OPTIMIZATION OF PROCESS PARAMETERS IN DRILLING OF BAMBOO FIBRE REINFORCED POLYMERIC COMPOSITES

Prasun Mazumder[1], Y. H. K. Reddy[2],
Manash P. Borsaikia[3], Satadru Kashyap[4]
[1,2,3,4]Department of Mechanical Engineering,
Tezpur University, Napaam, Assam - 784028, (India)

ABSTRACT

A tremendous effort has been made to study bamboo based polymer composites as a response to the growing demand for developing low cost, renewable and eco-friendly material. As such study of machining characteristics of bamboo fiber reinforced polymer (BFRP) is of fundamental importance. Drilling is a commonly practiced machining process used for making holes in materials for joining various structural components. But drilling of composite materials is subjected to delamination due to generation of high thrust force and torque during machining. This study focuses on optimizing a set of process parameters namely cutting speed, feed rate and point angle in drilling of BFRP composite using HSS twist drill. The experiments are conducted according to Taguchi's L16 orthogonal array to study the influence of process parameters on the performance characteristics such as thrust force and torque. Analysis of variance (ANOVA) is also performed to examine the significance of each process parameter on the performance characteristics. Additionally, regression models are also developed for thrust force and torque which showed promising prediction capability at any desired set of input parameters. Results from this investigation illustrate appreciable improvement in the performance characteristics.

Keywords –Bamboo Fiber Reinforced Polymeric Composite,Drilling, Delamination, Regression, Taguchi

I INTRODUCTION

Glass fibre reinforced polymer (GFRP) composites have been widely used in various industries due to their high strength, lightweight and resistance to corrosion. However, increased production of this synthetic fibre composite has posed serious environmental threats which forced researchers to explore natural fibres as alternative to synthetic fibres. In addition, the disposal and recycling of GFRP is very expensive and unsafe for ecosystem. So, for the past few years, numerous researches have been carried out for development and fabrication of natural fibre composites. Of all the natural fibres, bamboo fibres has been extensively investigated due to its unique properties such as high strength to weight ratio, biodegradability, durability, abundance and low cost of production compared to GFRP. Many researchers have reported that bamboo fibre reinforced polymer (BFRP) composites have high specific mechanical properties which are comparable to GFRP composites [1-3]. Hence, there is a promising opportunity for bamboo fibre to replace or minimise glass fibre content in composites and to be utilized commercially on an industrial scale [4].

To practically apply the benefits of BFRPs on a commercial level, it is of fundamental importance to study their machining characteristics. But as of today, there is no literature available on the machining characteristics of BFRPs. Among various machining processes, drilling with twist drill still remains one of the most economical and efficient method for hole making as well as for riveting and fastening structural assemblies in the aerospace and automotive industries [5]. However, properties of composite materials such as non-homogeneous, anisotropy and hard reinforced fibres make them difficult to drill [6]. As a result, drilling of composite materials gives rise to many problems such as fibre pull-out, delamination, rough surface finish, etc. For rivets and bolted joints, damage free and precise holes must be drilled in the components to ensure high joint strength and precision. Thus, proper selection of drilling parameters is of paramount importance to achieve high quality and damaged free holes.

Precise selection of optimum machining conditions have been a major challenge and numerous researches have been carried out so far to investigate the effects of drilling parameters on the performance characteristics of the composite materials. Literature survey [7-11] reveals that the quality of the drilled holes strongly depends on the cutting parameters, tool geometry and cutting forces (thrust and torque). Davim et.al. [12] investigated the influence of process parameters like cutting speed and feed rate on thrust force, delamination and surface roughness in drilling of GFRP's using cemented carbide (K10) drill bits. They conducted experiments based on Taguchi design of experiment (DOE) technique and performed ANOVA to determine the contribution of the process parameters. The results indicated that feed rate has a greater influence on thrust force than cutting speed and "Brad & Spur" drill gives a better surface finish than "Stub Length" drill.

Taguchi DOE is based on the concept of designing a product or process in such a way so as to make its performance less sensitive to variation due to uncontrolled or noise variables which are not economical to control [13]. Taguchi method employs orthogonal arrays to determine the important factors affecting the operation with simultaneous improvement in quality and cost of manufacturing. The orthogonal arrays reduce the number of experiments to be studied as compared to a full factorial set which saves both time and resource. In addition the conclusions drawn from the small number of experiments are valid over the entire experimental region spanned by the control factors and their settings.

Palanikumar [14] optimized the drilling process parameters of GFRP composites using Taguchi method with grey relational analysis. The author employed L16 orthogonal array to conduct the experiments and determine the influence of cutting speed and feed rate on performance characteristics like surface roughness, thrust force and delamination factor. The results revealed that feed rate is the more influential parameter than cutting speed. Mohan et al. [15] carried out experiments to analyze the effects of process parameters in drilling of GFRP composites. Based on the results obtained, they concluded that feed rate, cutting speed and material thickness are the main contributing parameters for delamination in drilling of GFRP. Khashaba [16] studied drilling of

GFRP composites and asserted that with increase of cutting speed thrust force decreases. Kilickap [17] employed Taguchi method and ANOVA to investigate optimal drilling parameters of GFRP composite using four different drills. The results revealed that feed rate is the major influential parameter in delamination of GFRP. So, a significant amount of research has been carried out to study the machining characteristics of GFRP composites but there is no literature available on machining characteristic of BFRP composites despite its special properties which are comparable to that of GFRP.

The objective of this study is to optimize the process parameters in drilling of BFRP composite using Taguchi DOE technique and determine the most significant parameter affecting the performance characteristics (thrust force and torque) using ANOVA. Taguchi L16 orthogonal array is employed to find the optimal levels of the process parameters and then ANOVA is carried out to determine the percentage contribution of each process parameter. Confirmation tests are also performed to verify the optimal conditions achieved by Taguchi analysis. In addition, second-order linear regression models are also developed to predict the values of thrust force and torque at any desired set of input parameters. The result obtained from regression models showed good agreement with that of confirmation test.

II METHODOLOGY

2.1 Taguchi Method

Taguchi method was developed by Dr. Genichi Taguchi to improve the quality of manufacturing product or process and at the same time save resources to increase profitability. Taguchi method employs orthogonal arrays from design of experiments theory to study a large number of parameter space with a small number of experiments. The orthogonal arrays are balanced with respect to each control factor (parameter) and give the best set of experiment for a set of selected parameters and their levels, which reduce the number of experiments compared to a full factorial design. The experimental results are then transformed into signal to noise ratios. The signal-to-noise ratios are log functions of the desired output characteristic which serve as objective functions for optimization, help in data analysis and prediction of optimum results.

Taguchi design of experiments utilizes these signal-to-noise ratios to identify the control factors that reduce variability in a product or process by reducing the effects of uncontrollable factors (i.e. noise factors). During experimentation, the noise factors are manipulated to force variability to occur and than from the results, optimal set of control factors are identified that make the process or product robust i.e. resistant to variation from the noise factors.

The three signal-to-noise ratios that are commonly used in optimization process are:

- Smaller the better: It is used where smaller value of the response is desired.

$$\mathbf{S/N\,ratio(\eta) = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} y_i^2} \quad (1)$$

- Larger the better: It is used where larger value of the response is desired.

$$\mathbf{S/N\,ratio(\eta) = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}} \quad (2)$$

- Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

$$\mathbf{S/N\,ratio(\eta) = 10\log_{10}\frac{\mu^2}{\sigma^2}} \quad (3)$$

Where, $y_i = i^{th}$ observed response value and $n =$ number of observations in a trial, $\mu =$ average of observed response values and $\sigma =$ variance.

2.2 Selection of process parameters

Delamination in fibre reinforced polymer (FRP) composites during drilling is a major concern which affects the quality of drilled holes (surface roughness and dimensional precision) and strength of the composites. Much of the literature reported on drilling induced damage of composite materials have shown that quality of drilled holes strongly depends on cutting parameters, tool geometry, tool material, etc. Palanikumara et.al. [14] investigated the influence of drilling parameters namely cutting speed and feed rate on thrust force, delamination factor and surface roughness using a L16 orthogonal array. The results revealed that feed rate is more influential parameter than cutting speed. Murthy et.al [19] studied the effect of cutting parameters such as cutting speed, feed, drill diameter, point angle and material thickness on thrust force and torque produced during drilling of GFRP composites using solid carbide drill bit. The results indicated that cutting speed is the main contributing process parameter for thrust force and drill diameter for torque. So, for the present investigation, process parameters namely spindle speed, feed rate and drill point angle are selected as input parameters for optimizing thrust force and torque.

Taguchi design of experiments is employed in this study to design and conduct the experiments. In Taguchi experimental design 3 levels of input parameters are enough to handle the problem. But, to analyse the presence of any non linearity in the drilling experiments 4 levels are considered. For three process parameters and four levels L16 Taguchi orthogonal array (as shown in Table 2) is selected. Table 1 shows the input parameters and their corresponding levels.

2.3 Analysis of Variance

Analysis of variance (ANOVA) is a statistical model that was developed by R.A.Fisher to identify which input parameter (control factor) significantly affects the output characteristic. This can be achieved by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error [20]. The total sum of squared deviation SS_T can be calculated from total mean of S/N ratio η as shown in eqn. (4):

$$SS_T = \sum_{i=1}^{m}(\eta_i - \bar{\eta})^2 = \sum_{i=1}^{m}\eta_i^2 - \frac{1}{m}\left[\sum_{i=1}^{m}\eta_i\right]^2 \quad (4)$$

Where, m is the number of experiments in the orthogonal array (m=16 in this case) and η_i is the mean S/N ratio for the *i*th experiment. SS_T is divided into two sources: the mean sum of squares SS_m and the sum of the squared error SS_e as shown in eqn. (5):

$$\mathbf{SS_T = SS_m + SS_e} \quad (5)$$

Where, $SS_m = nM^2$ and $SS_e = \Sigma(y_i - M)^2$, with $M = \Sigma y_i / n$ (i = 1, 2, …, n) [11]. F-test is carried out to identify the process parameter which has the most significant effect on the output characteristic. Conclusions are drawn using the F-value such that the process parameter with higher F-value has greater contribution on the output characteristic. The actual amount of contribution of each process parameter on the output characteristic is indicated by the percentage contribution (P) in the ANOVA table. A significant amount of research has been performed to optimize the machining parameters on delamination of composite laminates using the Taguchi's experimental design in conjunction with ANOVA technique [12, 15, 17].

Table 1: Selected process parameters and their levels

Code	Variable	Level 1	Level 2	Level 3	Level 4
A	Cutting Speed (rpm)	500	1000	1500	2000
B	Feed Rate (mm/rev)	0.02	0.04	0.06	0.08
C	Point Angle (degree)	103	108	113	118

Table 2 – The basic L16 (4^3) orthogonal array

Experiment No.	Control factors and their levels		
	Speed	Feed	Point angle
1.	1	1	1
2.	1	2	2
3.	1	3	3
4.	1	4	4
5.	2	1	2
6.	2	2	1
7.	2	3	4
8.	2	4	3
9.	3	1	3
10.	3	2	4
11.	3	3	1
12.	3	4	2
13.	4	1	4
14.	4	2	3
15.	4	3	2
16.	4	4	1

III EXPERIMENTAL PROCEDURE

In the present investigation, bi-directional BFRP composite laminates are prepared with epoxy resin as the matrix material by compression moulding technique (CMT) as in [2]. The composites are made with 40% fibre volume ratio and have tensile strength of 67.24 MPa. The test specimens of size 120 × 20 × 5 mm were cut from the composite laminates of size 120 × 120 × 5 mm. The drilling experiments are conducted according to Taguchi's L16 orthogonal array as shown in table 2 on the BFRP test specimens with 8mm diameter high speed steel (HSS) drill. Each experiment is performed twice without using any coolant to reduce the experimental error. All the experiments are conducted on a vertical milling machine (Maker: Bharat Fritz Werner; Type: HF-2; Sl. No.-298).The test specimens are properly clamped to the machining centre as shown in fig. 2 before conducting the experiment. A Kistler piezoelectric dynamometer (type: 9272) is used to measure the axial thrust force and torque. Measuring range of thrust force varies from – 5 to 20 kN with a sensitivity of – 3.8 pC/ while range of torque varies from – 200 to 200 Nm with a sensitivity of – 160 pC/Nm. The proportional charge output from the dynamometer is passed through a low pass filter, than amplified by a charge amplifier (Kistler, type 5015) and finally stored in the computer through a data acquisition system (Advantech, PCL 818 HG, 100 KHz span length). The experimental setup used for conducting the drilling operation is presented in Fig.1

Figure 1 - Experimental set-up

Figure 2 – BFRP samples with drilled holes

IV RESULTS AND DISCUSSION

4.1 Experimental results

Drilling operations have been conducted according to Taguchi's L16 orthogonal array on the BFRP specimens and the samples are shown in Fig.2. The results obtained from the experiment are tabulated in Table 3 which shows the thrust force and torque generated corresponding to 16 different drilling conditions. The obtained experimental values are then converted into S/N ratio using (3) i.e. smaller-the-better criteria because lower values of thrust force and torque are required to reduce delamination in BFRP composites.

Table 4 shows the response table for thrust force which separate out the effect of each process parameter at different levels and thus identify the optimum level of each process parameter for particular performance characteristic. The response for cutting speed at level 1 is calculated by taking the average of the four observed responses corresponding to the same level. Similarly, S/N ratio for levels 2 and 3 are also calculated. By applying the same method, responses for feed and point angle are evaluated. The rank is assigned to each process parameter according to smaller-the-better criteria for obtaining minimum thrust force. The response table for torque is created by following the same method.

From Table 4, it is observed that the optimal combination for minimum thrust force according to the rank obtained is $\mathbf{S_3F_1P_4}$ i.e. cutting speed – 1500 rpm, feed – 0.02 mm/rev and point angle – 118^0. The main effects plot for S/N ratios of F_Z is shown in Fig.3. From the response table for torque (shown in table 5), it can be observed that optimal combination for lower torque according to the rank obtained is $\mathbf{S_1F_1P_4}$ i.e. cutting speed – 500 rpm, feed – 0.02 mm/rev and point angle – 118^0. The main effects plot for S/N ratios and mean of M_Z is shown in Fig.4.

4.2 ANOVA Results

In drilling of any composite material, lower values of thrust force and torque are always desired for achieving good quality holes. So, it is very important to understand the effect of process parameters on these performance characteristics. ANOVA is used in this study to determine the percentage contribution of each process parameter upon the output responses. Statistical analysis software MINITAB 17 is used to carry out ANOVA with 5% significance level and 95% confidence level. Table 6 and 7 shows the ANOVA tables based on S/N ratios of thrust force and torque respectively.

Table 3 – Taguchi's L16 standard orthogonal array with responses.

	Thrust Force (N)				Torque (N-m)			
Ex. No.	Trial 1	Trial 2	Mean	S/N	Trial 1	Trial 2	Mean	S/N
1	19.56	20.84	20.20	-26.1070	0.07	0.09	0.08	21.9382
2	15.24	13.82	14.53	-23.2453	0.10	0.08	0.09	20.9151
3	31.56	35.28	33.42	-30.4801	0.13	0.11	0.12	18.4164
4	19.23	17.81	18.52	-25.3528	0.08	0.08	0.08	21.9382
5	11.34	10.00	10.67	-20.5633	0.08	0.10	0.09	20.9151
6	21.54	19.52	20.53	-26.2478	0.09	0.11	0.10	20.0000
7	10.56	11.92	11.24	-21.0153	0.07	0.09	0.08	21.9382
8	25.66	26.98	26.32	-28.4057	0.16	0.14	0.15	16.4782
9	14.51	12.05	13.28	-22.4640	0.06	0.08	0.07	23.0980
10	14.56	14.08	14.32	-23.1189	0.08	0.06	0.07	23.0980
11	23.65	20.99	22.32	-26.9739	0.13	0.11	0.12	18.4164
12	17.25	12.89	15.07	-23.5623	0.14	0.16	0.15	16.4782
13	13.55	11.49	12.52	-21.9521	0.07	0.05	0.06	24.4370
14	30.84	25.72	28.28	-29.0296	0.11	0.13	0.12	18.4164
15	16.23	18.77	17.50	-24.8608	0.16	0.17	0.15	16.4782
16	41.87	38.57	40.22	-32.0888	0.19	0.17	0.18	14.8945

Table 4 - Response table for thrust force (F_Z)
(Smaller-the-better)

Level	Speed(S)	Feed (F)	Point Angle
1	-26.30	-22.77	-27.85
2	-24.06	-25.41	-23.06
3	-24.03	-25.83	-27.59
4	-26.98	-27.35	-22.86
Δ	2.95	4.58	4.99
Rank	3	2	1

Δ = (Largest value – Smallest value) of the

Table 5 - Response table torque (M_Z)
(Smaller-the-better)

Level	Speed (S)	Feed (F)	Point Angle
1	20.80	22.60	18.81
2	19.83	20.61	18.70
3	20.27	18.81	19.10
4	18.56	17.45	22.85
Δ	2.25	5.15	4.16
Rank	3	1	2

Δ = (Largest value – Smallest value) of the

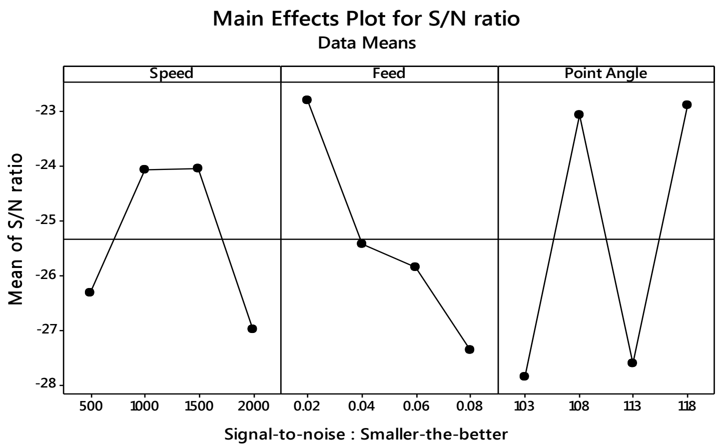

Figure 3 – Main effects plot for S/N ratios of thrust force (F_Z)

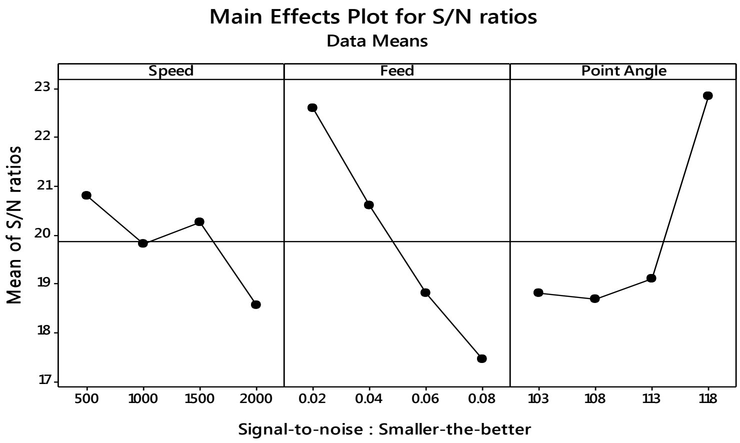

Figure 4 – Main effects plot for S/N ratios of torque (M_Z)

Table 6 - ANOVA data for S/N ratio of thrust force

Source	DOF	Sequential SS	Adjusted SS	Adjusted MS	F	P	% C
Speed (rpm)	3	27.89	27.89	9.298	5.31	0.040	13.08
Feed (mm/rev)	3	43.58	4358	14.525	8.29	0.015	22.15
P. A (degree)	3	91.06	91.06	30.355	17.33	0.002	49.58
Error	6	10.51	10.51	1.751			15.19
Total	15	173.04					100

S (mean square error) = 1.32336, R^2 = 93.93%, R^2 (adjusted) = 84.82%

The result of ANOVA for thrust force as shown in Table 6, reveals that point angle has the highest percentage contribution (49.58%) followed by feed rate (22.15%) and cutting speed (13.08%). This indicates that point angle is the most significant factor in minimising thrust force. This can be due to the reason that tool wear increases with reduction in point angle thereby increasing the chatter during drilling of hard reinforced fibre composites. Also better tool geometry allows the cutting action to take place from the outer diameter to the inner diameter. Therefore the drill acts as trepanning tool and prevents severe plastic deformation by reducing thrust force at the centre of the drill.

Table 7 – ANOVA data for S/N ratio of torque

Source	DOF	Sequential SS	Adjusted SS	Adjusted MS	F	P	% C
Speed (rpm)	3	11.029	11.029	3.676	6.29	0.028	7.58
Feed (mm/rev)	3	59.876	59.876	19.958	34.17	0.000	47.51
P.A (degree)	3	47.929	47.929	15.976	27.35	0.001	37.74
Error	6	3.504	3.504	0.584			7.17
Total	15	122.339					100

S (mean square error) = 0.764251, R^2 = 97.14%, R^2 (adjusted) = 92.84%.

The ANOVA for torque as shown in Table 7, reveals that feed rate has the highest percentage contribution (47.51%) followed by point angle (37.74%) and cutting speed (7.58%). Hence, feed rate is the most significant factor in minimising toque. It is observed that toque increases more rapidly with increase in feed rate whereas it decreases with increase in cutting speed. This can be attributed to the fact that chip loading action and shear area increases with increase in feed rate which in turn increases the torque.

4.3 Regression Analysis

Regression is a simple technique for investigating the functional relationship between the input and output parameters of a cutting process and can be used for parameter estimation. In this study, multiple linear regression equations are modelled to establish a correlation between the process parameters and output characteristics. The regression equations for thrust force (F_Z) and torque (M_Z) are:

$$F_Z = 79367 - 0.0019(S) + 1965(F) - 2161(PA) + 0.000013(S^2) - 834(F^2) + 19.59(PA^2) - 0.000285(S \times PA) - 15.8(F \times PA) - 0.0591(PA^3), R^2 = 89.78\% \quad (6)$$

$$M_Z = -4.80 - 0.000011(S) + 0.931(F) + 0.0910(PA) + 1.56(F^2) - 0.000425(PA^2), R^2 = 93.41\% \quad (7)$$

Where S = cutting speed (rpm), F = feed rate (mm/rev) and PA = point angle (degree). The regression equations (6) and (7) can be employed for estimating thrust force and torque for any combination of process parameters.. Statistical analysis software MINITAB 17 is used to model the regression equations. The normal probability plots for F_Z and M_Z as shown in Fig. 5 reveal that almost all the residuals follow a straight line pattern implying that the errors are distributed normally.

4.4 Confirmation Test

After determining the optimal levels of process parameters, confirmation tests are conducted to predict and verify the improvement in performance characteristics (thrust force and torque) using the optimal levels of process parameters. For thrust force the optimal levels are (**$S_3F_1P_4$**) i.e. cutting speed – 1500 rpm, feed – 0.02 mm/rev and point angle – 118 degree. For torque the optimal levels are (**$S_1F_1P_4$**) i.e. cutting speed – 500 rpm, feed – 0.02 mm/rev and point angle – 118 degree. The estimated S/N ratio corresponding to the optimum levels of process parameter is calculated as:

$$\eta_p = \eta_m + \sum_{i=1}^{n} \left(\eta_{im} - \eta_m\right) \quad (8)$$

Where, η_m is the total mean of the S/N ratio, η_{im} is the mean S/N ratio of the *i*th level and ***n*** is the number of process parameters affecting the performance characteristic [Nalbant].

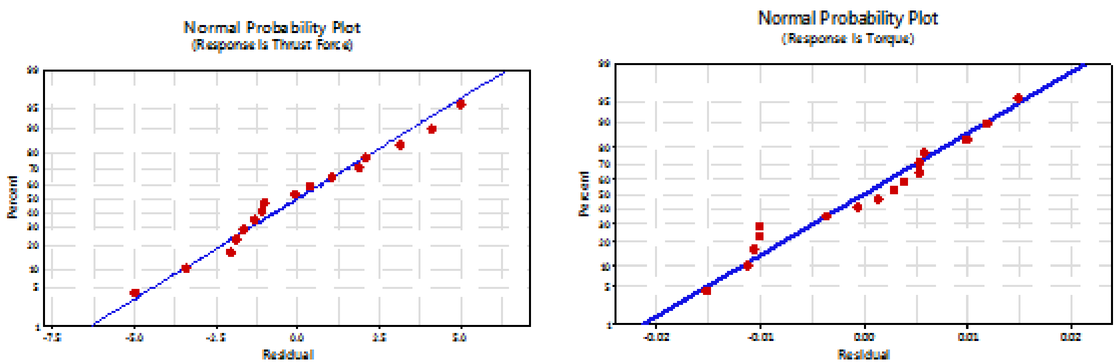

Figure 5 - Normal probability plot of residuals for thrust force and Torque

Subsequently, the performance characteristic corresponding to the estimated S/N ratio is calculated by using (3). After predicting the values, confirmation tests are carried out with optimum levels of the process parameters to verify the improvement in the performance characteristics. From Table 8, it can be observed that the results of the confirmation test have shown promising improvement of the performance parameters. This proves that the optimization method adopted in this study is feasible and very effective for optimizing the process parameters in drilling.

Table 8 – Results of the confirmation test and regression analysis

Sl. No.	Performance characteristic	Predicted value from eqn.9	Experimental value	Regression equation value
1.	Thrust force, N ($S_3F_1P_4$)	8.948	9.763	14.60
2.	Torque, Nm ($S_1F_1P_4$)	0.047	0.051	0.035

V CONCLUSIONS

This study presents the optimization of process parameters such as cutting speed, feed and point angle in drilling of BFRP composite laminates using Taguchi method. Based on experimental results, regression models are developed to predict the performance parameters at various drilling conditions. The following conclusions can be drawn based on the experimental results and analysis of this investigation:-

a) The optimal combination of process parameters for minimum thrust force is $\mathbf{S_3F_1P_4}$ (cutting speed – 1500 rpm, feed – 0.02 mm/rev and point angle – 118 degree). For minimum torque the optimal combination is $\mathbf{S_1F_1P_4}$ (cutting speed – 500 rpm, feed – 0.02 mm/rev and point angle – 118 degree).

b) The ANOVA results revealed that point angle is the most influencing parameter affecting thrust force with a contribution of 49.58% followed by feed rate (22.15%) and cutting speed has the least contribution of 13.08%. But feed rate plays the most significant role in minimising torque with a contribution of 47.51% followed by point angle (37.74%) and cutting speed (7.58%).

c) The results of confirmation test carried out at the optimal conditions demonstrated lower values of thrust force, torque, circularity error and surface roughness. Thus it can be concluded that the optimization method adopted in this study is very effective for increasing quality of the drilled holes.

d) The results obtained from the regression models also indicated good agreement with that of the confirmation test and demonstrated favourable prediction capability for any combination of the process parameters. However the accuracy can be improved by deriving higher order or non-linear regression equations in the future.

From the above points it is clear that this study will help in selection of optimal process parameters in drilling of BFRP composites to reduce delamination along with minimising surface roughness and circularity of drilled holes. Hence, both the performance and operational life of the BFRP composites will increase making it more desirable for industrial applications.

VI ACKNOWLEDGEMENT

We are grateful to Central Workshop, IIT Guwahati and Advanced Manufactured Lab, IIT Guwahati for their assistance. We are also indebted to the Department of Mechanical Engineering and Chemical Sciences, Tezpur University for extending their valuable assistance in completion of this research.

REFERENCES

[1] O. Kazuya, F. Toru and Y. Yuzo, *Development of bamboo-based polymer composites and their mechanical properties, Journal of Applied Science and Manufacturing, 36*, 2004, 377-383.

[2] Abhijit P. Deshpande, M. Bhaskar Rao and C. Lakshmana Rao, *Extraction of bamboo fibers and their use as reinforcement in polymeric composites, Journal of Applied Polymer Science, 76*, 2000, 83-92.

[3] R. Zahari, P. Zakikhani, M.T.H. Sultan and D.L. Majid, *Extraction and preparation of bamboo fiber-reinforced composites, Journal of Materials And Design 63*, 2014, 820-828.

[4] H.P.S. Abdul Khalil, I.U.H. Bhat, M. Jawaid, A. Jaidon, D. Hermawan and Y.S. Hadi, *Bamboo fiber reinforced bio composites: A review, Journal of Materials and Design, 42*, 2012, 353-368.

[5] C.C. Tsao, *Experimental study of drilling composite materials with step-code drill, Journal of Materials and Design, 29*, 1740-1744, 2008.

[6] H. Hocheng, C.C. Tsao, *Taguchi analysis of delamination associated with various drill bits in drilling of composite materials, Journal of Machine Tools and Manufacture, 44*, 2004, 1085-1090.

[7] N. Bhatnagar, N. Ramakrishnan, N.K. Naik and R. Komanduri, *On the machining of fiber reinforced plastic composite laminates, International Journal of Machine Tools and Manufacture, 35*, 1995, 701-706.

[8] R. Teti, *Machining of composite materials, CIRP ANN Manufacturing Technology, 51*, 2002, 611-634.

[9] A. Manna, B. Bhattacharyya, *Taguchi method based optimization of cutting tool flank wear during turning of SiC-MMC, International Journal of Machine Materials, 14*, 2006, 488-499.

[10] A.M. Abrao, P.E. Faria, Rubio Campos and J. Paulo Davim, *Drilling of fiber reinforced plastics: A review, Journal of Material Process Technology, 186*, 2007.

[11] B. Gopalsamy, B. Mondal and S. Ghosh, *Taguchi method and ANOVA. An approach for process parameters optimization of hard machining while hardened steel, Journal of Science and Industrial Research, 68*, 2009, 686-695.

[12] J. Paulo Davim, P. Reis and C. Antonio, *Experimental study of drilling GFRP manufactured by hand layup, Journal of Composite Science and Technology, 64*, 2004, 289-297.

[13] I. Mukherjee and P.K. Ray, *A review of optimization techniques in metal cutting processes, Journal of Computers and Industrial Engineering, 50*, 2006, 15-34.

[14] K. Palanikumar and J. Paulo Davim, *Assessment of some factors influencing tool wear on the machining of glass fiber-reinforced plastics by coated cemented carbide tools, Journal of Material Processing Technology, 209*, 2009, 511–519.

[15] N.S. Mohan, A. Ramachandra and S.M. Kulkarni, *Delamination analysis in drilling process of GFRP composite material, Journal of Materials Processing Technology, 186*, 2007, 265-271.

[16] U.A. Khashaba, I.A. Sonbaty and A.A. Megahed, *Machinability analysis in drilling of GFRP composites: Effect of machining parameters, Journal of Applied Science and Manufacturing, 41*, 2010, 391-400.

[17] Erol Kilickab, *Determination of optimum parameters on delamination in drilling of GFRP composites by Taguchi method, Indian Journal of Engineering and Material Science, 17*, 2010, 265-274.

[18] V.K. Vankati and V. Ganta, *Optimization of process parameters in drilling of GFRP composite using Taguchi method, Journal of Materials Research and Technology, 03*, 2014, 35-41.

[19] B.R.N. Murthy, L.R. Rodrigues and D. Anjaiah, *Process parameter optimization in GFRP drilling through integration of Taguchi and response surface methodology, Journal of Recent Trends in Science and Technology, 1*, 2012, 7-15.

[20] M. Nalbant, H. Gokkaya and G. Sur, *Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning, Journal of Materials and Design, 28*, 2007, 1379-1385.