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Optimization of the Drilling Parameters on Delamination Factor at Hybrid Fiber Reinforced Polymer Composites

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Abstract— Delamination is one of the common failures in composite materials that affect the strength of the composite, which appears during the machining, and drilling of composite materials. This paper focuses on the effect of the drilling parameters spindle speed, and feed rate on the delamination factor during the drilling process of Hybrid Fiber Reinforced Polymer (HFRP) with 5 mm thickness. Taguchi design is employed to study the drilling parameters of HFRP using an orthogonal array with L16. It is concluded that feed rate is the significant parameter that affects delamination damage comparable with spindle speed. The optimum experiment is with a minimum delamination factor is 1.304 at 1273 rpm spindle speed and 0.05 mm\rev of feed rate. Also, the maximum delamination factor is 1.496 occurred at a spindle speed of 318 rpm and a feed rate of 0.20 mm/rev.

Keywords—Composite Materials, Delamination, Taguchi design, Drilling process.

1. Introduction

Recently the applications of composite materials have increased due to produce new Fiber-Reinforced Composites (FRCs) with better damage resistance, impact strength, high toughness, sustainability, renewability, long-life, environmentally friendly, low cost, easy production process, reduction of parts count, high stiffness, design flexibility, low weight-to high strength ratio, mechanical damping, also the chemical, thermal, corrosion, and wear resistance when compared with the traditional metallic material.[11,9]

Composites have been used in different engineering and industrial fields due to their superior properties such as high stiffness/weight ratio, high strength/weight ratio, and good corrosion resistance. Composites are usually done near net shape but sometimes they are needed for machining like drilling, finishing, and grinding. For this reason, machining composite materials is important to achieve quality and dimensional accuracy. Drilling composites are widely used in mechanical applications that require assembly.

Many researchers report that the quality of drilling holes and machined surfaces depends on drilling and cutting parameters respectively, these parameters are type of composites, tool geometry, diameter of drill bits, spindle speed, feed rate, etc. Inaccurate choice of these parameters drives an accepted composite disintegration like fiber pull out, delamination, and thermal damage [16].

Hybrid Fiber Reinforced Plastic (HFRP) composite is a developed composite material using two or more fibers to fabricate a composite. HFRP composite improves the failure strain by combining glass fiber with high elongation, and carbon fiber with low elongation, usually drilling holes in HFRP composite is for mechanical fastening, and has many applications such as oil platforms and drain grates [4].

Maoinser, et al. [8] fabricated an HFRP composite of glass and carbon fibers with a volume fraction of 45% of the HFRP composite. For the drilling process used carbide drill with a diameter of 6 mm. They used cutting speeds 53, 106, and 212 m/min, feed 0.02, 0.06, and 0.12 mm/rev, and point angles of the drill 85º, 118º, and 135º.

The optimal experiment was maintained when drilling HFRP composite at 106 m/min cutting speed, feed 0.02 mm/rev, and drill point angle 85º. Also, they found that the thrust force at drilling HFRP composite is minimum than in drilling Glass Fiber Reinforced Polymer (GFRP) with the same conditions at high cutting speed, low point angle of the drill, and low feed rate. Satyanarayana and Prasad [4] investigated HFRP with 4 mm thickness consisting of 7 layers of woven fabric; 4 layers of glass and 3 layers of carbon using a hand lay up technique. The drilling process was performed using HSS drill. They concentrated on studying the effect of the parameters spindle speed 485, 795, 1250 rev/min, feed rate 18, 20, 26 mm/min, point angle 100º, 118º, 135º on delamination. ANOVA with three levels for each parameter was used to optimize the results, they concluded that spindle speed is a significant parameter for the delamination factor. Also, the optimum experiment was a spindle speed of 795 rev/min, feed rate of 20 mm/min, and point angle of 135º.

Mohd Azuwan Maoinseret et al. in [6] compared drilling 3 mm thickness of HFRP and GFRP at different spindle speeds and feed rate values. The quality of holes was assessed by the delamination factor of the drilled holes, the results showed that HFRP composite has a lower delamination factor compared to GFRP composite at a lower spindle speed and/or feed rate. Sarower Kabir et al [10] studied the influence of spindle speed and feed rate on coated HFRP composite consisting of woven glass and carbon reinforcement layers, using HSS twist drill tool for drilling, ANOVA was used to find the optimum parameters. The results showed that the optimum experiments with minimum surface roughness and delamination at parameter 3000 rpm spindle speed, and 0.08 mm/rev feed rate with 1 mm coating thickness HFRP composite, also at parameters 6000 rpm, and 0.02 mm/rev with 1.5 mm coating thickness HFRP composite. Delamination factors at the entrance decrease with increasing cutting speeds, but the delamination factors at the exit showed the opposite results. Tan, C.L. et al. in [13] focus on the delamination that occurs in drilling carbon-glass fiber hybrid composite under different drilling conditions using an 8 mm diameter uncoated cement carbide tool. The desirable drilling parameters have been determined by Taguchi design for the minimum delamination at 7500 rpm spindle speed, 0.08 mm/rev feed rate. G. Anand et al [3] used the Taguchi L25 orthogonal array to optimize the parameters; drill diameter, spindle speed, and feed rate for the responses delamination, thrust force, and torque. They found that the optimized results were drill diameter of 4 mm, spindle speed of 2700 rpm, and feed rate of 30 mm/min for lower delamination, thrust force, and torque. Mohd A. Maoinser et al [7] Studied the effect of the feed rate and point angle of the twist drill tool on the thrust force and delamination factor on drilled holes of HFRP composite material with a 45% volume fraction of glass and carbon fibers. The point angle was 85°, 118°, and 135°, the results indicated that minimum feed rate values and point angle of the drill tool can reduce the delamination on both the entry and exit sides of drilled holes.

2. Delamination Phenomena

Delamination is considered the most widespread defect that occurs during the drilling of composite materials. Delamination usually appears at the upper and lower layers of the laminates. At the entry side, delamination damage occurs when the drill tool gets into the top layers and separates these layers from the composite work part. On the bottom side, delamination occurs when the drill tool pushes the bottom layers of the composite work part [11]. **Figure 1** clears the delamination mechanism.

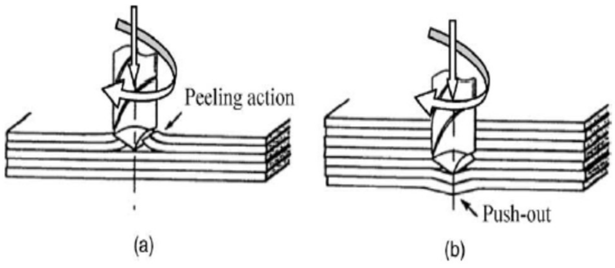

Figure 1: Delamination during the Drilling Process (a) delamination at the entrance side (b) delamination at the exit side. [2].

The delamination factor is an index used to calculate the ratio between the delamination zone diameter and drilled hole diameter, equation (1) shows the relation between parameters [13].

$$\mathrm{Fd} = \frac{\mathrm{Dmax}}{\mathrm{D}} \tag{1}$$

Fd is the delamination factor, Dmax is the delamination diameter (mm), and D is the diameter of the drilled hole.

3. Experimental Procedure

3.1 Fabrication HFRP Composite

The woven glass and carbon fibers are selected as reinforcement materials, and polyester is selected as the matrix material. The choice of the mixture of carbon and glass fibers to make a new composite material with new mechanical properties that are different from GFRP and CFRP. This composite was prepared at room temperature 20°C; an aluminum brush was used to distribute the polyester over the fibers. After finishing the fabrication of the composites; use the vacuum bagging technique to get rid of extra resin, and air bubbles from the composite sheet. The weight percentage of reinforcement is 36% of the total weight of the HFRP composite with a thickness of 5 mm, Figure 2 shows the HFRP composite sheet after passing 24 hours at room temperature in the mold.

Figure 2: HFRP Composite Sheet.

Mechanical tests were implemented on the HFRP composite according to ASTM standards; the average results of three specimens of each test are summarized in **Table 1**.

Table 1: HFRP Mechanical Properties Results.

Property	ASTM Standards	Result
Ultimate tensile strength	D3039	133 MPa
Ultimate bending strength	D790	9.73 MPa
Ultimate compression strength	D695	242 MPa
Hardness	D2240	81 Shore D
Toughness	D256	0.11 J/mm^2

3.2 Drilling Processes

The drilling process was conducted on a CNC vertical drilling machine as cleared in **Figure 3**; the drill used throughout the test was HSS with a 10 mm diameter and point angle of 118°. All experiments were done without coolant. **Figure 4** presents the schematic of the HFRP composite with 16 holes after the drilling process, and the machining setup for the drilling process is illustrated in **Figure 5**.

Figure 3: CNC Vertical Drilling Machine.

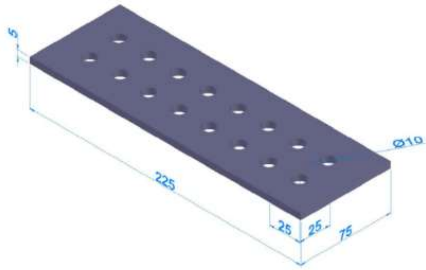

Figure 4: Schematic of HFRP Composite Sheet after the Drilling of 16 Holes (all dimensions in mm).

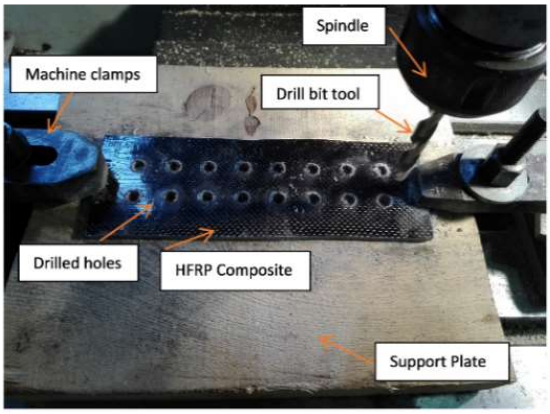

Figure 5: Machining Set up.

4. Taguchi Design

Recently, orthogonal arrays have been used in many engineering and industrial applications, the objective of this approach is to control the data and also to get information about the attitude of the process [15]. In this paper, two parameters were indicated as a controlling factor; each parameter was designed to have four levels as in **Table 2**, these values were indicated according to the type of drill tool and thickness of the composite part.

Table 2: Drilling Parameters and its Four Levels.

Levels	Spindle speed (rpm)	Feed rate (mm/rev)
1	318	0.05
2	637	0.10
3	955	0.15
4	1273	0.20

The experiments were designed based on the L16 (4^2) array based on the Taguchi method which was used to reduce the number of experiments. **Table 3** shows the L16 experiments. **Figure 6** shows the 16 holes of the HFRP composite sheet using a stereo microscope that is cleared in **Figure 7.**

Table 3: Orthogonal Array of Taguchi L16.

Experiment No.	Spindle speed (rpm)	Feed rate (mm/rev)
1	318	0.05
2	318	0.10
3	318	0.15
4	318	0.20
5	637	0.05
6	637	0.10
7	637	0.15
8	637	0.20
9	955	0.05
10	955	0.10
11	955	0.15
12	955	0.20
13	1273	0.05
14	1273	0.10
15	1273	0.15
16	1273	0.20

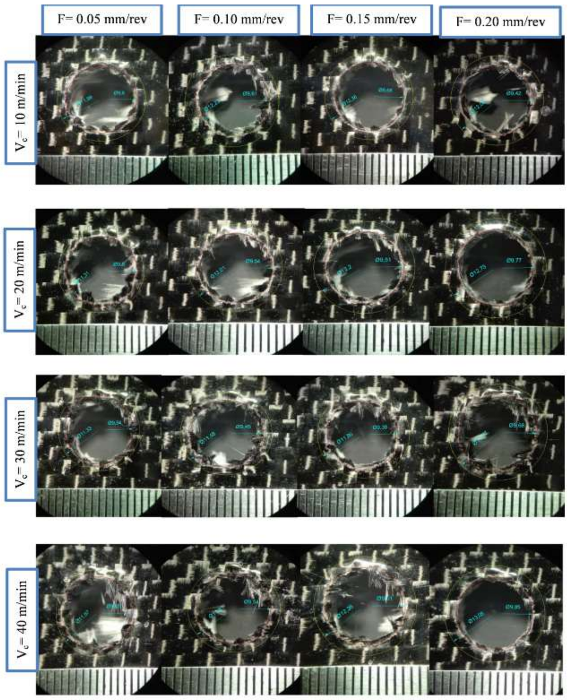

Figure 6: Holes of HFRP Composite Sheet using Stereo Microscope.

Figure 7: Stereo Microscope.

5. Results and Discussion

After finishing the drilling process, a microscope with a magnification of 20x and resolution of 0.8 was used to indicate the delamination zone to find the delamination factor for each hole **Table 4** presents the results.

Table 4: Experiments and Results.

Experiment No.	Spindle speed (rpm)	Feed rate (mm/rev)	F_d
1	318	0.05	1.369
2	318	0.10	1.424
3	318	0.15	1.476
4	318	0.20	1.496
5	637	0.05	1.365
6	637	0.10	1.405
7	637	0.15	1.439
8	637	0.20	1.451
9	955	0.05	1.274
10	955	0.10	1.306
11	955	0.15	1.339
12	955	0.20	1.390
13	1273	0.05	1.304
14	1273	0.10	1.337
15	1273	0.15	1.389
16	1273	0.20	1.433

The analysis of variance was done by Taguchi Design using Signal-to-Noise ratio (S/N) which has many categories, in this paper the goal is for minimum delamination factor so the category smaller is better was chosen according to equation (2)

$$S/N = -10 \log \frac{1}{n} \sum_{1}^{n} \frac{1}{y^2} \tag{2}$$

Table 5 shows the experiments' S/N ratio depending on the delamination factor value, also **Figure 8** shows the influence of drilling parameters on the delamination factor.

Table 6 presents the feed rate rank as the first followed by spindle speed meaning that feed rate has a major effect on the delamination factor than spindle speed. Chetan M. Rathod and Mahesh Chudasama [1], and K. W. Liew et al [5] found that the minimum value of the delamination factor occurs when drilling composite materials with a low value of feed rate, and a high value of spindle speed.

Table 5: S/N Ratio for Delamination Factor.

Experiment No.	F_d	SNRA1
1	1.369	-2.72807
2	1.424	-3.07020
3	1.476	-3.38173
4	1.496	-3.49863
5	1.365	-2.70265
6	1.405	-2.95353
7	1.439	-3.16122
8	1.451	-3.23335
9	1.274	-2.10339
10	1.306	-2.31886
11	1.339	-2.53561
12	1.390	-2.86030
13	1.304	-2.30555
14	1.337	-2.53363
15	1.389	-2.85404
16	1.433	-3.12492

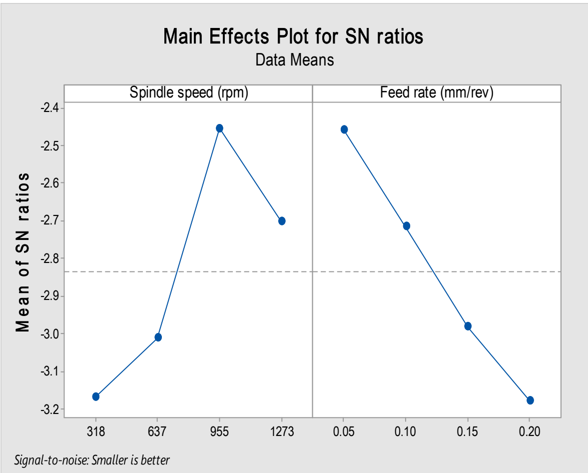

Figure 8: Main Effects Plot for Drilling HFRP Composite.

Table 6: Responses for Signal to Noise Ratios (Smaller is better).

Levels	Spindle speed (rpm)	Feed rate (mm/rev)
1	-3.170	-2.460
2	-3.013	-2.716
3	-2.455	-2.983
4	-2.702	-3.179
Delta	0.715	0.719
Rank	2	1

Experiment no.13 is the optimum experiment with minimum delamination at a high value of cutting speed and a lower value of feed rate as shown in **Figure 9**. Usually in machining processes especially at the drilling processes, it is preferred to remove material at a lower feed rate and high spindle speed to achieve a better surface finish and good hole quality; and also to prolong the cutting tool life which is proved in this paper.

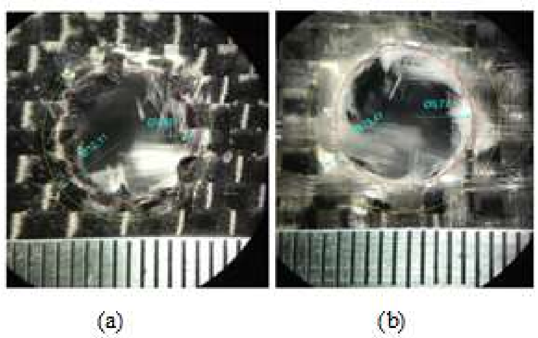

Figure 9: Drilled Hole no.13 using the Stereo Microscope (a) at the entrance side of the hole (b) at the exit side of the hole.

6. Conclusion

In this paper, fabricated HFRP composite from glass and carbon fibers, the used four levels of cutting speed and feed rate in drilling the HFRP composite sheet; using an L16 orthogonal array in the Taguchi technique, the delamination was measured by a stereo microscope, from this paper, it has been concluded the following:

1- Feed rate is the most effective parameter on delamination factor than spindle speed.

2- The delamination factor increases when the feed rate increases and the spindle speed decreases.

3- The optimum experiment was with a minimum delamination factor of 1.304 at 1273 rpm spindle speed and 0.05 mm/rev feed rate.

4- The maximum delamination factor of 1.496 was achieved with a spindle speed of 318 rpm and feed rate of 0.20 mm/rev.

Nomenclature

F_d Delamination Factor

D_{max} Delamination Diameter (mm)

D Diameter of the drilled hole (mm)

y Data observed

n number of observation

log Logarithm

Abbreviations

HFRP Hybrid Fiber Reinforced Polymer

FRCs Fiber Reinforced Composites

GFRP Glass Fiber Reinforced Polymer

CFRP Carbon Fiber Reinforced Polymer

ASTM American Society for Testing and Materials

SNRA1 Single-to-Noise ratio

7. References

[1] Chetan M. Rathod and Mahesh Chudasama, "An Investigation of Hole Size, Circularity, and Delamination During Drilling Operation of Carbon Fiber Reinforced Polymer with using ANOVA", International Journal of Science Technology and Engineering, vol. 2, no. 1, pp. 53-59,2015.

[2] Faramarz Ashenai Ghasemi, Abbas Hyvadi, Gholamahassan Payganeh, and Nasrollah Bani Mostafa Arab "Effects of Drilling Parameters on Delamination of Glass-Epoxy Composites", Australian Journal of Basic and Applied Science, Vol. 5, No.12, pp. 1433-1440, 2011.

[3] G. Anand, N. Alagumurthi, R. Elansezhian, K. Palanikumar, N. Venkateshwaran "Investigation of drilling parameters on hybrid polymer composites using grey relational analysis, regression, fuzzy logic, and ANN models", Journal of the Brazilian Society of Mechanical Sciences and Engineering, Mar 2018.

[4] K.V. Satyanarayana and D.V.V. Krishna Prasad, "Optimization of Drilling Parameters for Delamination Factor in of Hybrid Fiber Reinforced Polymers", International Journal of Innovative Science, Engineering and Technology, Vol.3 No. 6, pp. 353-359, 2016.

[5] K. W. Liew, A. Ramasegar, M. Souiyah, and N.S.M. El-Tayeb "Minimizing Push-out Delamination in Glass Fiber Reinforced Polyester using RSM", International Journal of Applied Science and Technology, vol.2, no. 3, pp. 183-191, 2012.

[6] Mohd Azuwan Maoinser, Faiz Ahmad, and Safian Shariff "Effects of Cutting Parameters on Hole Integrity when Drilling GFRP and HFRP Composites" Advanced Materials Research, Vol. 845, pp. 960-965, 2014.

[7] Mohd Azuwan Maoinser, Faiz Ahmad, and Safian Shariff "Effects of Twist Drill Point Angle on Thrust Force and Delamination Factor in Hybrid Fiber Composites Drilling" Applied Mechanics and Materials, Vol. 564, pp. 501-506 June 2014.

[8] Mohd Azuwan Maoinser, Faiz Ahmed, Safian Sharif, and Woo Tze Keong, "Minimizing Drilling Thrust force for HFRP Composite by Optimization Process Parameters using Combination of ANOVA Approach and S/N Ratios Analysis" EDP Sciences, 2014.

[9] P.N.E. Naveen, M. Yasaswi and R.V. Prasad, J. Mech. Civil Eng. Vol. 2 (2012), pp 30-37.

[10] Sarower Kabir, Faiz Ahmad, Chowdhury Ahmed Shahed, and Ebru Gunister "Influence of Drilling Parameters on the Delamination and Surface Roughness of Insulative-Coated Glass/Carbon-Hybrid Composite" Advances in Polymer Technology, June 2023.

[11] S. Madhavan and S. Balasivanandha Rad "An Experimental Study of Influence of Drill Geometry on Drilling of Carbon Fiber Reinforced Plastic Composites "International Journal of Engineering Research and Development, Vol.3, No.1, pp. 36-44, 2012.

[12] S. Sridharan, Delamination behavior of composites (Woodhead Publishing Limited, Cambridge England, 2008).

[13] Tan, C.L, Azmi, A.I., Mohamad, N., Khalil, A.N.M., Leong, K.W. "Delamination analysis of carbon/glass hybrid polymer composites in drilling process" Advances in Materials Processing Technologies, Nov 2014.

[14] Tom Sunny, J. Babu, and Jose Philip" Experimental Studies on Effect of Process Parameters on Delamination in Drilling GFRP

Composites using Taguchi Method", Procedia Materials Science, pp. 1131-1142, 2014.

[15] Vimanyu Chadha, Sanchay Gupta, and Ranganath M. Singer, "Optimization of Cutting Parameters on Delamination using Taguchi Method during Drilling of GFRP Composites", Proceedings of the International Multi-Conference of Engineers and Computer Scientists, Vol.2, 2017.

[16] Vinod Kumar Vankanti and Venkateswarlu Ganta "Optimization of Process Parameters in Drilling of GFRP Composite using Taguchi method" Journal of Materials Research and Technology, Vol. 3, pp.35-41, 2014.

أمثلية عوامل التثقيب على معامل الانفصال الطبقي لمواد مركبة من بوليمر مقوى بفايبر هجيني

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الخلاصة – الانفصال الطبقي هو احد انواع الفشل الشائعة في المواد المركبة الذي يؤثر على متانة المادة المركبة، والذي يظهر خلال تشغيل أو تثقيب المواد المركبة. في هذ البحث, تم التركيز على تأثير عوامل القطع سرعة عمود الدوران ومعدل التغذية على معامل الانفصال الطبقي الحاصل أثناء تثقيب مواد مركبة من بلاستك مقوى بألياف فايبر هجيني بسمك 5 ملم. تم الأعتماد على طريقة تاكوشي من أجل دراسة تأثير عوامل التشغيل على المادة المركبة الهجينة بأستخدام طريقة الصفوف المتعامدة L16 . تم التوصل أن معدل التغذية هو العامل الأكثر تأثيرا على الأنفصال الطبقي مقارنة بسرعة عمود الدوران. التجربة الأمثل بأقل معامل انفصال طبقي 1.304 عند سرعة عمود الدوران 1273 دوره/دقيقة وبمعدل تغذية 0.05 ملم/دورة. بالاضافة الى ذلك، اعلى معامل انفصال طبقي 1.496 عند سرعة عمود الدوران 318 دورة/دقيقة وبمعدل تغذية 0.20 ملم/دورة.

الكلمات الرئيسية – المواد المركبة، الانفصال الطبقي، طريقة تاكوشي، عملية التثقيب.