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EFFECTS OF DRILLING PARAMETERS ON DELAMINATION OF HEMP FIBER REINFORCED COMPOSITES

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ABSTRACT

Natural fiber composites today are replacing synthetic fiber composites due to superior properties of natural fibers such as low density, high specific strength and modulus, relative nonabrasiveness, ease of fiber surface modification, and wide availability. Drilling is often required to facilitate the assembly of the parts to get the final product. However, drilling composite materials present a number of problems such as delamination associated with the characteristics of the material and with the used cutting parameters. The present investigation is an attempt to study the factors and combination of factors that influence the dalamination of the drilled unidirectional hemp fiber reinforced composites using Taguchi and ANOVA analysis and to achieve the conditions for minimum delamination. Confirmation experiments were conducted to verify the predicted optimal parameters with the experimental results.

Keywords: Delamination, Drilling, Hemp fiber reinforced polymer composite, Taguchi.

1. INTRODUCTION

Natural fibers like jute, hemp, sisal, coconut (coir) and bamboo in their natural form as well as several waste cellulosic products such as shell flour, wood flour and pulp have been used as reinforcing agents of different thermosetting and thermoplastic composites. Several authors have reported the chemical composition, properties of natural fibers and their composites by incorporating the fibre in different matrices before and after treatment by different methods [1–5].

The manufacturing of the natural fiber reinforced composite can broadly be classified as primary and secondary manufacturing. The primary manufacturing results in a near-net shape of the final product. The various primary manufacturing processes are hand lay-up, pultrusion, filament winding, vacuum bag molding and resin transfer molding. Although most of the composite products are made to a near-net shape, a certain degree of intricacy in the product design necessitates the development of the composite product in parts. The independently manufactured parts are then finally assembled to get the final composite product. Machining thus becomes imperative to ascertain the structural integrity of complex composite products. Hole making is one of the important machining operations to facilitate the assembly operations. Though a number of approaches have been used for making holes in composite laminates, conventional drilling till date is the most widely acceptable and frequently practiced machining operation for hole making. Conventional drilling however results in damage in the form of delamination, micro cracks, fiber pull out and matrix burning around the hole and may ultimately cause variation in the strength of the component with a drilled hole.
Koenig et al. [6] studied in 1985 the machining of fiber reinforced plastics and concluded that a high feed rate of drilling will cause a crack around the exit edge of the hole. Miller Hocheng and Puw [7] in 1992 presented a study of the chip formation and assess the machinability of two composite materials and concluded that from cutting chips the former presents a large amount of deformation in chip formation, while the latter tends to fracture. Chambers and Bishop [8] in 1995 investigated the effect of the cutting parameters on drilling carbon/epoxy and carbon/peek and concluded that the drilling of carbon composites is dependent upon the characteristics of the matrix and the helical PCD drill geometry gave the best overall performance.

Lin et al. [9] in 1996, carried out a study on drilling of carbon fiber reinforced composite at high speed and concluded that an increase of the cutting velocity leads a increasing of the drill wear. In this way the fact of increasing the wear of drill causes a rising of thrust force. Wen-Chou Chen [10] in 1997 studied the variations of cutting forces with or without onset delamination during the drilling operations and concluded that the delamination free drilling processes may be obtained by the proper selections of tool geometry and drilling parameters. Piquet et al. [11] in 2000 carried out a study of drilling thin carbon/epoxy laminates with two types of drills, a helical drill and a drill of special geometry, and concluded that both drills leads a damage at the entrance in the wall and the exit of the hole, with the exception of special geometry drill which is possible a significant reduction in the final damage. Enemuoh et al. [12] in 2001, realize that with the application of the technique of Taguchi and other methods, were possible to achieve the cutting parameters that allowed the absence of damage in the drilling of fiber reinforced plastics.

In order to understand the effects of process parameters on the delamination, a large number of machining experiments have to be performed and analyzed mathematical models to be built on the same. Modeling of the formation of delaminations is highly complex and expensive. Hence, empirical/statistical approaches are widely used over the conventional mathematical models. In this paper, an approach based on the Taguchi method is used to determine the desired optimum cutting parameters for minimized appearance of delaminations in drilled unidirectional hemp fiber reinforced composites.

2. EXPERIMENTAL SET-UP AND MACHINING CONDITIONS

2.1. HFRP specimen preparations

The composite materials used in the tests are made with hemp fiber reinforcement. The resin polyester possessing a modulus of 3.25 GPa and density 1350 kg/m^3 was used in preparing the specimens with hand lay-up process. Required numbers of layers were stacked to give intended thickness and a fiber volume fraction, which was determined later to 0.52 using weight loss method.

2.2. Machining set-up

The carbide drill bit used in the experiments was of 5mm diameter. Drilling tests were conducted on CNC machining center supplied by MTAB, India. The laminate composite specimen was held in a rigid fixture attached to the machine table. The experimental set-up is as shown by the schematic in Fig. 1.

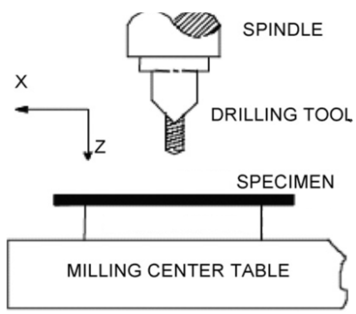

Fig. 1. Schematic diagram of experimental set-up.

2.3. Design of experiments

The cutting speed and the feed rate are the two most important parameters that characterize the drilling operation and have been selected for investigation. The feed rate and the speed are the two parameters under investigation in the present study. A L9 orthogonal array is selected for the present investigation. The factors and their respective levels are shown in Table 1. The treatment of experimental results is based on the analysis of variance (ANOVA). The analysis of variance of the experimental data for the Peel up delamination and Push down delamination generated during drilling of UD-HFRP is done to study the relative significance of the cutting speed and the feed rate.

Table 1
Levels of the variables used in the experiment.

Process parameters	Low (1)	Center (2)	High (3)
Speed (A) in rpm	1000	1500	2000
Feed (B) in mm/min	100	200	300

3. MEASUREMENT OF DELAMINATION FACTOR

To determine the differing extent of intrinsic hole machining defects (delamination) caused by drilling, both the upper (Peel up delamination) and lower (Push down delamination) surfaces of each specimens were examined using The Mitutoyo TM 500 toolmakers' microscope of 1µm resolution with 30X magnification was employed to measure the delamination damage of holes and each trial was replicated twice, as it can be observed in Fig. 2. The value of delamination factor (F_d) can be obtained by the following equation:

$$F_d = D_{max} / D \qquad (1)$$

where, D_{max} is the maximum diameter of the damage around the hole periphery and D is diameter of the drill.

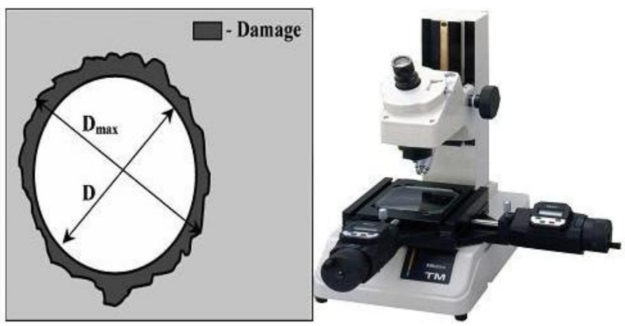

Fig.2. Measurement of the maximum diameter (D_{max}) with a tool maker's microscope.

The average readings of two trials of delamination factor were taken as process response. Table 2 presents the experimental layout plan and the computed values of delamination factor.

Table 2
Design and experimental results of the L9 orthogonal array experiment

Sl.	Factors		Push down delamination		Peel up delamination	
no.	A	B	Trial 1	Trial 2	Trial 1	Trial 2
1	1	1	2.00	1.80	1.80	1.60
2	1	2	2.80	2.60	2.40	2.20
3	1	3	3.60	3.50	2.80	2.40
4	2	1	1.20	1.00	1.00	0.80
5	2	2	1.60	1.80	1.40	1.20
6	2	3	2.20	2.00	1.80	2.20
7	3	1	0.70	0.80	0.30	0.40
8	3	2	1.60	1.80	0.80	0.96
9	3	3	1.70	2.00	1.0	1.25

4. EXPERIMENTAL RESULTS AND DATA ANALYSIS

4.1. Analysis of S/N ratio

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. Taguchi uses the S/N ratio to measure the quality character deviating from the desired value. The S/N ratio η is defined as

$$\eta = - 10 \log_{10} (M.S.D.) \qquad (2)$$

where M.S.D. is the mean-square deviation for the output characteristic.

To obtain optimal cutting performance, the-lower-the-better quality characteristics for delamination should be taken for obtaining optimal cutting performance. The optimum process design is achieved when the S/N ratio is maximized. Since - log is a monotonically decreasing the function, it implies that we should maximize. The M.S.D. for the-lower-the-better quality characteristic can be expressed as:

$$M.S.D. = \frac{1}{M}\left(\sum_{i=1}^{m} F_i^2\right) \qquad (3)$$

where F_i is the value of delamiantion factor for the i^{th} test and M is the number of tests.

The response obtained from experiments was analyzed using response table and graphical representation of mean effects and interaction effect of parameters on the quality characteristics. Table (3) shows the experimental results for delamination factors of push down delamination and peel up delamination and the corresponding S/N ratio using Eqs. (2) and (3). The S/N response graph for push down and peel up delaminations are shown in Figure (3). Regardless of the-lower-the-better of the-higher-the-better quality characteristic, the greater S/N ratio corresponds to the smaller variance of the output characteristic around the desired value (Eqs. (2) and (3)). Therefore, based on the S/N, the optimal parameters for peel up delamination are the feed rate at level 1 (100 mm/min), the cutting speed at level 3 (2000rpm). Similarly, the optimum parameters for push down delamination are the feed rate at level 1 (100 mm/min), the cutting speed at level 3 (2000 rpm).

Table 3

Response for raw data and S/N ratios of delamination for smaller is better

		Push down delamination factor Average Values			Peel up delamination factor Average Values		
	Parameter	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
raw data	Speed (A)	2.717	1.633	1.433	2.200	1.400	0.785
	Feed (B)	1.250	2.033	2.500	0.983	1.493	1.908
S/N data	Speed (A)	-8.409	-3.981	-2.505	-6.731	-2.502	3.01
	Feed (B)	-1.324	-5.960	-7.611	1.756	-2.824	-5.155

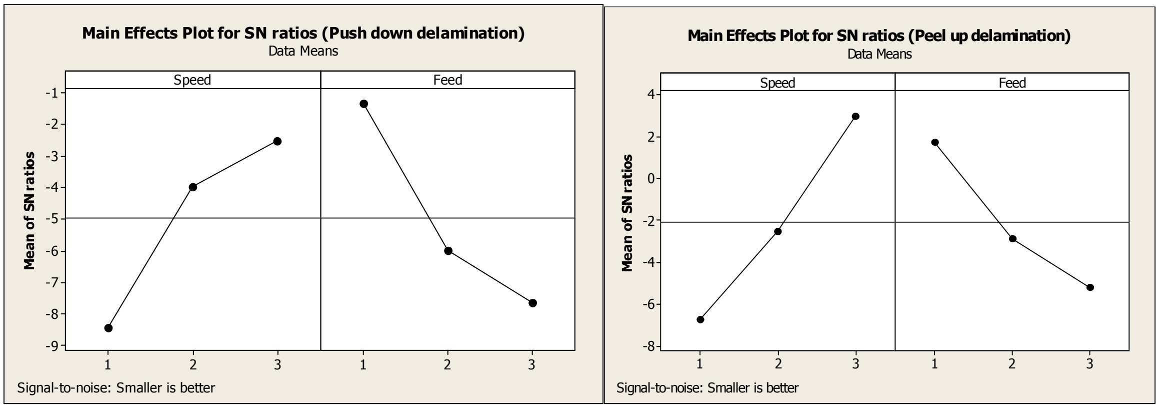

Fig. 3. Push down and Peel up delamination main effect plots for S/N ratio.

4.2. Analysis of variance:

The purpose of the analysis of variance (ANOVA) is to investigate the design parameters significantly affect the quality characteristic of a product or process. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters. Statistically, there is a tool called an *F* test named after Fisher to see which design parameters has a significant effect on the quality characteristic. In performing the *F* test, the mean of squared deviations due to each design parameter needs to be calculated. Then, the *F* value for each design parameter is simply the ratio of the mean of squared deviations to the mean of squared error. Usually, when $F > 4$, it means that the change of the design parameter has a significant effect on the quality characteristic.

From Table 4, which gives ANOVA response results, it can be found that cutting speed and feed rate are the significant parameters affecting the peel up delamination and feed rate and cutting speed are the significant parameters affecting the push down delamination. Figure (4) illustrate the interaction plots for different S/N ratios for push down and peel delaminations.

Table 4
ANOVA response for push down and Peel up delamination[a]

		Push down delamination				Peel up delamination			
Source	DF	Seq SS	Adj MS	F	P	Seq SS	Adj MS	F	P
Speed	2	56.63	28.315	23.53	0.006	143.13	71.56	20.75	0.008
Feed	2	63.74	31.873	26.49	0.005	74.18	37.09	10.75	0.025
Error	4	4.813	1.203			13.8	3.45		
Total	8								

[a] Using adjusted SS for tests.

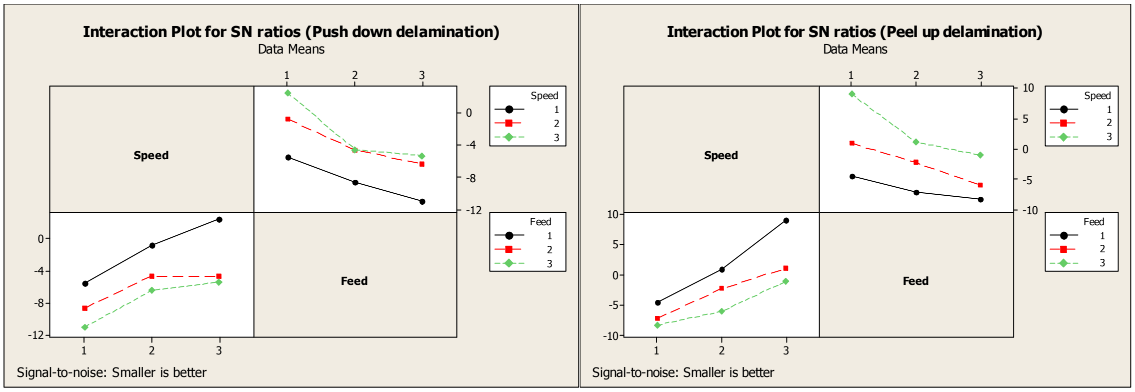

Fig. 4. Push down and Peel up delamination interaction plots for S/N ratios.

5. CONCLUSIONS

From the analysis of results in drilling of HFRP composite plates using conceptual S/N ratio approach, ANOVA and response surfaces, the following can be concluded from the present study within the range of the experiments.

(1) As seen in this study, the Taguchi method provides a systematic and efficient methodology for the design optimization of the process parameters resulting in the minimum delamination with far less effect than would be required for most optimization techniques.
(2) Based on the S/N, the optimal parameters for the minimum peel up delamination are the feed rate at level 1 (100 mm/min), the cutting speed at level 3 (2000 rpm).
(3) Similarly, the optimum parameters for the minimum push down delamination are the feed rate at level 1 (100 mm/min), the cutting speed at level 3 (2000 rpm).
(4) The feed rate and cutting parameters influences the push down and peel up delaminations. Therefore, the feed rate and cutting speed seems to be the most critical parameters and should be selected carefully in order to reduce all kinds of damages.
(5) Conceptual S/N ratio and ANOVA approaches for data analysis draw similar conclusion.

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