase in feed rate results in higher thrust force for a twist drill and lower thrust force for a trepanning drill. The variation of torque with a cutting speed for a twist drill is nearly a constant but for trepanning drill torque decreases. The torque increases with feed rate for both drill geometries. [7]. A mathematical model were developed using non linear regression analysis and the results were compared with experimental result. Delamination area is measured using a digital scanning method . The bamboo is subjected 10% NaOH treatment and the mesh is weaved with 0/90° orientation. The drilling variables are speed, feed and drill bit diameter. Experiments are designed by fractional factorial design. Grey relational analysis employed to find the optimum parameters. Confirmation experiments have been carried out to validate the mathematical model. By performing analysis of variance, it was found that the feed rate has a maximum contribution of 40.05 % followed by drill diameter of 32.25 % percentage and then the influence of speed with 24.58 %. [8]. The effect of NaOH treatment and fiber length on drilling of short agave fiber reinforced epoxy composites by using HSS twist drill of diameter (4,6,8.5 mm) were studied. The results described that increasing the fiber length decrease the thrust force. Increase in drill diameter reduces the thrust force. Also
not much significant variations in thrust force between the treated and untreated fibers. [9]. In order to produce damage free holes, an attempt made in this work by varying the twist drill point angles and drilling parameters. From the literature review, the following natural fiber reinforced polymer materials were undergone drilling analysis i.e., coir, bamboo, banana, hybrid glass-sisal fiber, hemp, jute fiber. Extend this research work to hybrid natural fiber polymer composites. In this work hybrid (coir, bagasse) natural fiber composite were selected for the drilling experiment. Furthermore, the thrust force, torque, tool geometry are the factors which influence the quality of the drilled holes. In drilling of natural fiber reinforced composites no work has been reported about the effect of tool geometry.

2 MATERIALS AND METHODS

2.1 Materials
Raw coir was purchased from Rajathi coir industries pollachi, Tamilnadu. After the extractions of juice from sugarcane it was collected from sugarcane processing industry. The sodium hydroxide purchased from local chemical shop. The polyester resin (Thermo set) purchased from GVR Enterprises Madurai. The physical and chemical properties of the raw coir and bagasse fibers were shown in table 1. The fiber extraction process of bagasse and coir shown in Fig. 1 and Fig. 2. Coir and bagasse fiber reinforced polyester composites were selected for the investigation both fibers having good tensile strength that may enhance the composites property. [10]

2.2 Fiber chemical Treatment
Natural fibers are generally hydrophilic (water absorption) and polymer matrices are hydrophobic (water repelling) in nature that will affect the chemical bonding between fibers and matrices. Chemical composition of natural fibers includes hemicelluloses, lignin, and pectin etc. Alkali treatment of fiber reduces the hemicelluloses, lignin, and pectin and increases the aspect ratio. [11] Raw coir and bagasse was initially washed with water to remove the dirt and mud’s and dried for 48 h. afterwards, these fibers soaked in 5% NaOH concentration with maintaining liquor ratio of 1:20 for 1 h at room temperature. The treated fibers are taken and finally washed with distilled water to remove the sodium hydroxide presence in surface of fiber then again dried for 24 h. Fig. 3 depicts the chemically treated fiber.

2.3 Composite Preparation
The treated coir and bagasse fibers were cut into length of 10mm. For this work, a steel mould of length 250 mm, width 150 mm, and thickness 3 mm will be made. In natural fiber reinforced polymer composites, the volume fraction level can vary from 10% to 40 % in the total volume. In this experiment coir and bagasse volume fraction was taken as each 20% of total volume of composite. Composites will be fabricated by hand layup process at most care will be taken for equal distribution of fiber and matrix in the mould. The mechanical and physical properties of coir and bagasse are listed in Table 1.

2.4 Taguchi Method
Design of experiment is a structured way of planning the experiments and it reduces the cost and time. Among all design of experiment techniques Taguchi method is widely adopted for designing the experiments. This method is related to finding the best values controllable factors and to reduce the variations in the uncontrollable factors. This method addresses the issues of both on-line and off-line quality.

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**TABLE 1 PROPERTIES OF RAW FIBER**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Coir</th>
<th>Bagasse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.15</td>
<td>1.25</td>
</tr>
<tr>
<td>Diameter (µm)</td>
<td>100-450</td>
<td>10-34</td>
</tr>
<tr>
<td>Tensile Strength (Mpa)</td>
<td>131-715</td>
<td>222-290</td>
</tr>
<tr>
<td>Cellulose (wt %)</td>
<td>36-43</td>
<td>32-55.2</td>
</tr>
<tr>
<td>Hemicellulose (wt %)</td>
<td>10-20</td>
<td>16.8-24.7</td>
</tr>
<tr>
<td>Lignin (wt %)</td>
<td>41-45</td>
<td>19-25.3</td>
</tr>
</tbody>
</table>

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Fig. 3. Coir and Bagasse Fiber after Chemical Treatment

Fig. 4. Bagasse Fiber Separation Process

Fig 2 Coir Fiber Separation Process
controls. Taguchi method is based on mixed levels of highly fractional factorial design and orthogonal designs. It deals with two types of variables: Control variable, which are the factors that can be controlled and noise variables, which are the factors that cannot be controlled during the experiments [12]. For this work, the control variables are feed rate, spindle speed, drill bit diameter, point angle. The uncontrollable (noise) variables are thrust force, torque, delamination. For this drilling experiment, four control factors at three level shave been selected. Here, only the main factors are taken into consideration not the interaction. The degree of freedom for this investigation is Band Taguchi’s L9 orthogonal array is used to define the 9 trial conditions. However, Taguchi technique was developed to optimize the single performance characteristics [13]. The process parameters and levels are listed in Table 2. The orders of experiments are listed in table 3. The feed rate, speed and drill bit diameter process values are selected based on the previous research. Drilling at higher spindle speed will soften the matrix [5].

### Table 2

<table>
<thead>
<tr>
<th>Factors and Levels</th>
<th>Feed Rate (mm/rev)</th>
<th>Cutting Speed (rpm)</th>
<th>Drill Diameter (mm)</th>
<th>Point Angle (deg)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0.1</td>
<td>300</td>
<td>6</td>
<td>98</td>
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<tr>
<td></td>
<td>0.2</td>
<td>600</td>
<td>8</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>900</td>
<td>10</td>
<td>118</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Order of Experiments</th>
<th>Feed Rate (mm/rev)</th>
<th>Cutting Speed (rpm)</th>
<th>Drill Bit Diameter (mm)</th>
<th>Point Angle (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>300</td>
<td>6</td>
<td>98</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>600</td>
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<td>108</td>
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<tr>
<td>3</td>
<td>0.1</td>
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<td>4</td>
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<td>900</td>
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</table>

2.5 Drilling Experiment

For drilling, the composite specimen will be cut in the rectangular shape of 40×40×3 mm³ respectively. Drill tool dynamometer will be used to measure the thrust force and torque. The drilling process will be carried out under dry conditions. The coir-bagasse hybrid polyester composite is a soft material, so general purpose HSS drill bit will be used. [7] The drilling experiment is carried out on a drilling machine with variable speed drive. HSS drill bit material is used for the experiment. To measure the thrust force and torque a multi component Kistler Dynamometer is placed below the work piece and above to the drilling bed. The dynamometer was connected by a data acquisition system that is assembled in a personal computer to monitor the test values. The output signals received from the dynamometer were filtered and amplified using charge amplifiers were fed as an input to a computer through the digital signal oscilloscope. The experimental setup is shown in Fig. 4. The variation in values of thrust force and torque while drilling a hole with respect to machining time were plotted as a frequency wave forms in the digital oscilloscope.

2.6 Delamination Factor

Delamination failure occurs in a laminate composite material because of the action of machining forces. Peel-up delamination usually occurs at the entrance plane of the work piece. Push-down delamination occurs at the exit side of the work piece. The delamination factor can be measured using tool maker’s microscope. The delamination factor (F_d) is the ratio of the maximum diameter (D_max) of the delamination area to the drill diameter (D_0), this can be calculated using (1). [14]

\[
F_d = \frac{D_{\text{max}}}{D_0}
\]

2.7 GREY RELATIONAL ANALYSIS

Grey relational analysis is based on the Grey system theory. It was introduced in the year of 1982. In Grey system grey means poor, incomplete, uncertain. The Grey system theory is interdisciplinary and it bridges the gap between social science and the natural science. The applications of Grey theory were used in many fields such as ecology, agriculture, economy,
material science and engineering [15]. The grey relational analysis is used to measure the degree of relationship between sequences by grey relational grade. It is a measurement of absolute data difference between sequences, and is also used to measure an approximate correlation between the sequences. The use of Taguchi method with grey relational analysis to optimize the drilling process parameters the steps adopted for this work [16].

3. RESULTS AND DISCUSSION

3.1 RESULT ANALYSIS FOR COIR AND BAGASSE REINFORCED POLYESTER COMPOSITE

The Table 4 shows the grey relational analysis for coir & bagasse fiber reinforces polyester composites. ‘Lower-the-better’ quality characteristics were selected for thrust force, torque and delamination. Grey relational grade can be obtained by taking the average of grey relational coefficients. The higher value of grey relational grade is near to the product quality for optimum process parameters. In Table 5 the max-min column indicates that speed is the most significant parameter among the four input variables. In order to produce the best output the optimal combination of parameters as determined from response table shows that feed, speed must be maintained at level 1 (0.06,300) and a diameter, point angle must be maintained at level 3 (10,118). The purpose of the ANOVA is to investigate which factors significantly affect the performance characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions by each machining parameter and the error.

From the above Fig.6 it can see that the speed is the most influencing factor affects the multi performance characteristics having the higher grey grade value. Next to the speed, point angle influencing output characteristics which conforms to result of analysis of variance that shown in Table 6.

3.2 Result Analysis of Bagasse Fiber Reinforced Polyester Composites

The Table 7 shows the grey relational analysis for coir & bagasse fiber reinforces polyester composites.

* Indicates sum of squares added together to estimate the pooled error sum of squares shown within parenthesis. F ration is calculated as the ration of factor mean square to the error mean square. Results of analysis of variance indicate that Speed is the most significant machining parameter followed by point angle affecting the multiple performance characteristics.

3.2 Result Analysis of Bagasse Fiber Reinforced Polyester Composites

The Table 7 shows the grey relational analysis for coir & bagasse fiber reinforces polyester composites.
Table 8 shows response table for grey relational grade of bagasse. In order to produce the best output the optimal combination of parameters as determined from response table shows that feed must be maintained at level 1 (0.06 mm/rev), Speed must be maintained at level 1 (310 RPM), diameter must be maintained at level 3 (10 mm), Point angle must be maintained at level 1 (90 deg).

From the Fig. 7 it can be seen that speed is the most influencing factor affects the multi performance characteristics having the higher grey grade value.

4. CONCLUSION

Compatibility of coir-bagasse hybrid natural fiber reinforced polymer composite for structural assembly/bolted joints will be analyzed from the result. Taguchi based grey relational analysis is used in this work to optimize the values of input parameters such as feed, speed, point angle, drill bit diameter. From the Drilling experiments conducted on coir-bagasse hybrid fiber reinforced composites the following conclusions were made.

- Speed is the most contributing factor (69.01 %) that affects the hole quality of the drilling experiment.
- To produce a hole with less delamination, the input parameter must be maintained at the following levels Feed – 0.06 mm/rev, Speed – 300 RPM, Diameter – 10mm, Point angle – 118 deg

From the Drilling experiments conducted on bagasse fiber reinforced composites the following conclusions were made.

- Speed is the most contribution factor (44.48 %) followed by point angle at (28.80 %) affects the hole quality of the drilling experiment.
- To produce a hole with less delamination, the input parameter must be maintained at the following levels Feed -0.06 mm/rev, Speed – 300 RPM, Diameter – 10mm, Point angle – 90 deg

5. REFERENCES

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