Investigation on Drilling of Banana Fibre Reinforced Composites

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Abstract—India offered a biggest source of natural fiber like banana, rice husk, coconut and jute fiber etc. All the natural fiber has its unique advantages as well as mechanical properties which are very useful in the development of potential composites for various applications like transportation, automotive etc. There are various machining process in which drilling is most useful process for the assembly of different work pieces. During the drilling of composites it will undergo in the delamination process, which in turn reduces the strength as well as the efficiency of composites materials. In the present work drilling was carried out by using the various feeds (0.1, 0.2, 0.3 mm/rev), speeds (1000, 2000, 3000 rpm) and drill point angles (90^0, 104^0, 118^0) on the banana polyester reinforced composites. The delamination factor was measured by using machine vision system and digital image analysis. The mathematical model were developed using regression analysis to correlate the various machining parameters with the delamination factor and thrust force. Also the ANOVA has been used to found the effectiveness of the factors as well as their combinations. Optimization has been performed using the desirability function to find out the optimum machining condition for drilling of banana fibre reinforced composites.

Keywords-Drilling; Banana Fibre Reinforced Composites; Delamination; Design of experiment; Image analysis; ANOVA; Optimization.

I. INTRODUCTION

There has been intense investigation on natural fiber composites in past. These investigations show that natural fiber composites reveal greater properties than conventional composites. Several studies showed that by adding natural fiber reinforcement many properties like strength and stiffness can be improved significantly. The vital thing is the similar separation of fiber for obtaining improved properties. The physical and mechanical properties make these materials appropriate for a comprehensive variation in applications like construction, electronics, automotive and packaging.

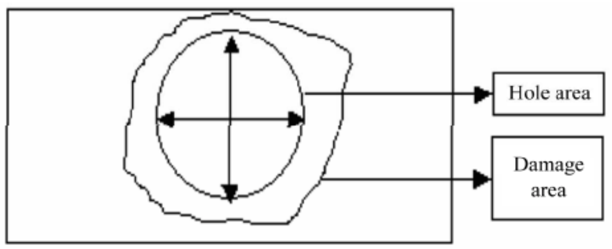
Among the common machining methods used for composites, drilling is the most often adopted. Joining of composites are possible by screws, rivets and bolts because the welding is not possible. As composites are anisotropic materials, drilling rises certain problems that can be associated with successive damage in the area around the holes. The most common damages caused by drilling are fibre pull-out, delamination, interlaminar cracking and thermal degradation. Among these damages delamination is the greatest critical. Delamination is defined as “the separation of the layers of material in a laminate”.

Numerous methods have been used to measure delamination like scanning electron microscope [1], C-Scan [3] and shop microscope [5,10]. In general a measureable assessment is required in order to assess the effect of the cutting parameters and the geometry of drill tool [1-6].

II. MATERIAL AND METHODS

In this study the composite specimen was prepared using general purpose polyester and pure banana fiber which is procured from Sunrise Handmade Paper Pvt. Ltd. Fibers were randomly oriented and 11.85 % weight fraction was obtained. The specimens of 8 mm thickness were prepared using the hand lay-up process as shown in figure 1(a).

(a)



(b)

Fig. 1(a) Prepared specimen of Banana Fibre Reinforced Composite. (b) Delamination.

III. DESIGN OF EXPERIMENTS

Design of Experiments (DOE) refers to planning, designing and analysing an Experiment so that valid and objective conclusions can be drawn effectively and efficiently. This design models have been prepared by using the various feeds (0.1, 0.2, 0.3 mm/rev), speeds (1000, 2000, 3000 rpm) and drill point angles (90^0, 104^0, 118^0). Full Factorial design was used for experimental runs. Drilling tests were carried on CNC vertical machining centre with standard HSS twist drills.

IV. DAMAGE AREA DETERMINATION

Delamination in the banana-polyester composite was investigated by machine vision technique at entry and exit. The image of damage was taken using a shop microscope Mitutoyo QS – L 2010 ZB. The images were captured by improving contrast to have clear separation of delamination. The damaged area was measured by image analysis using MATLAB programming. The value of the delamination factor (DF) can be calculated using the following equation:

$$DF = A_{damage} / A_{hole}$$

where A_{damage} is the maximum area of the damage around the hole periphery (including hole area) and A is the actual hole area as shown in Fig. 2(b).

V. RESULTS AND DISCUSSION

A full factorial design with total no. of 54 experimental runs were carried out. Table 1 shows the results for various experimental runs of drilling.

TABLE 1 EXPERIMENTAL RESULTS.

Sr. No	Point Angle (Deg.)	Feed (mm/rev)	Speed (rpm)	Thrust Force (N.m)	DF Entry	DF Exit
1	90	0.1	1000	20.5394	1.0126	1.0039
2	90	0.1	2000	19.0133	1.0149	1.0019
3	90	0.1	3000	15.9611	1.0345	1.0261
4	90	0.2	1000	28.1701	1.0428	1.0223
5	90	0.2	2000	32.7485	1.0687	1.0589
6	90	0.2	3000	29.6962	1.0906	1.0562
7	90	0.3	1000	37.3268	1.0837	1.0790
8	90	0.3	2000	46.4836	1.0755	1.0877
9	90	0.3	3000	44.9575	1.0923	1.0733
10	104	0.1	1000	22.0656	1.0169	1.0371
11	104	0.1	2000	23.5917	1.0380	1.0476
12	104	0.1	3000	19.0133	1.0203	1.0566
13	104	0.2	1000	44.9575	1.0545	1.0552
14	104	0.2	2000	37.3268	1.0628	1.0590
15	104	0.2	3000	38.8530	1.0773	1.0607
16	104	0.3	1000	70.9016	1.0910	1.0873
17	104	0.3	2000	73.9539	1.0833	1.0635
18	104	0.3	3000	57.1665	1.0880	1.0330
19	118	0.1	1000	23.5917	1.0348	1.0164
20	118	0.1	2000	22.0656	1.0338	1.0260
21	118	0.1	3000	28.1701	1.0240	1.0340
22	118	0.2	1000	41.9052	1.0288	1.0358
23	118	0.2	2000	44.9575	1.0316	1.0357

24	118	0.2	3000	40.3791	1.0175	1.0456
25	118	0.3	1000	63.2710	1.0309	1.0511
26	118	0.3	2000	52.5881	1.0567	1.0438
27	118	0.3	3000	58.6926	1.0216	1.0170
28	90	0.1	1000	23.5917	1.0149	1.0042
29	90	0.1	2000	17.4872	1.0162	1.0059
30	90	0.1	3000	15.9611	1.0261	1.0337
31	90	0.2	1000	34.2746	1.0488	1.0277
32	90	0.2	2000	31.2223	1.0746	1.0542
33	90	0.2	3000	32.7485	1.0689	1.0619
34	90	0.3	1000	37.3268	1.0762	1.0721
35	90	0.3	2000	44.9575	1.0865	1.0918
36	90	0.3	3000	46.4836	1.0969	1.0762
37	104	0.1	1000	25.1178	1.0246	1.0298
38	104	0.1	2000	28.1701	1.0103	1.0451
39	104	0.1	3000	20.5394	1.0128	1.0523
40	104	0.2	1000	44.9575	1.0459	1.0536
41	104	0.2	2000	40.3791	1.0674	1.0606
42	104	0.2	3000	37.3268	1.0820	1.0597
43	104	0.3	1000	67.8494	1.0910	1.0857
44	104	0.3	2000	69.3755	1.0912	1.0652
45	104	0.3	3000	58.6926	1.0880	1.0316
46	118	0.1	1000	22.0656	1.0214	1.0297
47	118	0.1	2000	25.1178	1.0440	1.0199
48	118	0.1	3000	26.6439	1.0228	1.0352
49	118	0.2	1000	48.0097	1.0436	1.0414
50	118	0.2	2000	43.4313	1.0301	1.0329
51	118	0.2	3000	46.4836	1.0118	1.0375
52	118	0.3	1000	67.8494	1.0441	1.0487
53	118	0.3	2000	58.6926	1.0567	1.0438
54	118	0.3	3000	64.7971	1.0259	1.0129

VI. THRUST FORCE

It is observed through main effect plot for thrust force as shown in fig. 3, the feed have predominant effect on thrust forces. Point angle has quite dominant effect on thrust forces, but speed does not have much effect on thrust forces. The thrust force increases with the increase in the feed. The Thrust force increases suddenly with increase in point angle from 90^0 to 104^0, but it almost remains same for the point angle 104^0 and 118^0. The thrust force decreases with the increase in the speed.

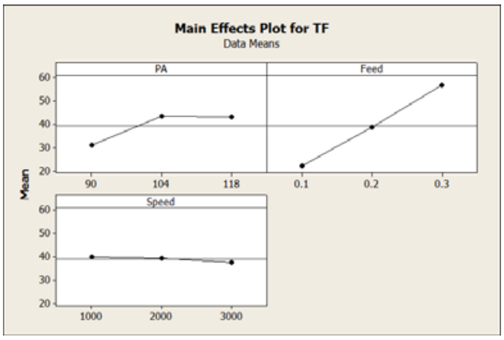
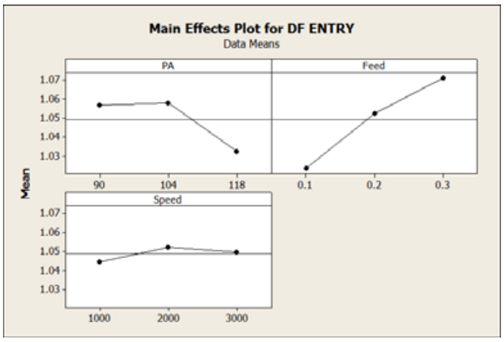


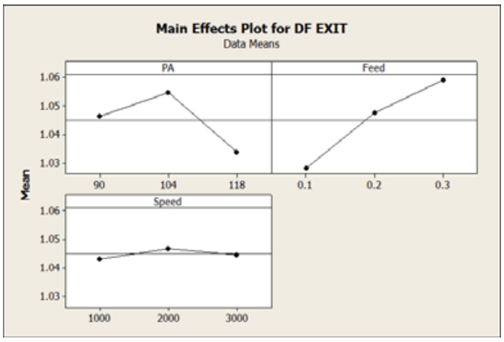
Fig. 3 Main Effect Plot For Thrust Force.

VII. Delamination Factor at Entry and Exit

It is observed through main effect plot for delamination factor at entry as shown in fig. 4(a), the feed has predominant effect on delamination factor at entry, point angle have quite dominant effect on delamination factor at entry and also a speed does not put much effect on delamination factor at entry. The delamination factor at entry decreases with the increase in the point angle. The delamination factor at entry increases with the increase in the feed.



(a)



(b)

Fig. 4 (a) Main Effect Plot for Delamination Factor at Entry (b) Main Effect Plot for Delamination Factor at Exit

It is observed through main effect plot for delamination factor at exit as shown in fig.4 (b), the point angle have quire dominant effect on delamination factor at exit, feed have predominant effect on delamination factor at exit, but speed does not have much effect on delamination factor at exit. The delamination factor at exit increases with the increase in the feed and it decreases with the increase in drill point angle and speed. It is observed in fig.4 (b) that the point angle has a certain effect on the delamination factor at exit.

VIII. Analysis of Variance (ANOVA):

An analysis of variance of the data was carried out with the delamination factor (DF) and torque in banana fiber-reinforced composites with the objective of analyzing the influence of the point angle (pa) and feed rate (f) and cutting speed (s) on the total variance of the results.

TABLE 2 ANOVA FOR THRUST FORCE

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
pa	2	1801.23	1801.23	900.61	148.09	0.000	13.7108
f	2	10775.12	10775.12	5387.56	885.90	0.000	82.0201
s	2	49.77	49.77	24.89	4.09	0.028	0.3789
Error	27	164.20	164.20	6.08			0.09256
Total	53	13941.48		6568.58			
S = 2.46606 R-Sq = 98.82% R-Sq(adj)=97.69%							

TABLE 3 ANOVA FOR DELAMINATION FACTOR AT ENTRY

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
pa	2	0.0076749	0.0076749	0.0038374	79.41	0.000	20.6979
f	2	0.0207209	0.0207209	0.0103605	214.39	0.000	55.8818
s	2	0.0005408	0.0005408	0.0002704	5.60	0.009	1.4581
Error	27	0.0013048	0.0013048	0.0000483			0.2605
Total	53	0.0420015	0.0420015	0.01854			
S=0.006951 R-Sq = 96.89% R-Sq (adj) =93.90%							

TABLE 4 ANOVA FOR DELAMINATION FACTOR AT EXIT

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
pa	2	0.0039924	0.0039924	0.0019962	161.96	0.000	20.3870
f	2	0.0088650	0.0088650	0.0044325	359.63	0.000	45.2711
s	2	0.0001119	0.0001119	0.0000559	4.54	0.020	0.5709
Error	27	0.0003328	0.0003328	0.0000123			0.1256
Total	53	0.0270119	0.0270119	0.009791			
S=0.00351073 R-Sq98.77% R-Sq (ad)=97.58%							

From table 2, it can be seen that the point angle and the feed rate factor have statistical and physical significance on the thrust force.

Table 3 shows that the point angle and the feed rate factor have statistical and physical significance on the delamination factor at entry.

Table 4 shows that the point angle and the feed rate factor have statistical and physical significance on the delamination factor at exit.

IX. OPTIMIZATION

To find the optimal value for point angle, feed, speed we have used the Design Expert 8. The optimization module in searches for a combination of factor levels that simultaneously satisfy the requirements placed on each of the responses and factors.

In optimization, Desirability is an objective function that ranges from zero outside of the limits to one at the goal. The numerical optimization finds a point that maximizes the desirability function.

Based on the optimization performed for thrust force, the optimal value of the thrust force is at 90^o point angle, 3000 rpm cutting speed and 0.1 mm/rev feed.

Based on the optimization performed for delamination factor at entry, the optimal value of the delamination at entry is at 90^o point angle, 1000 rpm cutting speed and 0.1mm/rev feed.

Based on the optimization performed for delamination factor at exit, the optimal value of the delamination at exit is at 90^o point angle, 2000 rpm cutting speed and 0.1 mm/rev feed.

X. CONCLUSION

It is seen that the thrust force increases with increase in the point angle and feed. The thrust force decreases with the increase in the speed. It is seen that the delamination at entry decreases with the increase in the point angle. And the delamination factor at entry increases with the increase in the feed and speed. Also it is observed that the delamination at exit increases with the increase in the feed. And the delamination factor at exit decreases with the increase in the speed and point angle.

The overall optimization has been performed with a goal to optimize the value of thrust force, delamination factor at entry and exit simultaneously. It has been found that the optimal value for thrust force, delamination factor at entry and exit is at 90^o point angle, 1000 rpm cutting speed and 0.1 mm/rev feed.

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