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Optimization of Process Parameters in Drilling of Polyurethane Reinforced Jute Fiber Composite using Taguchi and Analysis of Variance (Anova)

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Abstract: ***In the modern days composites are being aggressively used because of low weight to volume ratio and ease in manufacturing. While machining of composite materials Drilling is a very common and important process used in industry to assemble composite structures. However, drilling composite materials present a number of problems such as reinforced of materials with the characteristics and cutting parameters. In order to reduce these problems, we present this study with the objective of evaluating the cutting parameters (cutting velocity and feed rate) and the influence of the fibers under the thrust force. The approach is based on the combination of Taguchi techniques of orthogonal arrays with the analysis of variance (ANOVA). An experimental plan was performed involving drilling with cutting parameters in Polyurethane Reinforced Jute Fiber composite (PURJFC) using a cemented carbide drill. The results were compared with the Natural fiber Reinforced composites. An experimental and finite element approach has been proposed to study the drilling characteristics of Polyurethane Reinforced Jute Fiber composite (PURJFC) with FEA.***

Keywords: Polyurethane Reinforced Jute Fiber Composites, Drilling, Taghuchi approach with ANOVA analysis

1. Introduction

In present days, composites processed from natural fibers are increasingly useful and preferred in the field of automotive, aircraft and construction industries. Natural fibers provide an additional advantage over synthetic fibers due to their low cost, biodegradability and eco-friendly properties. Consumption of synthetic fiber has been reduced in aircraft and military application due to high cost even though they have good mechanical properties. El Tayeb [1] has investigated and acknowledged the fact that the composites reinforced with natural fibers and polymer matrices have better mechanical properties. Malkapuram et al. [2] studied the adhesion between the fiber and matrix surface and concluded that the mechanical properties can be improved by chemical modification methods and novel processing techniques. Various natural fibers like jute, flax, sisal, kenaf, abaca and acacia are used for commercial purposes [3]. An investigation shows that jute-flax hybrid composite has better tensile and shear properties than flax-fiber mono composite but flax composite is superior to hybrid composites in flexural and impact properties [4]. Srinivasan *et al* [5] have experimentally tested and proved that hybrid composite with glass fiber reinforced composite (GFRP) have better thermal properties and also shows higher resistance under impact and flexural loading when compared to single fiber composite. Vijaya Ramnath *et al* [6, 7] have fabricated abaca-jute hybrid composite and evaluated various mechanical properties. They concluded that hybrid natural fiber composites have better tensile, flexural, impact and shear properties when compared with mono fiber composite. Wong *et al* [8] has studied the fracture characteristics of short bamboo fiber reinforced polyester composite and concluded that fracture toughness of all types of composites are higher compared to mere polymer composite. Koenig *et al* [9] has studied the various factors affecting machining of FRP’s and concluded fiber orientation also affects machining. Teti [10] and Abrao *et al* [11] have concluded that various characteristics of composite lamination such as non-homogenous, anisotropic, high abrasiveness make them difficult to be machined. Ali *et al* [12] has performed comparative study of drilling and milling process in hole making of GFRP composites. They concluded that milling process has been more suitable than drilling at higher cutting speed and lower feed rate. Sonbaty *et al* [13] have performed the drilling operation on GFRP with twist drills of various diameters with constant rotational speeds and found that with increase in drill diameter and feed rate, thrust force and torque has been increased. Khashaba [14] has studied the influence of drilling variables and material variables on thrust force and torque and concluded that the feeds and fiber volumes have direct effects on thrust forces and torques. Ariffin *et al* [15] has performed optimization of drilling process using design of experiments on aircraft composite. It has been concluded that minimum and maximum damage length of 0.05mm and 0.44mm was obtained when performed at 3000rpm and feed rate of 80.2 mm/rev for high speed steel. Tsao and Chiu [16] have investigated the influence of cutting velocity, feed rate and drill diameters on thrust force and found that cutting velocity, feed rate are the most influential among a group of five control factors. Yang *et al* [17] has conducted end milling on high purity graphite and optimized the various parameters such as cutting speed, feed rate and depth of cut. Strenkowski *et al* [18] has described a model for determining thrust force and torque in drilling. This model has been applicable for general drill geometries under various cutting condition. Hocheng and Tsao [19] have studied the effects of special drill bits on drilling induced delamination of composite material and reviewed the application of special drill bits and non-traditional machining methods and they have also concluded that the drilling thrust force varies with feed rate and has devised a feed rate strategy that avoids delamination due to high thrust

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force in drilling. Jin *et al* [20] has concluded that the thrust force have been influenced by thickness of drilling plates and also thrust force increases with feed rate and number of holes drilled. Marta *el al* [21] has studied drilling of carbon epoxy using one shot drill bit and the results showed the influence of tool wear and thickness of the work piece on the thrust force and torque in the drilling process. Duraoa *et al* [22] and Hocheng *et al* [23] have analyzed the effects of drilling parameters on composite plate's damage. The study inferred that lower feed rates and conservative cutting speed are most suitable for drilling of the composite plates.

In this paper, an approach based on the Taguchi method is used to determine the desired optimum cutting parameters for minimized appearance of thrust force in drilling uni-directional Polyurethane Reinforced Jute Fiber composite(PURJFC) and establish a correlation between a cutting speed and feed rate with the torque along with thrust force.

2. Material and Composition

Polyurethane Rainforced Jute fibers composites (PURJFC) are substances produced by plants and animals and they are environment friendly. The added key advantages are their strength, high stiffness to weight ratio, acoustic isolation, high damping and rapid production. The following natural fibers namely jute and flax have been used in this work.

Jute fiber

Jute which is called as "The golden fiber" mainly because of its colour and high cash value comes under the family name of Sparrmanniaceae. Jute fibers are 100% bio-degradable and recyclable. They are environmental friendly. They are the 2nd most available vegetable fiber. They also have good tensile strength and low extensibility.

Polyurethane reinforced composite (PURC)

polyurethane (PU) is one of the most rapidly developing branches in polymer technology with a wide variety of applications, such as foams, coatings, elastomers, resins, and medicine. PU composites have good wear resistance and excellent mechanical properties, and it is easy to adjust their hardness by changing the ratio of hard and soft segments. As a result, they are an important class of materials for structural and tribological applications (that is, to do with interactions of moving surfaces, such as friction or lubrication). For example, they have been widely used to produce bearings, gears, and ships' tailshafts.

Resin and Hardener

The main purpose of Resin and Hardener are to bind various layers of fiber. Epoxy resins have excellent mechanical strength, resistance to heat, adhesive strength and low curing contraction. These resin and hardener are used at room temperature to achieve better results. Epoxy LY558 Resin and Araldite HY951 hardener are used for fabrication of composite in this work.

3. Fabrication of Composite

Hand layup process is used to fabricate Polyurethane Reinforced Jute fibers composites (PURJFC).Initially, the fibers are allowed to dry in sunlight for complete removal of moisture. Combing is done to separate small flakes present in jut fiber. A releasing agent (Poly Vinyl Alcohol) is spread over flat surface of mold for easy removal of composites. Resin hardener mixture is applied between layers of fibers for binding purpose. GFRP is used as laminate on outer side of composites so that it covers the composites on both sides. Here, the jute fibers are arranged in vertical orientation and flax fibers are arranged at 45o to jute fiber. The composite consists of 5 layers of fibers at different orientation as shown below:

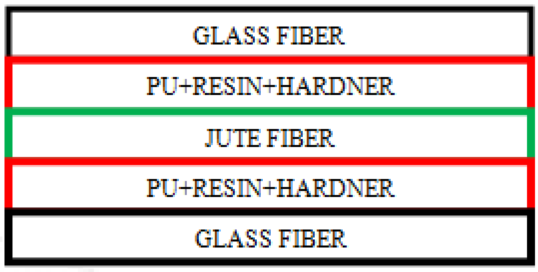

Figure 3.1: Schematic diagram of Jute+Flax composite

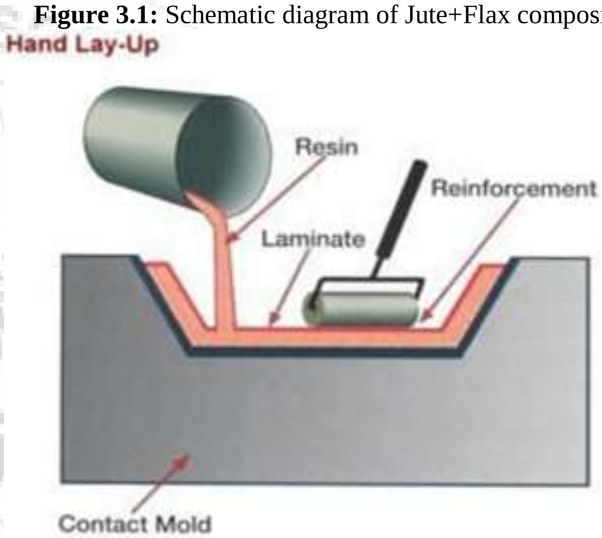

Figure 3.2: Fabricating Method

4. Experimental setup

Drilling machine

In this work, drilling was done on a vertical CNC machine, BMV TC24 manufactured by BFW as shown in figure 2. Initially, test drill was performed to ensure that the work piece is clamped properly. The drill was performed under varying combination of cutting parameters namely drill bit diameter, spindle speed and feed rate.

Figure 4.1 CNC drilling machine

A number of drilling experiments were carried out on a CNC machining center (Maxmill) using HSS twist drills for the machining of natural fiber reinforced epoxy composites. A two-component Drill tool dynamometer was used to record the thrust force and torque. Conventional high speed steel twist drills are used as much as cemented tungsten carbide drills. The results indicated that thrust force and torque increased with drill diameter and feed rate, due to the increase in the shear area. Increasing cutting speed also resulted in higher thrust force and torque, however, not to the same extent as when feed rate is elevated.

Figure 4.2: Drill Tool Dynamometer

From the table 4.1 the drill diameter are 4, 6, 8 are used and thus and the point angle, helix angle, rake angle, clearance angle, cutting angle, chisel angle are constant without the variation for the drill diameters and thus they are 118,30,30,12,3.75,2.2,45.

Table 4.1: Specifications of HSS Twist Drill

Drill diameter (mm)	Point angle (degree)	Helix angle (degree)	Rake angle (degree)	Clearance angle (degree)	Cutting edge length (mm)	Chisel edge length (mm)	Chisel edge angle (degree)
4	118	30	30	12	3.75	2.2	45
6	118	30	30	12	3.75	2.2	45
8	118	30	30	12	3.75	2.2	45

Selection of Maching Parameters

From the table 4.2 the levels of the 1,2 and 3 for their respective revolution in rpm is 600,800 and 1000 and the feed rate in mm/min are 50,100,150 thus through it the experiments were carried out as per L9 orthogonal array with each experiment performed under different conditions of feed rate and cutting speed. The thrust force and torque were the response variables recorded for each run. The effect of the machining parameters is another important aspect to be considered. It can be seen that cutting speeds from 50 to 150 m/min are usually employed, whereas feed rate values lower than 150 mm/rev are frequent. The use of feed rates below 150 mm/rev may be associated to the delaminating damage caused when this parameter is increased. In the present study, two parameters, namely, feed rate (f) and cutting speed (v) were identified and the range of the parameters for the present investigation was determined from the preliminary experiments. Each parameter was investigated at three levels to study the non-linearity effect of the process parameters. The identified process parameters affecting the thrust force and torque in drilling process and their levels are summarized in table.

Table 4.2: Machining Parameters Taken

Level	Revolution in rpm	Feed rate in mm/min
1	600	50
2	800	100
3	1000	150

Optimization of machining parameters

Design of Experiment

Taguchi method is mainly used to study the effect of all the parameters with minimum possible number of experiments. Initially, a proper orthogonal array must be selected based on the number of parameters. Since, this work is aimed to analyze the effect of machining parameter more accurately, signal to noise ratio are calculated. The contribution of each parameter can be clearly obtained using ANOVA method.

Taguchi approach

Taguchi approach is a statistical method. The experiments were performed using Taguchi approach which is used to investigate the effect of different parameter affecting the mean and variance of a process performance characteristic that define the outcome of the product with less number of experiments.

The cutting parameters which affecting the drilling process, considered in this experiment are spindle speed and feed rate. L9 orthogonal array is chosen. The plan of experiments is made of nine tests where the first column was assigned to spindle speed (N) and the second column to the feed rate (f) and the remaining to interactions. The output studied are the thrust force (Fz) and Torque in the Polyurethane reinforced Jute Fiber composite (PURJFC) material.

Each drilling process parameter is assigned to a column and nine drilling process parameter combinations are available. Thus, only nine drilling experiments are required to study the entire drilling process parameter space using L9 orthogonal array. The experimental layout plan for the drilling process parameters using L9 orthogonal array is shown in table 4.3.

Table 4.3: Orthogonal Array

Trail no.	Level of Input Factors	
	A	**B**
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

5. Results and Discussion

Drilling Forces

In general, the thrust and torque parameters will mainly depend on the manufacturing conditions employed, such as: feed, cutting speed, tool geometry, machine tool and cutting tool rigidity, etc. A larger thrust force occurred for larger diameter drills and higher feed rates. In other words, feed rate and drill diameter are recognized the most significant factors affecting the thrust force. The thrust force is not significantly affected by the speed. It can be seen that thrust force and torque increased with drill diameter and feed rate. Examining these results, it is found that the torque increased slightly as the cutting speed increased. However, the increase in torque was much smaller than that in thrust force as cutting speed increases. It was noticed that the average torque decreased as drilled length increased for twist drill. The results indicate that the torque increases as the feed increases. This increase is due to the increasing of the cross-sectional area of the un deformed chip ($A = D_f/4$). The results also indicate that the torque increases with the increase of the fiber volume fraction. This leads to the increase in the required thrust force and torque.

Figure 5.1: Drilling in PURJFC material

Using Analysis of Variance Methods (ANOVA)

The analysis of variance (ANOVA) of the experimental data was done to statistically analyze the relative significance of the parameters, and feed rate (A) and speed (B) under investigation on the response variables, the thrust force and the torque. The ANOVA is also needed for estimating the variance of error for the effects and confidence interval of the prediction error. The detailed analysis of variance (ANOVA) of the experimental data gave the valuable information regarding the significance of the factors under study on the thrust force and the torque. This analysis is performed on S/N ratios to obtain the percentage contribution of each of the factors.

The overall mean of ή associated with nine trials is computed as

$$m = \frac{1}{9}\sum_{k=1}^{k=9} \eta_k$$

The effect of a factor level i for parameter j is

$$(m)_{i,j} = \frac{1}{L}\sum_{i=1}^{L} (\eta_i)_j$$

The total sum of squares (SST) is determined as

$$SS_T = \sum_{k=1}^{9} (\eta_k - m)^2$$

SST is used to measure the relative influence of the process parameters on the response. The sum of squares due to factor j is computed as

$$SS_j = \sum_{i=1}^{3} 3[(m_j)_i - m]_i^2 \quad \text{for } j = f, v; \; i = 1, 2, 3$$

A factor j with largest SS value will have significant role in controlling the response.

The sum of the squares due to error (SSe) is given by

$$SS_e = SS_T - \sum_{j=1}^{2} SS_j$$

The variance of each factor j is

$$MS_j = \frac{SS_j}{L-1}$$

The percentage contribution of each factor j is given as

$$Q_j = \frac{SS_j}{SS_T}$$

ANOVA Results

From the results of ANOVA as illustrated in Table 5.2 & 5.3, it is observed that the feed rate is the only significant factor that influences the thrust force in the experimental domain. The torque is affected by the feed rate and also influences by the interaction of the two factors.

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Table 5.1: Summary of ANOVA for Thrust Force

Factor	Degree of Freedom (DOF)	Sum of Squares (SS)	Variance of Each Factors	Percentage of Each Factor (%)
Spindle Speed	2	57.33	28.66	96.83
Cutting Speed	2	1.249	0.624	2.11
Error	4	0.623	0.155	1.052
Total	8	59.20	7.40	100

Table 5.2: Summary of ANOVA for TORQUE

Factor	Degree of Freedom (DOF)	Sum of Squares (SS)	Variance of Each Factors	Percentage of Each Factor (%)
Spindle Speed	2	193.81	96.0	73.31
Cutting Speed	2	17.01	8.5	6.43
Error	4	53.54	13.38	20.25
Total	8	264.37	33.046	100

Regression Model

The statistical tool, regression analysis helps to estimate the value of one variable from the given value of another. In regression analysis, there are two types of variables. The variable whose value is influenced or is to be predicted is called dependent variable and the variable, which influences the values or used for prediction is called independent variables. (Using SPSS software) the tool regression can be extended to three or more variables. If two variables are taken into account, then it is called simple regression. The tool of regression when extended to three or more variables is called multiple regressions. The thrust force and the torque models using regression analysis are:

Non Linear Regression Equations

$Fz = k^* f^{a*} n^b (R^2)$

$Mz=k^*f^a{}^*n^b (R^2)$

Where, Fz – Thrust force (N)

Mz – Torque (N-cm)

f – Feed rate (mm/rev)

n – Speed (rpm)

R – Accuracy

Thrust Force

Nonlinear Regression Summary Statistics Dependent Variable F_Z can be calculated as:

Source	DF	Sum of squares	Mean of squares
Regression	3	44481.41109	14827.13703
Residual	6	172.13931	28.68988
Uncorrected Total	9	44653.55040	
Corrected Total	8	3550.04280	

{R squared = 1 - Residual SS / Corrected SS = **.95151**}

TORQUE

Nonlinear Regression Summary Statistics Dependent Variable T can be calculated as:

Source	DF	Sum of squares	Mean of squares
Regression	3	183.78427	61.26142
Residual	6	7.50963	1.25160
Uncorrected Total	9	191.29390	
Corrected Total	8	39.20334	

{R squared = 1 - Residual SS / Corrected SS = **.80844**}

Regression Model Result

$Fz=117.7019280 \text{ X } f^{0.685734030} \text{ X } n^{0.080880740}$ (R^2 = 0.95151)

$Mz=117.7019280 \text{ X } f^{1.178302203} \text{ X } n^{0.151045076}$ (R^2 = 0.80844)

6. Experimental and Predicted Values

Table 5.4 gives a comparison between the experimental and the predicted values from the thrust and the torque models. It is evident that the thrust and torque models fit the experimental data reasonably well and can be used to predict the drilling forces while drilling Polyurethane reinforced Jute fiber composites (PURJFC). The results of the experimental study were used as a basis for developing an initial Finite Element model for studying the drilling of Polyurethane reinforced Jute Fiber composite materials.

Table 5.4: Experimental & Predicted Values

S. no	Drill bit Diameter (mm)	Feed (mm/min)	Speed (rpm)	Thrust Force(N)	Torque (N/cm)	Damage Factor
1	4	50	600	44.14	2.94	1.06
2	4	100	600	58.86	3.92	1
3	4	150	600	89.92	5.89	1.18
4	4	50	800	45.14	2.14	1.07
5	4	100	800	60.86	4.15	1.09
6	4	150	800	88.56	5.82	1
7	4	50	1000	47.05	1.72	1.075
8	4	100	1000	67.48	4.52	1.005
9	4	150	1000	88.46	5.62	1.145
10	6	50	600	45.82	2.98	1.037
11	6	100	600	60.12	3.92	1.013
12	6	150	600	89.92	6.12	1.046
13	6	50	800	46.81	2.16	1
14	6	100	800	68.19	4.15	1
15	6	150	800	89.62	5.82	1.046
16	6	50	1000	48.81	1.86	1.08
17	6	100	1000	44.145	5.01	1
18	6	150	1000	58.86	5.71	1.056
19	8	50	600	89.92	3.01	1.07
20	8	100	600	45.14	4.13	1.1
21	8	150	600	60.86	5.72	1.047
22	8	50	800	88.56	2.14	1.01
23	8	100	800	47.05	4.15	1.03
24	8	150	800	67.48	5.14	1.052
25	8	50	1000	88.46	2.13	1.027
26	8	100	1000	45.82	4.52	1.042
27	8	150	1000	60.12	5.71	1.05

Variation of Thrust Force

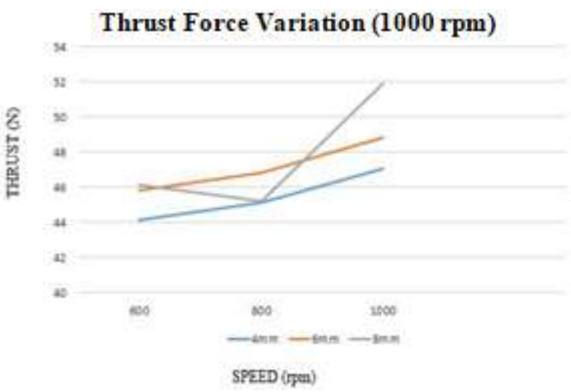

Figure 6.1: Variations of Thrust Force & Speed

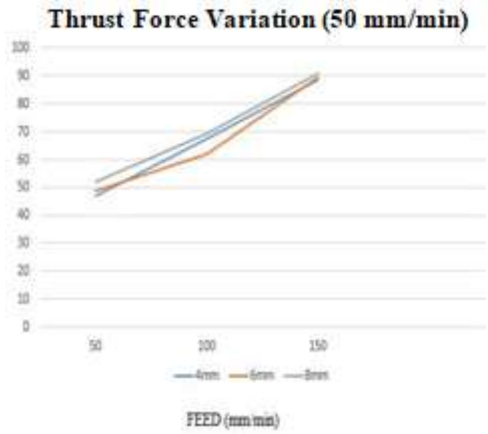

Figure 6.2: Variation of Thrust Force & Feed

Variation of Torque

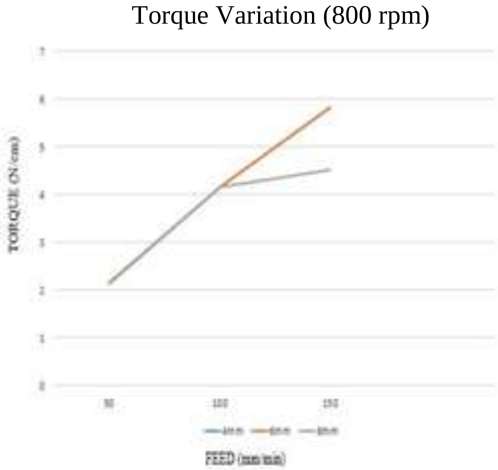

Figure 6.3: Variation of Torque & speed

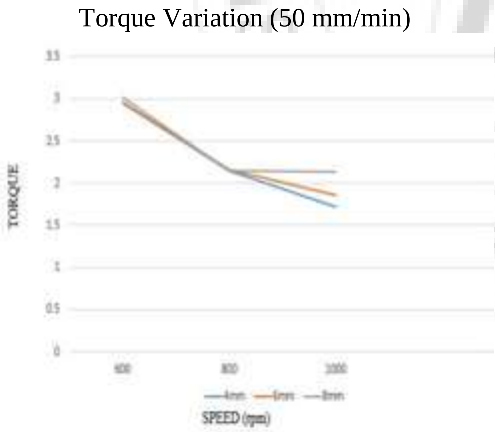

Figure 6.4: Variation of Torque & feed

Table 6.5: Orthogonal Taguchi Technique

	Drill bit Diameter (mm)	Feed (mm/min)	Speed (rpm)	Thrust Force(N)	Torque (N/cm)	Damage Factor
L9	4	600	50	44.145	2.94	1.06
Orthogonal Array	4	1000	150	88.46	5.62	1.145
Taguchi Technique	6	600	100	60.12	3.92	1.013
	6	800	150	89.62	5.82	1.046
	8	1000	100	69.48	4.52	1.042
	6	1000	50	48.81	1.86	1.08
	8	600	150	90.82	5.72	1.047
	4	800	100	60.86	4.15	1.09
	8	800	50	45.19	2.14	1.01

From the table 6.5 explains that the orthogonal Taguchi technique of the L9 array for which is preferable one to get the result and graph.

3-D Graph of various factors

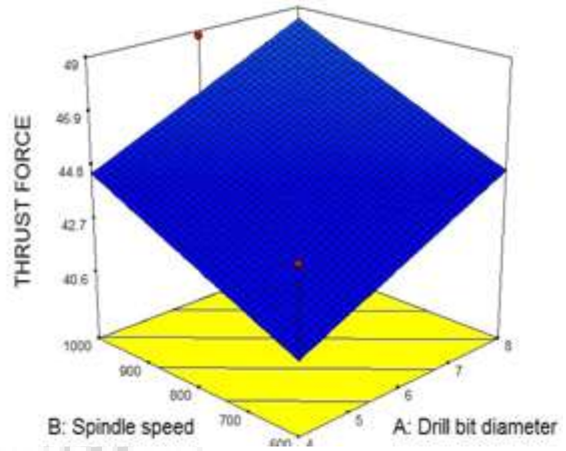

Figure 6.5: 3D graph for Thrust force and spindle speed, drill bit diameter.

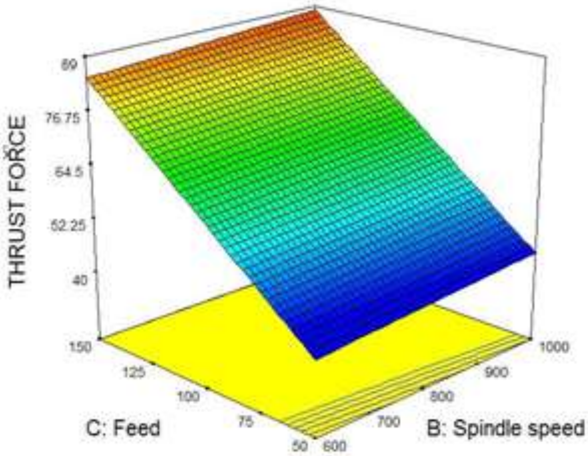

Figure 6.6: 3D graph for thrust force and spindle Speed and feed.

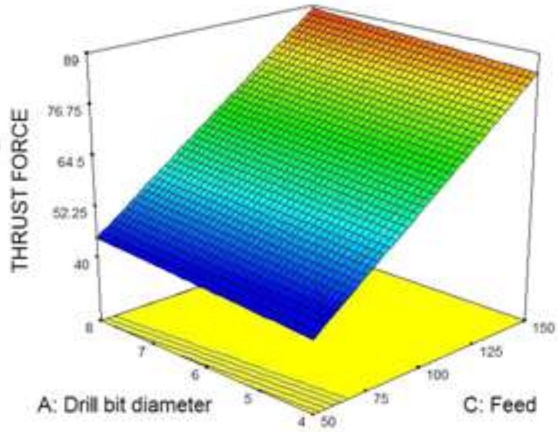

Figure 6.7: 3D graph for thrust force and drill bit diameter, feed.

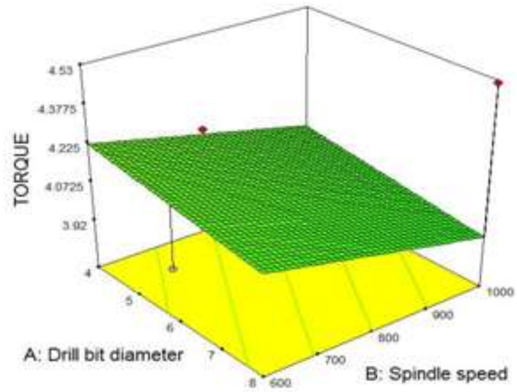

Figure 6.8: 3D graphs for torque and drill bit diameter, spindle speed.

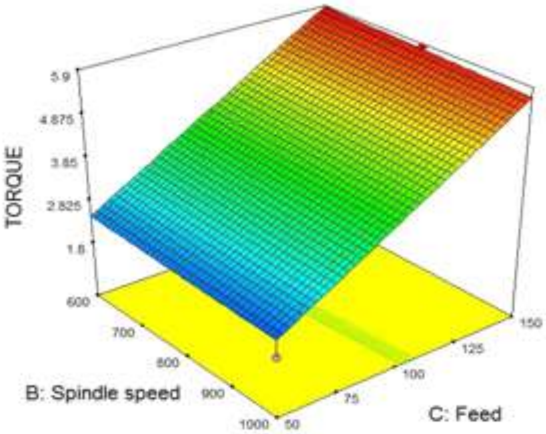

Figure 6.9: 3D graph for torque and spindle speed, feed

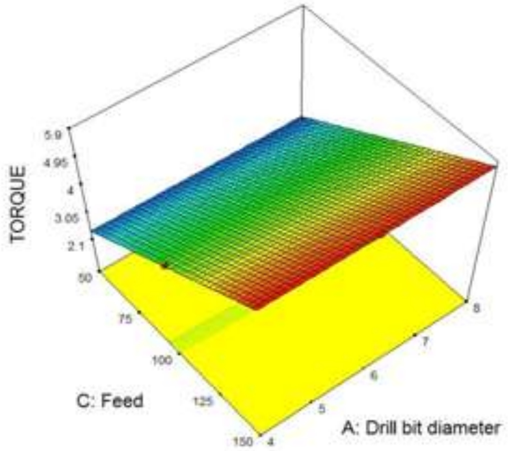

Figure 6.10: 3D graph for torque and drill bit diameter, feed

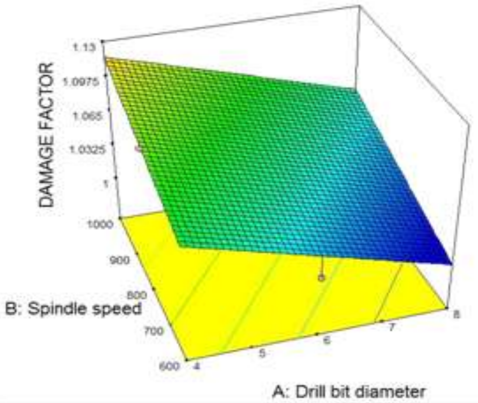

Figure 6.11: Damage factor and drill spindle speed, drill bit diameter

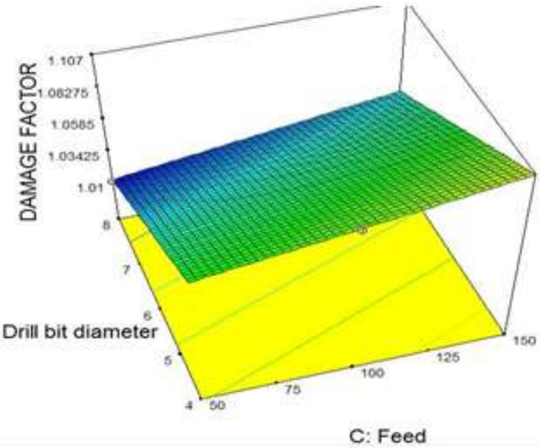

Figure 6.12: 3D graph for damage factor and bit diameter, feed

7. Conclusions

An experimental and finite element approach has been proposed to study the drilling characteristics of NFRC composite. In this study, the effects of feed rate and cutting speed were proven statically using analysis of variance (ANOVA). The following conclusions can be drawn from the present research initiative.

The feed rate parameter is the most significant factor, which influences the thrust force and torque. The influence of speed on thrust force and torque is low. The interaction of feed and speed is not affecting the thrust force. But, the interaction of feed rate and speed influences the torque. Thus, it is essential to employ a proper combination of cutting speed (in high range) and feed rate (in low range) so as to reduce the thrust force and torque in drilling of PRJF composites. Predictive models for thrust force and torque are proposed correlating the significant factors. Stress and deflection value is nearest the practical value A Finite Element approach is used to study the effect of drill point angle on drilling induced damage while drilling PRJF composite laminates. The Finite Element result is equal to practical value. Hence in order to reduce the amount of damage while drilling PRJF composites higher point angles are better. The NFRC material is structural result was good strength and equal to glass fiber strength.

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