Optimization Of Delamination Factor In Drilling Of Glass And Jute Fibers Reinforced Polymer Composite

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Abstract

The competitiveness in producing and using eco friendly materials is increasing with the increase in research in the particular field. Among the materials hybrid composites are becoming more familiar and famous as they can be tailored to required extensive properties and hence concentration is towards developing eco friendly composite material which is possible only through using the natural fibers along with the man made resin. Here in the study the natural fibers jute and glass are used along with the epoxy polymer to develop the eco friendly composite. As the fastening process gain much importance in all kinds of industries drillability of the concerned material is of major importance. Hence in this study drillability of the produced hybrid composite in terms of delamination factor which is the major issue in drilling of composite is concentrated. The experiments are designed through Taguchi and analysis of the effects of parameters is done through ANOVA and the optimization of process parameters is done using response surface methodology.

Keywords: Optimization, Taguchi, ANOVA, Response Surface Methodology, Hybrid Composites

1. INTRODUCTION

Each material has its own good and bad properties. The combination of materials can yield extensive properties which cannot be achieved by the single material alone. Hence researchers are working on developing material called as composite which is made up of two or more materials eventually having less weight compared to the conventional materials and have enhanced properties comparatively. Nowadays the concentration is mostly on developing the composite material made up of natural fibres mixed with the synthetic material which are advantageous as they possess beautiful properties such as light weight, plenty in availability and most importantly environmental friendly. The applicational areas of these hybrid composites are finding vast scope [1]. Many researchers have worked and found out the advantages of using natural fibers and mixing with the synthetic resin so as to obtain superior properties [2]. Banana, sisal and roselle fibers are used to build composite using mould method and the drill ability of the material is found out by considering parameters such as feed rate, spindle speed and tool dia and the output as thrust force and torque with HSS drill. It was found that the parameters are having major influencing the output. The torque as well as thrust force are increased with the increase in feed rate and decreases with the increase in speed [3]. These materials find their applications in major industries such as automotive, aircraft, defense and many other important sectors because of their intrinsic properties such as strength to weight ratio, enhanced corrosion and fatigue properties. Assemblies involving composites require high precision drilled holes so as to fasten the different parts made of composites. While drilling the composites the major issue is the fiber pull out which leads to delamination and other damages. These damages affects the durability of the joint which affects the whole assembly [4]. The drilling is carried out using different types of drill bits and found that brad and spur drill produces less delamination in turn the damage and induces less thrust force. The HSS twist drill produces more delamination which leads to more damage around the hole [5]. The natural composites have a high degree of properties which are less weight, less density, less abrasive nature and most importantly less cost. The machining of these composites poses a major challenge. To address these problems experiments were carried out on drilling glass fiber reinforced polymer and also natural fiber reinforced polymer using the carbide end milling cutter. It was clearly found that the damage in terms of fiber pull out and delamination is more in glass fiber reinforced composites than the natural fiber reinforced polymer. Surface roughness factor was also found to be best in natural fiber reinforced polymer [7]. Glass, hemp and sandwitched fibers with different volume fractions were considered to study the effects of process parameters during drilling of the material and the influence of feed rate and cutting speed were studied on the delamination factor. Observations made were the partial elliptical shape along the fiber directions and delamination increasing with the increase in the feed rates [8]. Coir-polyester composites were prepared to study the mechanical and also the machining characteristics. Tool wear along with thrust force and torque were analyzed and found that the tool dia of 6 mm and 600 rpm speed of the tool were the optimum values to obtain minimum outputs [9]. The reasearchers have also worked on the biological aspects of utilizing natural fiber composites instead of using orthopedic alloys. Experiments were conducted and revealed that the natural fiber composites have better qualities and properties than the orthopedic alloys. [10]. Factorial design method [11], regression model method [12], desirability function based method [12] and many other methods are employed to obtain optimum response values while machining the natural fiber composites. Here in this study the response surface methodology is adopted for optimizing the response values.

2. METHODOLOGY

Materials :

Here in the study jute fibers which are naturally available at 1-4 m of length are used which goes by the name sparrmanniaceae with better properties like high tensile strength and low extensibility, which is easily biodegradable, economical and easily available. The jute fibers are extracted in the chickballapur district and the glass fibers along with epoxy resin, HY951 hardener and drill bits are procured from local dealers in Bangalore.

Specimen preparation:

Glass and jute fibers are used in the fabrication of composite along with the epoxy resin and HY951 hardener. The method used to fabricate the composite is hand layup method which is completely manual process. Initially sunlight is used to dry up the fibers to remove any moisture present and after that the separation of small flakes is done. Application of releasing agent is done on a completely flat surface. The fibers sheet are placed alternatively then the resin with hardener is applied on both the sides of the layers. Fibers are placed horizontally as well as vertically so as to increase the strength of the laminate. The composite is then pressed using weight of 30 kgs at 60^0C for around 10 hrs and then cooled at roomed temperature and normal pressure. Finally 5mm thick specimen is obtained for the experimental work conducted at room temperature.

Experimental set up :

A sensitive drilling machine is used for the drilling purpose along with HSS drill bit of 3 different sizes (6mm, 9mm and 12 mm). The drilling machine is attached with a drill tool dynamometer for measuring dynamic torque and thrust force for each trial. 500 kgf is the maximum range of dynamometer for measuring thrust force with a least count of 1kgf. The delamination was measured using stereomicroscope by capturing images and using view 7 software by taking average of 4 diameters.

3. EXPERIMENTS AND RESULTS

Damage due to drill:

The delamination is the major factor which shows clearly the damage caused by the drill on the surface and throughout the hole. This can be studied by using Taguchi design of L27 array as shown in the above table . The delamination factor is calculated by using stereomicroscope by considering the average diameter as shown in fig 4. The formula given below is used to calculate DF and the same is tabulated in table 2

$F_d = D_{max}/D_{act,}$

D_{max}= Maximum Dia and D_{act} = Actual Dia, F_d=Delamination Factor

Similarly the thrust force and torque induced during the drilling is recorded directly through the digital output of the drill tool dynamometer and tabulated in table 2

The deviation and the measurement of delamination is done through S/N ratio and smaller is better condition is selected as the desired values of the outputs concerning the damage should always be minimum. Following observations were made using the S/N curve:

- Delamination decreases with the increase in the diameter
- Delamination decreases with the increase in the speed upto some point and then strarts increasing
- Delamination increases and finally decreases with the increase in feed rate

The ANOVA table can be utilized to know the contribution of parameters on the response considered. Here with table 3 it can be clearly seen that the major contributing factor is tool diameter followed by feed rate and finally the cutting speed. The reason for lower delamination at higher tool dia is may be due to more contact area and higher heat generated at the cutting zone which softens both fibers and matrix leading to less delamination. At higher feed rate the delamination reduces and again it may be due to high heat generation due to rubbing between the cutting edges.

Similarly, the taguchi analysis of thrust force and torque are also done and the S/N curves are as shown above. With increase in the dia of drill bit and rate of feed the thrust force increases and decreases with the increase in speed of the cutter. During drilling of laminates when the cutter enters new laminates the induced thrust force is high and reached to peak whereas when in between the layers the thrust force is minimum or forms a valley. This is due to more rubbing action at the starting of the layer due to which more heat is generated.

Optimization:

Using response methodology the whole system is analyzed in order to check the fitness of the model generated. The below graph (figure) gives the results of the analysis. The difference between the original and predicted values gives the residuals of that individual response. The normal probability plot clearly shows the point form a straight line which is a proof of the fitness of the model. It is clearly seen that there is no in obvious pattern or structure which is unusual.

The above figure shows the optimization curve for the delamination factor. It is clear that the delamination is minimized and the value is 1.2656 with the optimum parameters as cutter dia of

2mm, speed of 2400 rpm and a feed rate of 0.09 mm/rev. Similarly the optimum parameters for lower thrust force are dia of 2mm, cutting speed of 2400 rpm and a feed rate of 0.09 mm/rev. Also the optimum parameters for minimum torque are dia of 4mm, cutting speed of 1200 rpm and a feed rate of 0.07 mm/rev. The above table shows the comparison of experimental values with the predicted values using RSM. It can be seen that the values of responses predicted using optimum parameters are less than the experimental values. Hence the model is better than the models used in the literature.

Figure 1: Fibers used in the work

Figure 2: Glass and Jute fiber sheets

Figure 3: Sensitive drilling machine, dynamometer, fixture for load cell and stereomicroscope

Figure 4: Setup for measuring delamination

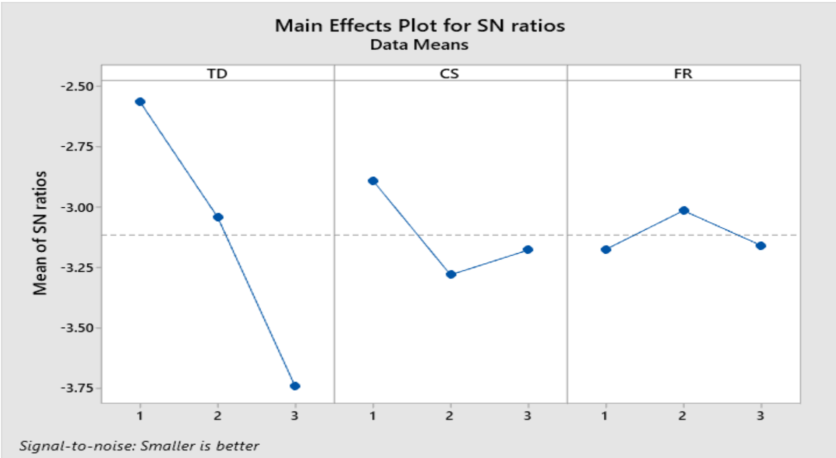

Figure 5: S/N ratio for delamination

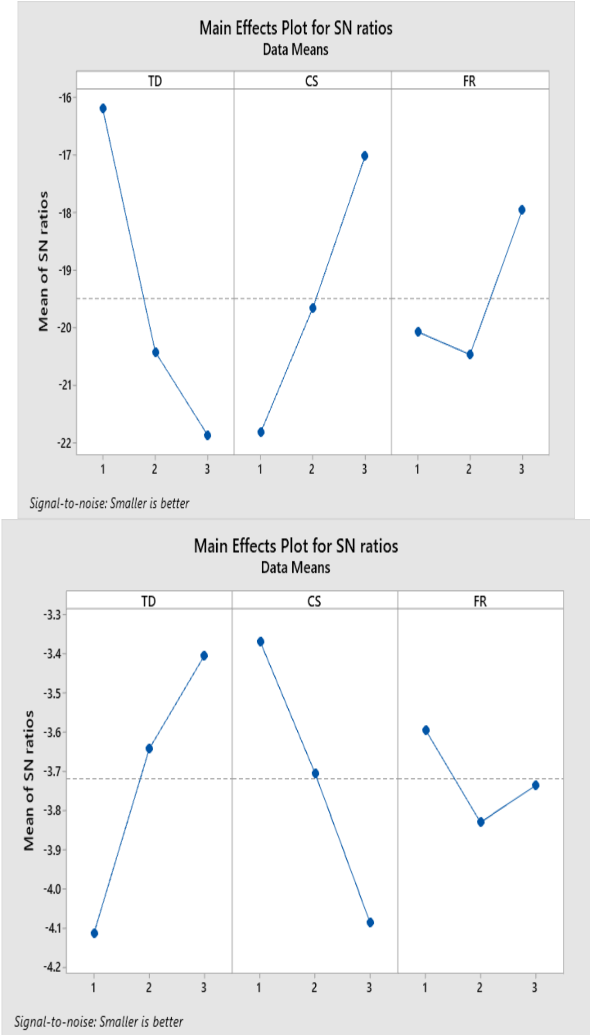

Figure 6: S/N ratio for thrust force and torque

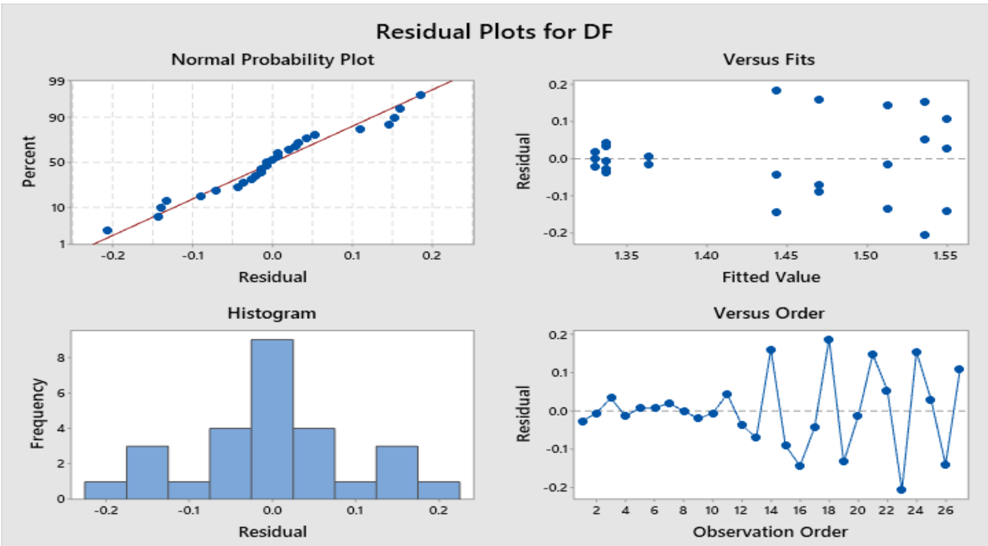

Fig7: Residual plots for delamination factor

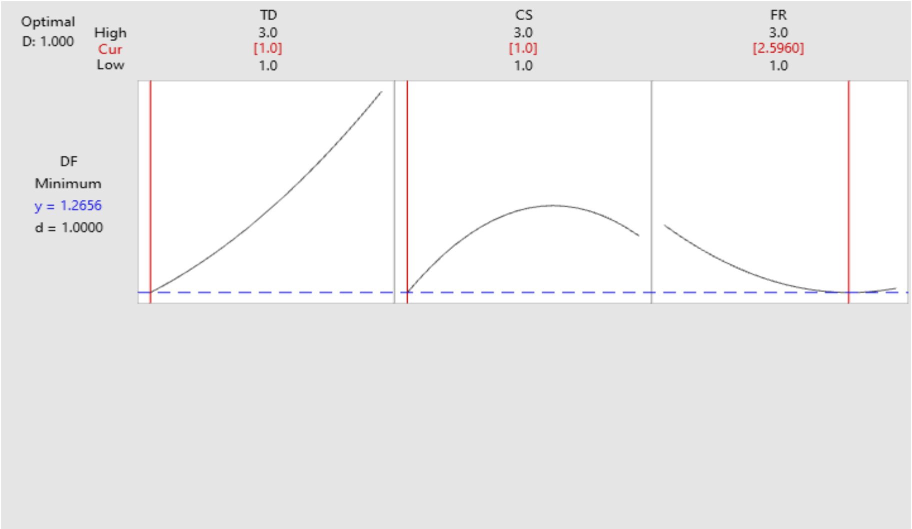

Fig 8: Optimization curve for delamination factor

Table 1. Levels and factors considered for analysis

Levels	Diameter(mm)	Cutting speed(rpm)	Feed rate(mm/rev)
1	**2**	**1200**	**0.05**
2	**4**	**1800**	**0.07**
3	**6**	**2400**	**0.09**

Table II. Table 1: DOE for thrust force, torque and delamination for the composite samples

Diameter (mm)	Cutting speed (rpm)	Feed rate (mm/rev)	Delamination factor	Thrust force (kgf)	Torque (Nm)
2	1200	0.05	1.31	5.5	1.41
2	1200	0.05	1.33	7.3	1.53
2	1200	0.05	1.37	16.4	1.66
2	1800	0.07	1.35	4.6	1.51
2	1800	0.07	1.37	6.4	1.62
2	1800	0.07	1.37	8.2	1.70
2	2400	0.09	1.35	4.6	1.63
2	2400	0.09	1.33	2.8	1.64
2	2400	0.09	1.31	3.7	1.74
4	1200	0.07	1.33	9.1	1.37
4	1200	0.07	1.38	12.7	1.45
4	1200	0.07	1.30	19.1	1.59
4	1800	0.09	1.40	8.2	1.46
4	1800	0.09	1.63	10.9	1.52
4	1800	0.09	1.38	12.7	1.63
4	2400	0.05	1.30	5.5	1.61
4	2400	0.05	1.40	4.6	1.67
4	2400	0.05	1.63	10.9	1.36
6	1200	0.09	1.38	8.2	1.41
6	1200	0.09	1.50	12.7	1.39
6	1200	0.09	1.66	14.6	1.44
6	1800	0.05	1.59	10.9	1.51
6	1800	0.05	1.33	11.8	1.32

6	1800	0.05	1.69	14.6	1.51
6	2400	0.07	1.58	10.9	1.58
6	2400	0.07	1.41	11.8	1.52
6	2400	0.07	1.66	14.6	1.64

Table III. ANOVA table for delamination factor

Source	**DOF**	**SS**	**Contribution of sources**	**Adj SS**	**Adj MS**	**F-Distribution**	**Probability Value**
Tool Dia	2	0.165267	37.37%	0.165267	0.082633	6.46	0.007
Speed of the cutter	2	0.018156	4.11%	0.018156	0.009078	0.71	0.504
Rate of Feed	2	0.002822	0.64%	0.002822	0.001411	0.11	0.896
Error	20	0.256022	57.89%	0.256022	0.012801		
Lack-of-Fit	2	0.012822	2.90%	0.012822	0.006411	0.47	0.630
Pure Error	18	0.243200	54.99%	0.243200	0.013511		
Total	26	0.442267	100.00%				

Table IV: Comparison of predicted values with the experimental values

Exp. values of Delamination factor	**Predicted values of Delamination factor**	**Exp. values of Thrust Force**	**Predicted values of Thrust force**	**Exp. values of Torque**	**Predicted values of Torque**
1.31	**1.45**	5.5	**5.2**	1.41	**1.21**
1.33	**1.41**	7.3	**7.1**	1.53	**1.45**
1.37	**1.39**	16.4	**15.2**	1.66	**1.54**
1.35	**1.32**	4.6	**4.1**	1.51	**1.25**
1.37	**1.40**	6.4	**6.2**	1.62	**1.6**
1.37	**1.36**	8.2	**7.2**	1.70	**1.66**
1.35	**1.34**	4.6	**4.1**	1.63	**1.56**
1.33	**1.31**	2.8	**2.5**	1.64	**1.24**
1.31	**1.33**	3.7	**3.2**	1.74	**1.67**
1.33	**1.39**	9.1	**8.3**	1.37	**1.28**
1.38	**1.36**	12.7	**12.1**	1.45	**1.39**
1.30	**1.32**	19.1	**17.9**	1.59	**1.49**
1.40	**1.44**	8.2	**7.1**	1.46	**1.40**
1.63	**1.65**	10.9	**8.9**	1.52	**1.44**

1.38	**1.41**	12.7	**11.6**	1.63	**1.59**
1.30	**1.28**	5.5	**5.7**	1.61	**1.56**
1.40	**1.36**	4.6	**4.9**	1.67	**1.55**
1.63	**1.70**	10.9	**10.1**	1.36	**1.29**
1.38	**1.27**	8.2	**7.4**	1.41	**1.34**
1.50	**1.47**	12.7	**10.9**	1.39	**1.26**
1.66	**1.67**	14.6	**13.1**	1.44	**1.35**
1.59	**1.57**	10.9	**9.3**	1.51	**1.44**
1.33	**1.30**	11.8	**9.8**	1.32	**1.29**
1.69	**1.71**	14.6	**15.1**	1.51	**1.50**
1.58	**1.53**	10.9	**9.8**	1.58	**1.49**
1.41	**1.42**	11.8	**10.8**	1.52	**1.38**
1.66	**1.61**	14.6	**12.8**	1.64	**1.66**

4. CONCLUSION

The analysis of the model for drilling composite material using HSS drill is done using Taguchi ANOVA and RSM and the following conclusions are made

- For delamination factor considered as response the major effecting factor is tool diameter followed by speed of drill and rate of feed. The optimum parameters for obtaining better or minimum delamination are 2mm, drill speed of 2400 rpm and rate of feed of 0.09 mm/rev.
- For the response that is thrust force the major effecting factor is tool diameter followed by speed of drill and rate of feed. The optimum parameters for obtaining better or minimum thrust force are 2mm, drill speed of 2400 rpm and rate of feed of 0.09 mm/rev.
- For the response torque, the major effecting parameter is cutting speed followed by tool dia and finally the rate of feed. The optimum parameters for obtaining better or minimum torque are dia of 4mm, cutting speed of 1200 rpm and a feed rate of 0.07 mm/rev.
- The fitness check of the model shows that the normal probability plot has a straight line by using the points obtained by the experiments. Hence the model is fit and acceptable.
- The predicted response values have shown lesser values as compared to the experimental values which clearly indicate the appropriateness of the model generated.

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