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Optimization of Process Parameters in Drilling of Short Fiber (KENAF) Composite

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Abstract :The availability of natural fibers and ease of manufacturing have made the researches to replace the expensive and non-renewable synthetic fiber. Natural fibers like kenaf, oil palm, vegetable, bamboo, jute, yepi, sisal, coconut and pineapple leaf , banana and coir has been used, till now as a reinforcement in thermoplastic composite for applications in consumer goods, transportation, aerospace automobile, furniture, low cost housing and civil structures etc. This is due to better mechanical properties like high strength to weight ratio, high stiffness etc. Among all the machining operation, drilling is one of the important machining processes to produce the holes. This paper optimizes the process parameters namely cutting speed, feed, point angle and chisel edge width in drilling of natural fiber composites. Experiments were carried out as per the Taguchi experimental design and an L_{18} orthogonal array was used to study the influence of various combinations of process parameters in drilling. The results indicate that on Trust force, chisel edge width has more influence followed by point angle, speed and feed and on Torque, speed has more effect followed by feed, point angle and chisel width.

Index Terms: Kenaf, drilling, Trust force.

I. INTRODUCTION

As humans has great effort for million years together to use readily available resources like clay, mud, stone, and wood for survival. Later on during early 1960's man discovered the secrets of nature and learned to exploit. There has been an increasing demand for materials that are stiffer and stronger yet lighter in fields as diverse as aerospace, energy and civil constructions by using synthetic materials. There by gradual decline of the direct application of natural resources has come in to existence. The demands made on materials for better overall performance are so great and diverse that no one material can satisfy them. This naturally led to a resurgence of the ancient concept of combining different materials in an integral-composite material to satisfy the user requirement. As natural composites had wide applications in day to day life of humans, they are synthesized from different kinds of fibers, such as: glass, aramid, graphite, carbon, boron, etc., and matrix materials such as polyester and epoxy resins. They have excellent properties but they are not biodegradable. Disposal of these material pose adverse effect on the environment releasing hazardous gases soil impermeability. Thus scientists and engineers for reviving the use of natural materials and development of composites called green composites that can be disposed easily without posing problems to the environment.

The objective of the present work is to prepare natural fiber reinforced polymer composite material with kenaf natural fiber and a polymer resin and is to optimize process parameters namely, cutting speed, feed, point angle, chisel edge width in drilling of the prepared natural fiber composite material. This work is useful in selecting proper process parameters in order to predict thrust force, torque and quality of the drilled hole.

II. LITERATURE REVIEW

Gheorghe Bejinaru Michoc [1] conducted experiments on Drilling of Composite Materials. In his experiments he stated that Drilling operation has a significant share in the machining of composite materials. In essence, the principle is known from the processing of metallic materials. Processing elements, however, present characteristics which are determined by the nature and characteristics fo the fiber material, the interface fiber/matrix geometry/etc configuration tool edges. These features, which determine the defect in the declamation noted. The paper makes a systematic analysis of the drilling process from the technological system, machine tool, tool, device and material processing. References are made on the mechanism generating the phenomenon of delimination.

H Ku+, H Wang, N Pattarachaiyakoop and M Trada[2] conducted experiments on tensile properties of natural fibers. In their investigation they had identified that due to their advantages such as low cost, fairly good mechanical properties, high specific strength, non abrasive, eco friendly and bio-degradability characteristics, they are exploited as a replacement for the conventional fiber, such as glass, aramid and carbon. The tensile properties of natural fiber reinforce polymers (both thermoplastics and thermosets) are mainly influenced by the interfacial adhesion between the matrix-fiber bonding resulting in the enhancement of tensile properties of the composites. In general, the tensile strengths of the natural fiber reinforced polymer composites increase with fiber content, up to a maximum or optimum value, the value will then drop. However, the young's modulus of the natural fiber reinforced polymer composites increase with increasing fiber loading.

M.S.Won and C.K.H.Dhran[3] studied the phenomenon of delamination. In their investigation they showed that the chisel edge of drill is a major contributor to the thrust force that is the primary cause of delamination when drilling of composite laminate to determine quantitatively the effect of chisel edge on the thrust force. In addition, tests were conducted to determine the effect of predrilling the laminate with a pilot hole to determine the chisel edge contribution on thrust force. They developed analytical model to predict the thrust force in drilling operation.

G.DiPaolo,S.G.Kapoor and R.E.DeVor[4], conducted experiments to study the crack phenomenon that occurs while drilling fiber-reinforced composite material specially

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unidirectional carbon fiber/epoxy resin. They used an experimental setup that exploits the technology of video to understand the complete crack growth phenomenon as the drill emerges from the exit side of the work piece. In experimental study they observed the significant damage mechanism and they formed correlations between the average exit drill forces and the crack tip position.

Vijayarangan & AbdulBudan[5] performed drilling experiments on unidirectional NFRP composites laminates with different volume fractions and evaluated the effect of fiber content on hole quality, delamination factor and drill wear. They found that poor surface quality, decreased delamination force and excessive tool wear and specimens with high fiber percentage. They also used Finite Element Model to evaluate the thrust force causing delamination and they found that the predicated FEA results shown close agreement with experimental results.

V.chandrasekhara, S.G.Kapoor and R.E.DeVor [6], developed mathematical models to predict thrust force and torque at the different regions during drilling. For modeling they adopted the mechanistic approach, those models exploits the geometry of the process, which was independent of the work piece material. Those models were calibrated to a particular material using the well established relationships between chip load and cutting forces, modified to take advantage of the characteristics of the drill point geometry. They validated the models with the experimental results independently for the cutting lips and the chisel edge for drilling both metals and fiber-reinforced composite materials for a wide range of machining conditions and drill geometry, in all the cases they found that the results from the models were agreed with the experimental results.

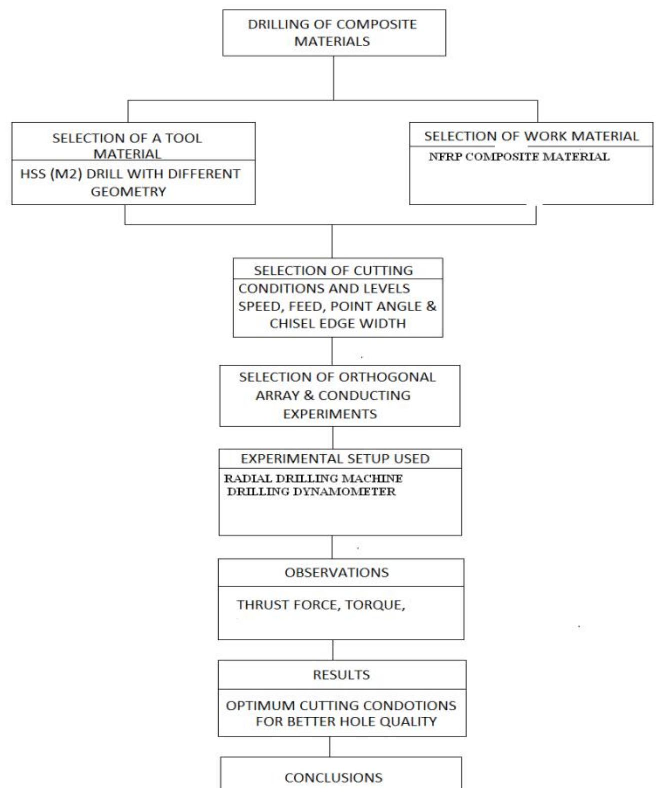
N.N.Z.Gindy [7], conducted experiments on drilling of GFRP composite laminates with HSS twist drill. In his investigation experiments were conducted using a wide range of cutting conditions and drill geometry, namely cutting speed, federate, drill point angle and helix angle. He conducted full factorial experiments and selected optimum drilling conditions based on the geometrical accuracy and the appearance of the drilled holes. He also measured the drill wear during test trails and used as a further constraint in ‘optimum’ cutting condition selection. He concluded that speed, federate and drill point angle were the most significant parameters influencing hole quality, helix angle has no effort on the hole quality and thrust force.

Md.Yuhazri Y.Phongsakorn P.T.Haeryip Sihomobing Jeefferie A.R.Puvanasvaram [8] studied the “MECHANICAL PROPERTIES OF KENAF/POLYESTER COMPOSITES”..The mechanical properties of kenaf fiber reinforced polyester composites made by vacuum infusion method were investigated. It has been found that the alkalization treatment used has improved the mechanical properties of the composites. Kenaf fiber can be a good reinforcement candidate for high performance polymer composites. The kenaf-polyester composite manufactured by vacuum infusion process provides an opportunity of replacing existing materials with a higher strength, low cost alternative that is environmentally friendly.”

Wen- chou chen[9] used the concept of delamination factor to analyze the degree of delamination. He conducted experiments on carbon fiber- reinforced composite material to investigate the variations of cutting forces with or without delamination during drilling operation. In addition to that he investigated the effects of drill geometry on cutting force variations and delamination. The effect of drilling parameters and tool wear on delamination factors was also discussed.The phenomenon of delamination during drilling was identified and analyzed by Hocheng and Dharan.They adopted plate bending theory and linear elastic fracture mechanics techniques to develop the model, which can be used to predict the critical thrust and cutting forces, which are important in optimizing drilling parameters.

From the literature it is clear that cutting conditions and drill geometry have much influence on hole quality during drilling short fiber composite materials has excellent machining properties . In this approach, investigation was done on NFRP composite laminates by considering the most important parameters influencing the hole quality namely speed, feed rate, drill point angle and chisel edge width. Inorder to reduce the large number of total experiments required, tests were conducted using Taguchi’s Design of Experimental technique to identify the factors that are most significant in affectining the quality and accuracy of the drilled holes and proposes an optimal setup of the process parameters to get delamination free holes.

III. EXPERIMENTAL METHODOLOGY



IV. FABRICATION OF LAMINA

A. Treatment of Fiber

The quality of a fiber reinforced composite depends considerably on the fiber-matrix interface because the interface acts as a binder and transfers stress between the matrix and fibers. Bonding between fibers and binder can be increased by chemical treatment of fibers using chemical agent like **sodium hydroxide (NaOH).** For treatment process water by volume is taken along with 2% of **NaOH**.The fibers are soaked in the water for 24 hours, and then the fibers are washed thoroughly with distilled water to remove the final residues of alkali. Good bonding is expected due to improved wetting of fibers with the matrix. In order to develop composites with better mechanical properties and good environmental performance, it is necessary to impart fibers by chemical treatments.

Figure 1:Untreated & Treated Fibers

B. Preparation of Lamina

The laminas are prepared by hand layup technique. The hand layup is the one of the Fabrication technique. First Wax polish is applied on the surfaces of the base plates and poly vinyl alcohol (PVA) is applied with a brush and allowed to dry for few minutes to form a thin layer. These two items will help in easy removal of the laminate from the base plates. PVA also provides a glossy finish to the surfaces of the laminate. The general purpose Unsaturated Isopthalic Polyester Resin is taken along with 2% each of catalyst-Methyl Ethyl Ketone Peroxide (MEKP) and accelerator- Cobalt Napthalate. The weight of the resin is 25 times the weight of the fiber mat taken for the laminate. The catalyst initiates the polymerization process and the accelerator speeds up this process. Initially the catalyst is added and then the accelerator is added next. The resin is mixed with the short fibers and mixing is done ,catalyst is added and again mixing of the composite is done and finally accelerator is added . the total composite is now evenly distributed in the mould by hand layup method . It is always preferable to add lesser quantity of accelerator than the specified amount to avoid solidification of the contents before they are poured and evenly layed up in the rectangular mould. Then the top base plate that was already applied with the wax and PVA is placed on the laid resin and a weight of about 1000 N is placed over for about 24 hours.

Figure 2: Wax, PVA, MEKP, Accelerator

Figure 3: Isopthalic, Glass Plate, Surface plate

V. EXPERIMENTAL SETUP

A Radial drilling machine was used for drilling holes on composite material and strain gauge dynamometer and drill tool force indicator were used to indicate the thrust force and torque acting during drilling process.

Radial drilling machine

Strain gauge dynamometer

Drill tool force indicator

Figure 4: Experimental setup

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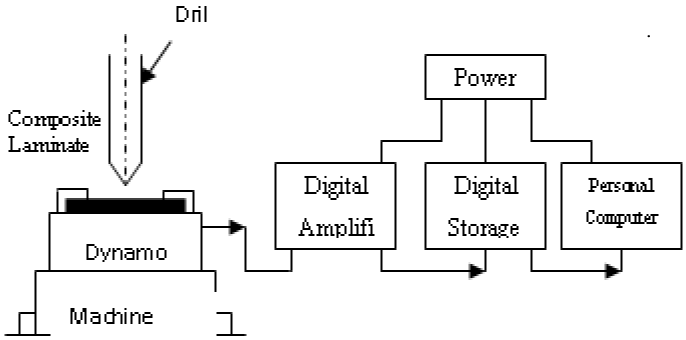

Figure 5: Schematic view of the experimental setup

A Radial Drilling Machine was used for conducting experiments. A syscon two component tube -type strain gauge type drilling dynamometer (model : SI-674) was used to measure the axial thrust force and torque. Composite laminate is clamped on the dynamometer, which is fixed on the machine tool bed. The proportion voltage output from the dynamometer was fed to a syscon amplifier (model SI – 223 D), thus producing a scaled voltage output signal proportional to the applied load. The amplifier directly gives the thrust force and torque values in the digital form. The thrust force and torque values were recorded .the system with Minitab software is used to obtain thrust force and torque graphs.

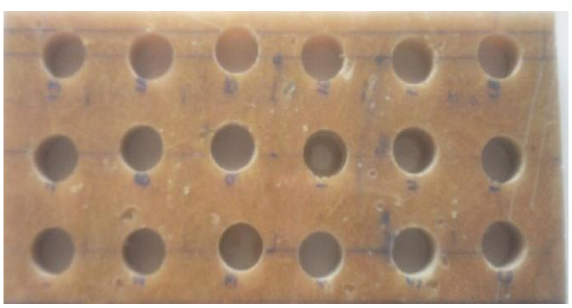

Figure 6: Shows the untreated drilled composite material

Figure 7:Shows the untreated drilled composite material

A. Selection of process parameters

In this work, the machining processes parameters speed, feed, point angle and chisel edge width were considered. According to Taguchi's design of experiments, for four parameters and three levels L18 Taguchi orthogonal array was selected. The number of factors and their corresponding levels are shown in the Table.

Table 1: Levels of selected process parameters for drilling

Code	Variable	Level1	Level2	Level3
A	Feed(mm/rev)	0.15	0.17	--
B	speed(rpm)	290	580	890
C	Point angle(deg)	98	108	118
D	Chisel edge width(mm)	1	1.5	2

B. Taguchi method

Taguchi developed a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the smaller the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given below.

SMALLER –THE- BETTER:It is usedwhere the smaller value is desired. In this the target value is zero.

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

Where y_i = observed response value, n= number of replications.

NOMINAL -THE -BEST:It is used where the nominal or target value and variation about that value is minimum. Here target value is finite not zero.

$$\text{S/N ratio } (\eta) = -10 \log_{10} \frac{\mu^2}{\sigma^2}$$

where μ =mean and σ = variance (2)

HIGHER -THE -BETTER:It is used where the larger value is desired. In this the target value is also zero.

$$\text{S/N ratio } (\eta) = -10 \log_{10} \frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2} \quad (3)$$

Where, y_i = observed response value, n= number of replications.

Table 2: The basic Taguchi L18 orthogonal array

Expt. No.	Control factors and Levels			
	A	B	C	D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3

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9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

C. Optimization of process parameters

The main objective of our project is to optimize the cutting parameters, such as cutting speed, feed, point angle and chisel edge width on delamination produced when drilling a NFRP composite using Taguchi method design. The optimization of process parameters using Taguchi method provides the evaluation of the effect of individual independent parameters on the identified quality characteristics. The results of thrust force, torque of each sample are shown in Table 3 and 4. The experimental results were transformed into S/N ratio.The main effect plots for S/N ratio and mean for thrust force and mean for torque are plotted in following figures respectively.

Table3: Taguchi's L_{18} standard orthogonal array with responses for Untreated laminates

No.	Feed (mm/rev)	speed (rpm)	Point angle(deg)	Chisel edge width(mm)	Thrust Force kgf	Torque kgf-m
1	0.15	290	98	1	5	0.03
2	0.15	290	108	1.5	9.2	0.04
3	0.15	290	118	2	9	0.04
4	0.15	580	98	1	5	0.03
5	0.15	580	108	1.5	7	0.08
6	0.15	580	118	2	10	0.07
7	0.15	890	98	1.5	4	0.04
8	0.15	890	108	2	4.6	0.06
9	0.15	890	118	1	5	0.05
10	0.17	290	98	2	4	0.07
11	0.17	290	108	1	6.1	0.07
12	0.17	290	118	1.5	5.1	0.16
13	0.17	580	98	1.5	4	0.05
14	0.17	580	108	2	5.1	0.07
15	0.17	580	118	1	4.9	0.08
16	0.17	890	98	2	5	0.07
17	0.17	890	108	1	6.1	0.06
18	0.17	890	118	1.5	6.1	0.07

Table 4: Taguchi's L_{18} standard orthogonal array with responses for Treated laminate

	Feed (mm/rev)	speed (rpm)	Point angle(deg)	Chisel edge width(mm)	Thrust Force kgf	Torque kgf-m
1	0.15	290	98	1	5	0.17
2	0.15	290	108	1.5	11.1	0.17
3	0.15	290	118	2	8.2	0.09
4	0.15	580	98	1	7	0.06
5	0.15	580	108	1.5	12	0.09
6	0.15	580	118	2	9	0.12
7	0.15	890	98	1.5	5	0.08
8	0.15	890	108	2	7	0.08
9	0.15	890	118	1	22	0.06
10	0.17	290	98	2	7	0.04
11	0.17	290	108	1	20	0.11
12	0.17	290	118	1.5	21	0.16
13	0.17	580	98	1.5	7	0.11
14	0.17	580	108	2	8	0.08
15	0.17	580	118	1	15	0.14
16	0.17	890	98	2	7	0.02
17	0.17	890	108	1	19	0.04
18	0.17	890	118	1.5	8.7	0.07

The above Thrust Force and Torque values along with speed, feed, chisel edge width and point angle values are entered in Minitab software to get the S/N ratio and Mean graphs. The S/N ratio and Mean graphs obtained for Thrust Force and Torque are as shown below.

D. Optimum values of process parameters for thrust force for untreated lamina:

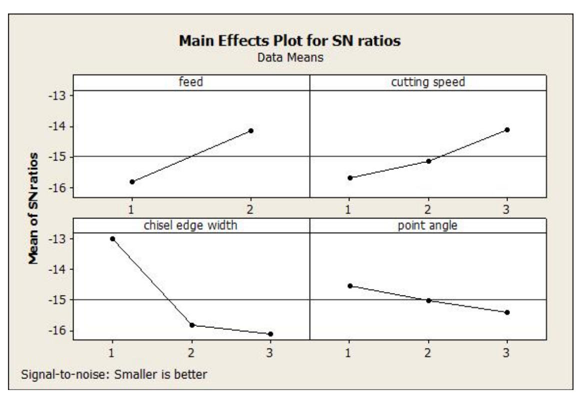

Figure 8: Main effects plot for SN ratios (Thrust force)

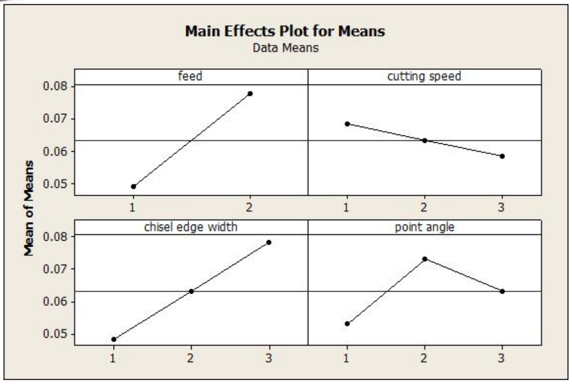

Figure 9: Main effect plots for means (Thrust force)

Table 5: Response Table for Signal to Noise Ratios Smaller is better (thrust force)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	-15.83	-15.71	-13.01	-14.53
2	-14.14	-15.15	-15.83	-15.02
3	----	-14.11	-16.12	-15.42
Delta	1.69	1.60	3.11	8.09
Rank	2	3	1	4

Table 6: Response Table for means (thrust force)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	6.533	6.400	5.350	4.500
2	5.156	6.000	5.900	6.350
3	---	5.133	6.283	6.683
Delta	1.378	1.267	0.933	2.183
Rank	2	3	4	1

From the S/N ratio graphs of Thrust force, the optimal values of Feed, Speed, Point Angle and Chisel Edge Width for Thrust force are calculated and results are displayed in the Table no. 7

Table 7: Optimum Cutting conditions for minimum thrust force

S.No	Parameter	Optimum value
1	Feed Rate	0.15 mm/rev
2	Cutting Speed	290 rpm
3	poimt angle	118^o
4	chisel edge width	2mm

E. Optimum values of process parameters of Torque for untreated lamina:

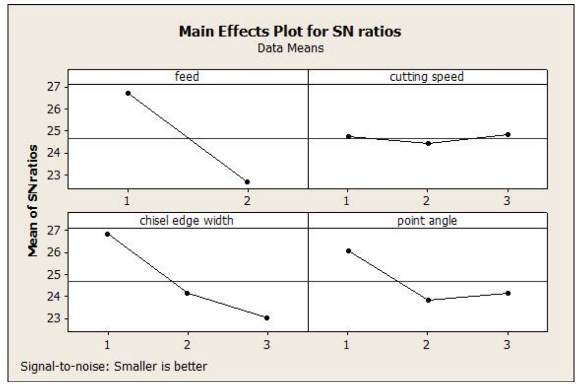

Figure 10: Main effect plot for SN ratios (Torque)

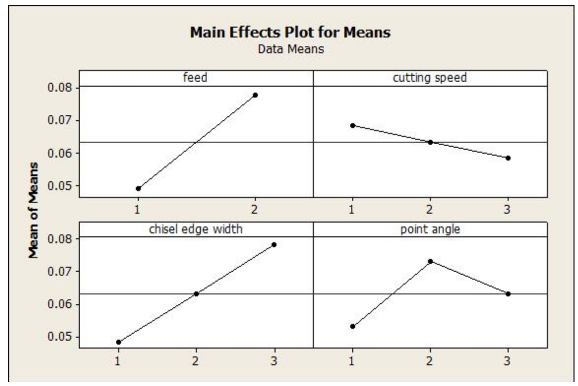

Figure 11: Main effect plots for Means (Torque)

Table 8: Response Table for Signal to Noise Ratios Smaller is better (torque)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	26.70	24.75	26.07	26.85
2	22.64	24.43	23.82	24.16
3	---	24.83	24.13	23.01
Delta	4.05	0.42	2.25	3.84
Rank	1	4	3	2

Table 9:Response Table for means (torque)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	0.04889	0.06833	0.05333	0.04833
2	0.07778	0.06333	0.07333	0.06333
3	---	0.05833	0.06333	0.07833
Delta	0.02889	0.01000	0.02000	0.03000
Rank	2	4	3	1

From the S/N ratio graphs of Torque, the optimal values of Feed, Speed, Point Angle and Chisel Edge Width for Torque are calculated and results are displayed in the Table no. 10

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Table 10: Optimum Cutting conditions for minimum torque

S.No	Parameter	Optimum value
1	Feed Rate	0.17 mm/rev
2	Cutting Speed	580 rpm
3	poimt angle	108^{o}
4	chisel edge width	2mm

F. Optimum values of process parameters of Thrust force for treated lamina:

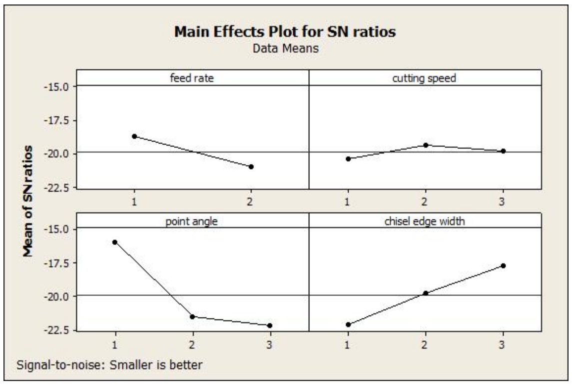

Figure 12: Main effects plot for SN ratios (Thrust force)

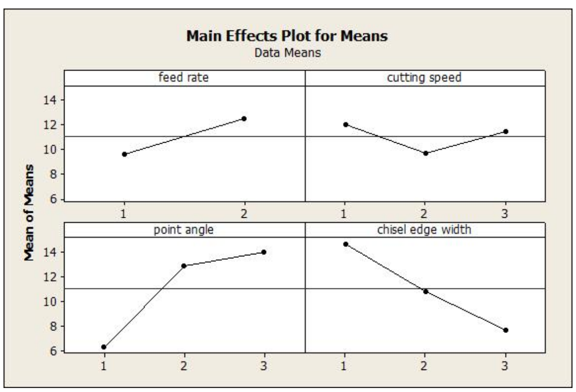

Figure 13: Main effect plots for means (Thrust force)

Table 11: Response Table for Signal to Noise Ratios Smaller is better (thrust force)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	-18.71	-20.41	-15.93	-22.14
2	-21.01	-19.34	-21.51	-19.77
3	---	-19.83	-22.15	-17.67
Delta	2.30	1.06	6.22	4.47
Rank	3	4	1	2

Table 12: Response Table for means (thrust force)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	9.580	12.037	6.333	14.667
2	12.522	9.667	12.850	10.800
3	---	11.450	13.970	7.687
Delta	2.942	2.370	7.637	6.980
Rank	3	4	1	2

From the S/N ratio graphs of Thrust force, the optimal values of Feed, Speed, Point Angle and Chisel Edge Width for Thrust force are calculated and results are displayed in the Table no. 13

Table 13: Optimum Cutting conditions for minimum thrust force

S.No	Parameter	Optimum value
1	Feed Rate	0.17 mm/rev
2	Cutting Speed	290 rpm
3	poimt angle	118^{o}
4	chisel edge width	1mm

G. Optimum values of process parameters of Torque for treated lamina:

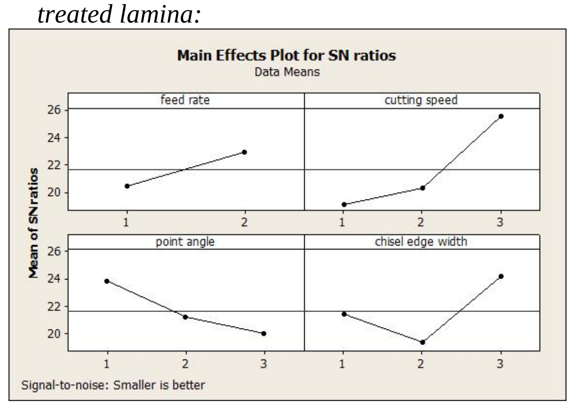

Figure 14: Main effect plot for SN ratios (Torque)

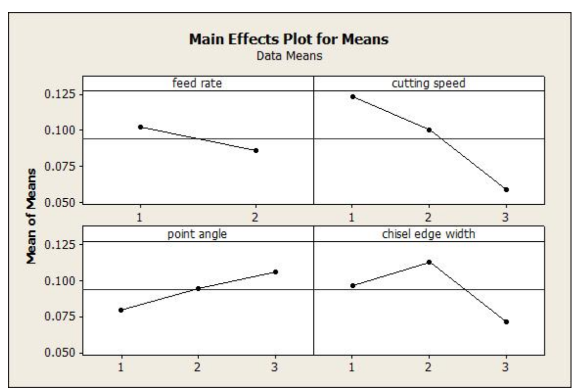

Figure 15: Main effect plots for Means (Torque)

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Table 14: Response Table for Signal to Noise Ratios Smaller is better (torque)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	20.42	19.12	23.81	21.41
2	22.92	20.33	21.22	19.41
3	---	25.56	19.98	24.19
Delta	2.50	6.43	3.84	4.79
Rank	4	1	3	2

Table 15: Response Table for means (torque)

Level	Feed	Speed	Point Angle	Chisel Edge Width
1	0.10222	0.12333	0.08000	0.09667
2	0.08556	0.10000	0.09500	0.11333
3	---	0.05833	0.10667	0.07167
Delta	0.01667	0.06500	0.02667	0.04167
Rank	4	1	3	2

From the S/N ratio graphs of Torque, the optimal values of Feed, Speed, Point Angle and Chisel Edge Width for Torque are calculated and results are displayed in the Table no. 16

Table 16: Optimum Cutting conditions for minimum torque

S.No	Parameter	Optimum value
1	Feed Rate	0.15 mm/rev
2	Cutting Speed	290 rpm
3	poimt angle	118^{o}
4	chisel edge width	1.5mm

VI. CONCLUSION

In this study investigation was done on the drilling of NFRP laminates by considering the important four parameters that affect the quality and accuracy of the drilled holes, namely speed, feed, point angle and chisel edge width of the drill. To reduce the number of experiments required, the study employs the Taguchi L18 Orthogonal array for setting up different combination of the respective control factors, each at different levels. From the S/N ratio graphs of Thrust force and Torque the factors that are most significant in affecting the quality and accuracy of the drilled holes are identified. From the experimental results the following inferences were made:

A. Results for Untreated Lamina

1) On Thrust force, Point Angle has more influence followed by Chisel Edge Width, Speed and Feed.
2) For minimum Thrust force to be generated and better quality of the holes produced without any burrs and fiber peel up and pullout, lower point angle of 118˚, low feed rate of 0.15mm/rev, low speed of 290rpm and medium chisel edge width of 2 mm are recommended.
3) On Torque, Feed has more effect followed by Speed ,Point Angle, and Chisel Edge Width.
4) For minimum Torque to be generated and better quality of holes produced without any burrs and fiber peel up and pull out, medium point angle of 108˚, feed rate of 0.175mm/rev, medium cutting speed of 580rpm and medium chisel edge width of 2mm are recommended.

B. Results for Treated Lamina:

1) On Thrust force, Point Angle has more influence followed by Chisel Edge Width, Speed and Feed.
2) For minimum Thrust force to be generated and better quality of the holes produced without any burrs and fiber peel up and pullout, lower point angle of 118˚, low feed rate of 0.17mm/rev, low speed of 290rpm and medium chisel edge width of 1 mm are recommended.
3) On Torque, speed has more effect followed by Feed ,Point Angle, and Chisel Edge Width.
4) For minimum Torque to be generated and better quality of holes produced without any burrs and fiber peel up and pull out, medium point angle of 118˚, feed rate of 0.150mm/rev, medium cutting speed of 290rpm and medium chisel edge width of 1.5 mm are recommended.

C. Result comparision for Treated & untreated Lamina:

When we compare with untreated fiber Lamina Treated fiber Lamina is Having Maximum strength due to which the Thrust Force and Torque is High For Treated Laminate.

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