Multi response optimization of drilling performance of MWCNT filled banana-glass fibre reinforced composite

T. Rajmohan¹, G.M. Dinesh¹, Gangamalla Vinay Raghavendra¹, Gayatri.S¹, K. R. Charan reddy¹, Kovuru Yogeswar¹

¹Department of Mechanical Engineering, Sri Chandrasekharendra Viswa Mahavidyalaya, Kanchipuram -631561, Tamilnadu, India.

Abstract. Natural fibres reinforced composites (NFRC) with their extended account of portion mankind are extremely significant in a broad variety of applications, and they battle and co-exist in the twenty-first century with man-made fibres, particularly as far as excellence, sustainability and cost-cutting measure of production are troubled. Numerous researchers have synthesized NFRCs using various natural fibres as well as matrix materials. Though, real-world applications of NFRCs involve some machining operations in order to complete the assembly of the parts. In this work, a technique based on the factorial design-based desirability analysis is used to determine the desired optimum machining parameters for minimum delamination, thrust force and surface roughness in drilling of MWCNT filled banana-glass natural fibres reinforced composites. The speed, federate, wt% MWCNT and point angle of drill are the most important parameters that characterize the machining operation and have been selected for investigation. Results indicated that point angle is playing major role on the responses followed by feed rate.

1. Introduction
Natural Fibre Reinforced Composites (NFRC) have turn into very significant materials in the recent years [1]. They have been used in numerous industries such as in automotive, aerospace, building and construction, and furniture industries [2]. NFRCs are inexpensive to produce, Eco friendly, safe to health, light in weight, High stiffness to strength ratio. Even though NFRC are lack in thermal stability, strength degradation, water absorption and poor impact properties [3]. To solve this problem, material engineers are investigating the use of hybridization and different nano particles mixed in different polymers to improve mechanical and wear properties of the polymer. The hybridization may be Natural – Natural, Natural – Artificial. It provides an alternative to achieve a mix together properties such as, high stiffness, Increased fatigue life, high toughness, high impact resistance [4]. The banana fiber was used as reinforcing agent in cement and polymer-based composites by various researchers [5-8]. Due to low density, high tensile strength, high tensile modulus, and low elongation at break of banana fibers, composites based on these fibers have very good potential use in the various sectors like construction, automotive, machinery, etc. [9]

Drilling building is one of the most important machining operations to make easy the assembly operations of components formed from NFRCs. Drilling of composite materials is considered to be a critical operation owing to their tendency to delaminate when subjected to cutting forces. In order to
defeat the issues such as delamination, poor surface roughness and etc., it is necessary to extend a appropriate method and choose suitable cutting parameters [10].

Durão et al. [11] assured that the decrease of delamination can be attained through the correct range of machining situation such as feed and cutting speed as well as tool material and tool geometry. Delamination mechanism takes place previous to the plates are entirely pierced by the drill, and it mostly depends on the feed rate and drill diameter [12]. Ramesh et al. [13] performed drilling by various drill geometries on hybrid glass-sisal, and glass-jute fiber reinforced composites. They concluded that the brad and spur drill created less induced break about the hole surface and produced lesser thrust force than the other two drills the delamination at hole exit increases with the increase in the feed rate and decreases with the increase in the speed and point angle [14]. Jayabal and Natarajan [15-16] showed that minimum drill forces are attained when using smaller diameter drill bits and functioning at higher spindle speed and lower feed rate in drilling of of coir fiber reinforced composites.

Patel et al. [14] found that the thrust force increases with the increase in the point angle and feed rate in drilling of banana fiber reinforced composites. Balaji et al. [17] found that treated woven coir mat exhibited low delamination when compared to non-woven coir reinforced polyester composites. Sakthivel et al. [18] found that the optimized parameter to control thrust force in basalt/sisal fiber. Venkateshwaran and ElayaPerumal [19] studied analysis of delamination at the entrance and exit of the composite plates as a function of the drilling process parameters. They used machine vision technique to analyse the quality of the hole and also the ultrasonic C-scan imaging method was carried out to find the amount of delamination.

Most of the published research work has been approved in machining of synthetic fibre reinforced composites. Not so much work has been reported on machining of NFRCs. Hence the present paper discusses the effect of drilling parameters on thrust force, surface roughness and delamination. Results revealed that point angle of drill are the significant factor followed by feed rate.

2. Materials and Methods

2.1 Materials used.
Epoxy resin Araldite LY556 and hardener Aradur HY951 is acquired from Huntsman group and MWCNT manufactured by M/S US Research Nano materials Inc, USA were used as components of the starting materials. Glass and banana fibres are acquired from M/s Suntech Fibers Chennai, India were used as a reinforcing agent. An ultrasonic bath sonicator, was used to make sure consistent dispersal of MWCNT particles into resin with no agglomeration. The present NFRCs includes of five layers in total, in which the glass fiber layers are set in the top, middle and bottom of the NFRC, whereas the second and fourth layers are filled by banana natural fibre. Compression moulding procedure is used to make the NFRCs for the present investigation. The composition of NFRC is presented Table 1

| Specimen | wt % Epoxy | wt % Glass | Wt % of MWCNT | wt % banana |
|----------|------------|------------|---------------|-------------|
| A1       | 60         | 25         | 0             | 15          |
| A2       | 60         | 25         | 1             | 15          |

2.2 Experimental design
Design of experiments (DoE) is an organized precise method in engineering problem cracking that applies principles and methods at the data compilation stage so as to make sure the generation of suitable, justifiable, and manageable engineering conclusions of manufacturing processes. To solve this problem a design in which every setting of every factor appears with every setting of every other factor is a full factorial design. An ordinary experimental design is one with all input factors set at two levels each. These levels are called ‘high’ and ‘low’ or ‘+1’ and ‘-1’, in that order. A design with all
probable high/low combinations of all the input factors is called a full factorial design in two levels. From the author’s earlier available research and numeral of tests conducted in the laboratory for polymer composites, four major control parameters were selected for the experiment (Rajmohan et al. 2015). The parameters selected for the present investigation are: 1. Spindle speed 2. Feed rate 3. wt% of filler 4. Drill point angle. In this research 4 factors 2 level full factorial $2^4$ experimental design is considered for conducting experiments are shown in Table 2.

**Table 2 Drilling parameters and their levels**

| Sno | Spindle speed rpm | Feed rate mm/rev | Point angle deg | Wt of MWCNT % |
|-----|-------------------|------------------|-----------------|---------------|
| Level 1 | 500              | 0.04              | 118             | 0             |
| Level 2 | 1250             | 0.08              | 135             | 1             |

**2.3 Experimental procedure**

Drilling engages the taking away the material from work piece such that a hole is obtained. Drilling is a difficult process; it needs methodical and quantitative swots on all the major controlling parameters on machining performance in order to structure the rule base under a wide range of work conditions. In the present investigation the drilling experiments were carried out in radial drilling machine. The machining samples were prepared in the form of 100 mm × 100 mm × 10 mm blocks for each material. Solid carbide Drills with diameter of 10 mm, a helix angle of 30°, and a point angle of 90° and 118° were used. The schematic arrangement of the experimental setup is shown in Figure 1.

![Figure 1 Experimental Setup](image)
The thrust force is measured directly from the strain gauge dynamometer. The surface roughness of the workpiece is measured with a Mitutoyo portable Surftest SJ-201 P/M contact profilometer at 2.4 mm cut-off value. Delamination is a damage phenomenon that occurs due to the anisotropic and brittleness of composite materials. The delamination was measured by using a coordinate measuring machine (CMM). The delamination factor is determined by the ratio of the maximum diameter Dmax of the delamination zone to the hole diameter D. The observed response values for all of the 16 experiments are listed in Table 3.

### Table 3. Experimental results

| wt % of MWCNT | Feed rate mm/rev | Point angle deg | Spindle speed rpm | Thrust force in N | Surface roughness um | Delamination factor |
|---------------|------------------|-----------------|-------------------|-------------------|----------------------|--------------------|
| 1             | 0                | 0.04            | 118               | 500               | 3                    | 1.813              | 1.001             |
| 2             | 0                | 0.08            | 118               | 500               | 3                    | 1.963              | 1.002             |
| 3             | 0                | 0.04            | 118               | 1250              | 5                    | 1.533              | 1.002             |
| 4             | 0                | 0.08            | 118               | 1250              | 7                    | 1.619              | 1.009             |
| 5             | 0                | 0.04            | 135               | 1250              | 7                    | 1.327              | 1.012             |
| 6             | 0                | 0.08            | 135               | 500               | 3                    | 1.985              | 1.011             |
| 7             | 0                | 0.04            | 135               | 500               | 5                    | 10.509             | 1.01              |
| 8             | 0                | 0.08            | 135               | 500               | 5                    | 12.939             | 1.009             |
| 9             | 5                | 0.08            | 135               | 500               | 3                    | 12.016             | 1.012             |
| 10            | 5                | 0.04            | 135               | 500               | 5                    | 12.939             | 1.009             |
| 11            | 5                | 0.04            | 135               | 1250              | 3                    | 5.155              | 1.011             |
| 12            | 5                | 0.08            | 135               | 1250              | 3                    | 12.016             | 1.001             |
| 13            | 5                | 0.04            | 118               | 1250              | 3                    | 10.849             | 0.999             |
| 14            | 5                | 0.08            | 118               | 1250              | 6                    | 9.722              | 1.001             |
| 15            | 5                | 0.04            | 118               | 500               | 6                    | 5.059              | 0.998             |
| 16            | 5                | 0.08            | 118               | 500               | 6                    | 5.059              | 0.998             |

3. Results and discussion

The machinability in this work was assessed by surface roughness (Ra) of the drilled surface of the work piece, thrust force and delamination. The Factorial design of experiments and desirability function analysis are applied in this project work for the identification of best levels of drilling parameters, significance, and optimisation of parameters.

- The individual desirability (di) is calculated for all the responses depending upon the type of quality characteristics. Since all the responses are possessing minimisation objective, the equation corresponding to smaller the better type is selected. The computed individual desirability for each quality characteristics using following equation

\[ d_i = \begin{cases} 
1, & \hat{y} \leq y_{\text{min}} \\
\left( \frac{y - y_{\text{max}}}{y_{\text{min}} - y_{\text{max}}} \right)^r, & y_{\text{min}} \leq \hat{y} \leq y_{\text{max}}, r \geq 0 \\
0, & \hat{y} \geq y_{\text{max}}
\end{cases} \]

where the \( y_{\text{max}} \) and \( y_{\text{min}} \) represent the upper/lower tolerance limits of by and s and t represent the weights.
The composite desirability values (dG) are calculated using following Equation

$$d_c = \sqrt{w_1 d_1^{w_1} \times w_2 d_2^{w_2} \ldots \ldots \times w_n d_n^{w_n}}$$

where $d_i$ is the individual desirability of the property $Y_i$, $w_i$ is the weight of the property “$Y_i$” in the composite desirability and $w$ is the sum of the individual weights. The weightage for responses are based on assumed weightage of 1:2:3 for thrust force, delamination and surface roughness, respectively. Finally, these values are considered for optimising the multi-response parameter design problem. The results are shown in the Table 4.

From the value of composite desirability in Table 4, the parameter effect and the optimal level are estimated and tabulated in Table 5. Considering the maximisation of composite desirability value, the optimal parameter condition is wt % MWCNT at level 1, spindle speed at level 2, feed rate at level 2 and point angle at level 1.

Using the composite desirability value, ANOVA is formulated for identifying the significant parameters. The results of ANOVA are given in the Table 6. Prediction of optimum condition: By using the identified optimal parameter condition, the quality characteristics are verified by conducting confirmation experiments.

### Table 4. Individual and composite desirability for responses

| S.No | $D_{\text{Thrust force}}$ | $D_{\text{Surface roughness}}$ | $D_{\text{delamination}}$ | Composite desirability |
|------|----------------------------|--------------------------------|---------------------------|------------------------|
| 1    | 0.958147                   | 0.785714                       | 1                         | 0.903242               |
| 2    | 0.848088                   | 0.785714                       | 1                         | 0.849784               |
| 3    | 0.945229                   | 0.714286                       | 1                         | 0.869079               |
| 4    | 0.98226                    | 0.714286                       | 0.6                       | 0.813634               |
| 5    | 0.926714                   | 0                               | 0.6                       | 0                      |
| 6    | 0.974854                   | 0.214286                       | 0.2                       | 0.451827               |
| 7    | 1                          | 0                               | 0.2                       | 0                      |
| 8    | 0.943334                   | 0.071429                       | 0                         | 0                      |
| 9    | 0.079487                   | 0                               | 1                         | 0                      |
| 10   | 0.209266                   | 0.142857                       | 0.6                       | 0.219622               |
| 11   | 0                          | 0.214286                       | 1                         | 0                      |
| 12   | 0.670341                   | 0.071429                       | 1                         | 0.339708               |
| 13   | 0.079487                   | 0.785714                       | 1                         | 0.260157               |
| 14   | 0.179986                   | 0.928571                       | 0.6                       | 0.380116               |
| 15   | 0.277041                   | 0.785714                       | 0.4                       | 0.416905               |
| 16   | 0.678608                   | 1                               | 0.4                       | 0.707109               |

### Table 5. Mean composite desirability for responses

| Level | wt % of MWCNT | Feed rate mm/rev | Point angle deg | Speed |
|-------|---------------|------------------|----------------|-------|
| 1     | **0.485**     | 0.333            | **0.65**       | 0.387 |
| 2     | 0.29          | **0.442**        | 0.126          | **0.402** |
| Optimal level | $W_1$ | $f_2$ | $P_1$ | $S_2$ |
5. Conclusions
Drilling experiments were conducted based on Factorial design technique for banana-glass fibre reinforced composites using carbide drill. The experimentally composed data were subjected to desirability function analysis for optimisation of machining parameters. From this analysis, the following conclusions are drawn for thrust force, delamination and surface roughness.

- Desirability function in the factorial design for the optimisation of multiple responses is a very useful tool for predicting surface roughness, thrust force and delamination in drilling of NFRCs.
- The optimal parameter condition is wt % MWCNT at level 1, spindle speed at level 2 feed rate at level 2 and point angle at level 1 to improve the performance in drilling of NFRCs.
- Point angle is the significant parameter followed by spindle speed and feed rate for drilling of NFRCs.

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Table 6. ANOVA for composite desirability

| Source          | Sum of Squares | df | Mean Square | F Value | p-value | Prob > F |
|-----------------|----------------|----|-------------|---------|---------|----------|
| Model           | 0.458733       | 4  | 0.114683    | 0.942037| 0.4755  |
| wt % MWCNT      | 0.107652       | 1  | 0.107652    | 0.884284| 0.3672  |
| Feed rate       | 0.000417       | 1  | 0.000417    | 0.003426| 0.9544  |
| Point angle     | 0.197793       | 1  | 0.197793    | 1.624718| 0.2287  |
| Spindle speed   | 0.152871       | 1  | 0.152871    | 1.255721| 0.2863  |

Table 7. Confirmation Experiments

| Optimum setting | Predicted values | Experimental values |
|-----------------|------------------|---------------------|
|                 | Roughness | Delamination | Thrust force | Roughness | Delamination | Thrust force |
| Wt% 1P1S2       | 1.62       | 1.002        | 5.25         | 1.67      | 1.004        | 5.5          |

3.1 Confirmation test
The intention of the confirmation test is to corroborate conclusions strained through the analysis phase. Once the optimum level of the process parameters is selected, the final step is to predict and verify the improvement of the performance characteristics using the optimum level of the process parameters. The confirmation experiment is conducted at the optimum test conditions to prove the quality characteristics for drilling of NFRCs. The summary of the results obtained from the confirmation tests are shown in Table 7. The predicted values are very close to the experimental results, and hence, the developed model is suitable for predicting the performance in drilling of NFRCs.

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