Optimization of Cutting Parameters on Delamination of Drilling Glass-Polyester Composites

Majid Habeeb Faidh-Allah
Assistant Professor
College of Engineering-University of Baghdad
dr_majidhabeeb@yahoo.com

Sanad Abdulkareem Ismail
Researcher
College of Engineering-University of Baghdad
sanadkarim@yahoo.com

ABSTRACT

This paper attempted to study the effect of cutting parameters (spindle speed and feed rate) on delamination phenomena during the drilling glass-polyester composites. Drilling process was done by CNC machine with 10 mm diameter of high-speed steel (HSS) drill bit. Taguchi technique with L16 orthogonal layout was used to analyze the effective parameters on delamination factor. The optimal experiment was no. 13 with spindle speed 1273 rpm and feed 0.05 mm/rev with minimum delamination factor 1.28.

Key Words: composite materials, drilling, delamination, Taguchi method.

أمثلية عوامل التثقيب المؤثره على الانفصال الطبقي الحاصل أثناء تثقيب مواد مركبة من ألياف زجاجية - بوليستر

ا.م.د مجيد حبيب فيض الله
جامعة بغداد- هندسة ميكانيك

سند عبدالكريم اسماعيل
جامعة بغداد – هندسة ميكانيك

الخلاصة

يحاول هذا البحث دراسة تأثير متغيرات التشغيل (سرعة عمود الدوران ومعدل التغذية) على الانفصال الطبقي اثناء عملية تثقيب مواد مركبة من ألياف زجاجية - بوليستر.وقد أجريت عملية التثقيب باستخدام ماكنة مبرمجة باستخدام بريمه بقطر 10 ملم مصنعة من صلب السرعات العالية.واستخدمت طريقة تاكوشي بتوزيع L16 لتحليل العوامل المؤثرة على الانفصال الطبقي الحاصل اثناء تثقيب ألياف زجاجية - بوليستر. وتعد التجربة الامثل هي 13 بسرعة عمود دوران تصل الى 1273 دوره بالدقيقة وبتغذية تصل الى 0.05ملم/ دورة مع 1.28 كحد ادنى من معامل الانفصال الطبقي.

الكلمات المفتاحية: المواد المركبة ، التثقيب ، الانفصال الطبقي ، طريقة تاكوشي.

1 INTRODUCTION

1.1 General Aspect

Recently, composites successfully alternated the traditional materials and metal alloys in high strength and low weight engineering fields.The machining of the composite materials includes drilling, cutting, and other processes. Basically, drilling process is the most machining process used for fastening and assembly composite parts.
The quality of these composite parts is affected by the drilling parameters, the geometry of the tool, tool material, type of workpiece, tool wear, coolant type, etc. In fact, an accurate drilling should be done in order to ensure the composite part in the dimensional constancy. Therefore, progression in optimizing the drilling parameters should be done in order to achieve better output in the drilling process. It is needed to realize the relationship between the different parameters that affected on composite parts during the drilling process. Moreover, it is necessary to achieve the optimal parameter to attain better productivity. **Jindal,** and **Singla, 2011**.

Glass Fiber Reinforced Polymer (GFRP) composite material has excellent mechanical properties, it is commonly used in industry like automobile, aerospace structures. Drilling GFRP is a rough process due to the delamination damage that occurs during drilling composite, in order to increase the quality and decrease the damages of the drilled holes in GFRP composite, it should understand the drilling performance which is achieved by executing many experiments also the drilling parameters spindle speed and feed rate should be optimized. **Babu, et al., 2014**.

In this paper, it has been studied the effect of cutting parameters spindle speed and feed rate on the delamination that occur during the drilling of glass-polyester composites using Taguchi method L16 with 4 levels for each parameter to analyze the information from the experiments then calculated the optimal drilling parameter in drilling glass-polyester composite material.

1.2 Literature Survey

Many researches have done on the quality of the holes and delamination that occur during drilling GFRP.

Ghasem, et al., 2011 studied the effect of parameters on delamination when drilling Glass Fiber Reinforced Polymer (GFRP) composites with five layers of E- glass fibers with volume fraction 0.55% from composite part. Using drilling tools made from HSS material for the drilling process. The Taguchi method helps to optimize the results. The optimal parameters were: speed 2000 rpm, feed 100 mm/min and drill point angle 90˚ (drill tip) for less delamination damage. **Liew, et al., 2012** concluded that minimizing push-out delamination damage in GFRP using hand lay-up method to fabricate the composites. The composite made from R-glass type chopped strand mat as the reinforcement and polyester as the matrix.

A mathematical model used to explain the effect of cutting speed, feed, and drill diameter on push-out delamination. Minimum delamination was reached when speed 1420 rpm, feed rate 83 mm/min, and diameter of the drill bit tool is 8 mm**. Babu, et al., 2014** proved that delamination zone increases with speed 1000-2500 rpm, also decreases with feed rate 100-400 mm/min using Taguchi design for optimizing the parameters with a minimum delamination during drilling GFRP. The optimal case was with speed 2500 rpm and feed 100 mm/min. **Sreenivasulu, 2013** concluded the optimal delamination damage on GFRP with rotation speed 1000 rpm, depth of cut 1.5 mm, and feed rate 200 mm/min by Taguchi experiments. The results show that the depth of cut is the most parameter that effect on the delamination.

Kavad, et al., 2014 suggested that cutting speed, feed rate, and material of the tool are the influential parameters that effect on delamination factor when working with high speed, low feed rate, and hard tool materials**.** Delamination factor (Df) is the index that generally used to estimate the delamination damage that occurs during the drilling process on composite specimens. At the entry of the hole, the relative piles can segregate from each other by the force of the drill because of the slope that generated from the flutes of the drill. On the other side, at the exit of the hole, the piles that still un-cut under the drill can be changed due to the deformation that happened when drilling composites which leads these layers to reduce in thickness. The drilling force that spent in drilling composites is more than the bonding strength between layers. **Melentiev, et al., 2016.**

2. EXPERIMENTAL PART

The experimental part started from fabricated glass-polyester composite, finding mechanical properties, the drilling process, measuring delamination and ends with optimization step.

2.1 Specimen Preparation

Hand lay-up technique is used to fabricate glass-polyester composite. Eight layers of E-glass woven fabric was used as reinforcement with weight fraction, 40% of the total weight of composite plate, unsaturated polyester was used as the matrix. The final thickness of the composite part is 5.5 mm after heat treatment in an autoclave for 15 min. **Fig.1** shows the glass-polyester composite plate.

2.2 Mechanical Tests

CNC milling machine with maximum rotational speed 6000 rpm was used to perform a cutting process on glass-polyester composite, **Fig.2** shows the milling machine. The purpose of cutting the composite work part, to achieve the specimens for mechanical properties tests. Each test included three specimens in order to take the average of them for more accurate in the results.

The mechanical tests were done according to ASTM standards the tests are tensile, compression, bending, impact, and hardness; tensile test specimens were cut to size 250*25 mm^2 at the tensile testing machine with stain rate 2.0 mm/min. Compression test specimens were in dimension 3*3 mm^2 at compression testing machine with stain rate 1.30 mm/min. Bending test carried out with specimen dimensions 125*12 mm^2 with a bending test machine at strain rate 2.0 mm/min. Impact test was done to find the toughness of each type of composite material with a dimension of specimen 63*12 mm^2. Hardness test was done by Shore D thermometer, the size of the specimen was

25*25 mm^2. **Fig.3** shows the mechanical test specimens. **Table.1** summarized the mechanical tests and the dimensions of each specimen and its result.

2.3 Drilling Process

After that, drilling process was accomplished using HSS drill tool with 0.066% Co with diameter 10 mm. Drilling process was carried out using the same CNC machine. Experiments were done on 16 holes with different spindle speed and feed rate using Taguchi Method to design these parameters as in **Table 2.**

2.4 Taguchi Design

Taguchi method with orthogonal array 16 was used to study the whole parameters that effected on delamination damage with less number of experiments. **Fig.4** shows the glass-polyester composite that has been drilled. Delamination zone observed in glass-polyester using Microscope with magnification 20x cleared in **Fig.5** then used Autodesk software 2016 for calculating the dimension of the delamination zone at the top and bottom surfaces of the drilled holes then take the average of each hole as it presented in **Fig. 6**. and **Fig.7**. (D_f) is calculated using equation (1):

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

Where D_f =Delamination factor, D_{max}= Diameter of delamination zone (mm), D= Diameter of drilled hole (mm)

Calculations of delamination factor for the experiments of the glass-polyester composite are shown in **Table 3**.

In Taguchi technique, the signal to noise ratio (s/n) characteristic smaller is better is applied to calculate the optimal parameter for less delamination factor, the equation (2) is showing the formula that used:

$$S/N = -\,10 \log \frac{1}{n} \quad (\Sigma\, y^2) \tag{2}$$

Where: n = number of observations, y = the observed data.

3. RESULTS AND DISCUSSION

It is inferred from **Table 3** it was that delamination factor (D_f) at the maximum value 1.47 in experiment 16 with spindle speed 1273 rpm the maximum value that is used in this study also the feed rate was the maximum value 0.20 mm/rev followed by the D_f 1.46 in experiment 12 with medium spindle speed 955 and maximum feed rate 0.20 mm/rev. The less delamination 1.28 was achieved in experiment 13 with maximum spindle speed 1273 rpm and minimum feed rate 0.05 mm/rev also experiment 9 with D_f 1.29 when the medium value of spindle speed was 955 rpm and minimum feed rate 0.05 mm/rev.

Table 4. shows the results after applying Taguchi design on the parameters, the rank of feed rate is 1 and spindle speed is 2 which means that the feed rate is more influential on the drilling parameters than rotation speed, it is clear in **Table 5**. In the **Fig.8**, the relationship between delamination and spindle speed and feed rate is indicated.

4. CONCLUSIONS

This paper presented the effect of spindle speed and feed rate on the delamination factor during the drilling process of glass – polyester composite material. The conclusions of this study were drawn as follows:

1- The optimal condition in drilling glass-polyester composite with high spindle speed and low feed rate. It is obviously an experiment no.13 with spindle speed 1273 rpm and feed rate 0.05 mm/rev the less delamination facto was achieved 1.28.

2- Feed rate is affected by the delamination factor more than spindle speed as it shown in experiments no. 12 and 16 with maximum delamination factor 1.46 and 1.47 respectively.

3- When feed rate increased, delamination factor increased with the same spindle speed value.

REFERENCES

- Babu, J., Sunny, T., Philip, J., 2014, *Experimental Studies on Effect of Process Parameters on Delamination in Drilling GFRP Composites using Taguchi* Method, PP 1131-1142.
- Ghasemi, F., A., Hyvadi, A., Gholamhassan, P., Arab, N., B., M.,2011, *Effects of Drilling Parameters on Delamination of Glass-Epoxy Composites*.PP.1433-1440.
- Jindal, A., Singla, V. K., 2011, *Experimental Investigation of Process Parameters in Drilling Operation Using Different Software Techniques,* Vol. 1, PP.135-154.
- Kavad, B., V., Pandey, A., B., Tadavi, M., V., Jakharia, H., C., 2014, *A Review on Effects of Drilling on Glass Fiber Reinforced Plastic.* PP. 457-463.
- Liew, K., W., Ramasegar, A., Souiyah, M., El-Tayeb, N., S., M., 2012, *Minimizing Push-out Delamination in Glass Fiber Reinforced polyester using RSM*, Vol.2, No.3, PP 183-191.
- Melentiev, R., Priarone, P.C., Robiglio, M., Settineri, L., 2016, *Effect of Tool Geometry and Process Parameters on Delamination in CFRP Drilling: An overview,* No.45, PP. 31-34.

- Sreenivasulu, R., 2013, *Optimization of Surface Roughness and Delamination Damage of GFRP composite Material in End Milling using Taguchi Design Method and Artificial Neural Network.* PP 75-794.

NOMENCLATURE

D = diameter of the drilled hole in mm
Df = delamination factor
Dmax = diameter of delamination zone in mm
GFRP = glass fiber reinforced polymer
HSS = high speed steel
rpm = revolution per minute
S/N = signal to noise ratio

Figure 1. Glass-polyester composite.

Figure 2. CNC milling machine.

Figure 3. Mechanical Test specimens (a) Tensile test (b) Compression test (c) Bending test (d) Impact test (e) Hardness test.

Table 1. Mechanical properties tests for glass-polyester composite.

Tests	Dimensions (mm)	Results
Tensile	250*25*5.5	Ultimate strength 195 MPa
Bending	125*12*5.5	Ultimate strength 268 MPa
Compression	3*3*5.5	Ultimate strength 250 MPa
Impact	63*12*5.5	0.13 J/mm^2
Hardness	25*25*5.5	84 shore D

Table 2. The experiments and their parameters.

Experiment	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

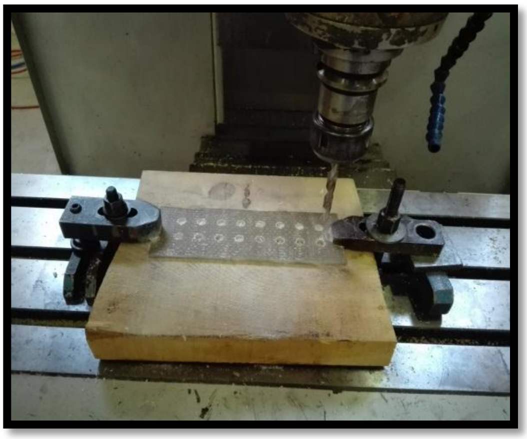

Figure 4. Glass – Polyester composite plate after drilling process.

Figure. 5 The microscope used in this study.

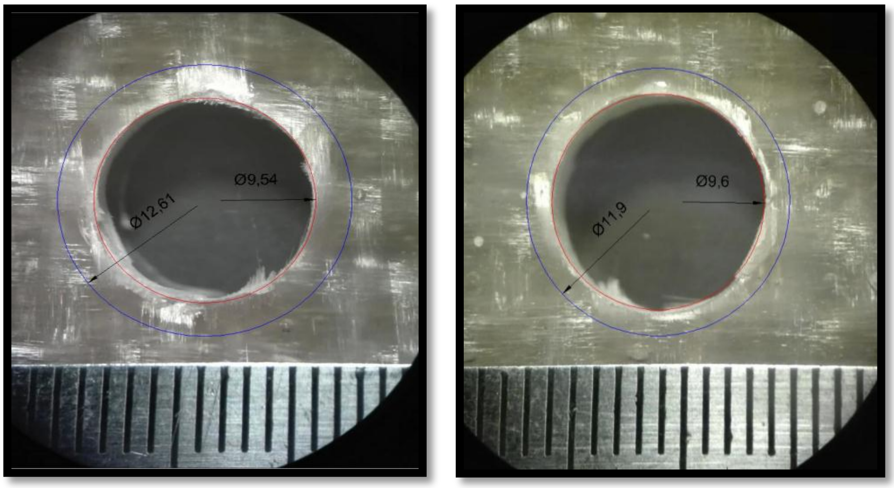

Figure 6. Hole no. 13 after processing using Autodesk software at the left the bottom view and at the right the top view of the same hole.

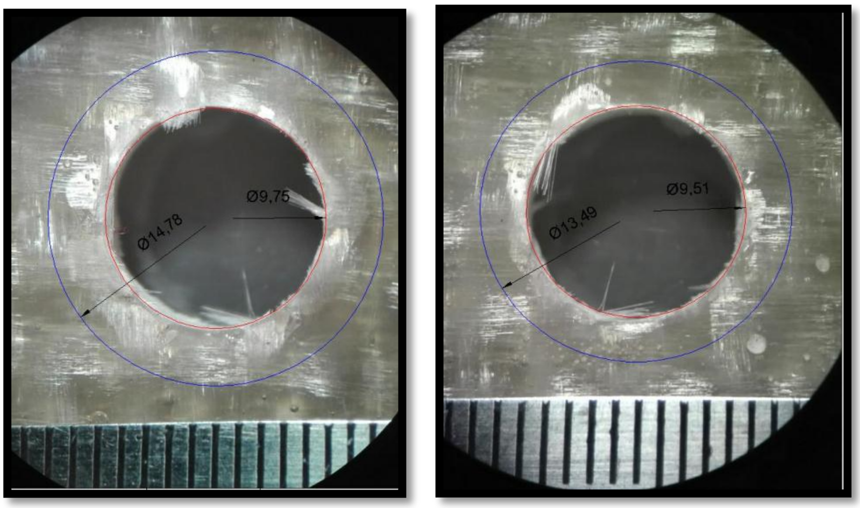

Figure 7. Hole no. 16 after processing using Autodesk software at the left the bottom view and at the right the top view of the same hole.

Table 3. The experimental results.

No. of Experiments	Spindle Speed (rpm)	Feed Rate (mm/rev)	Delamination factor
1	318	0.05	1.33
2	318	0.10	1.37
3	318	0.15	1.38
4	318	0.20	1.43
5	637	0.05	1.30
6	637	0.10	1.33
7	637	0.15	1.36
8	637	0.20	1.41
9	955	0.05	1.29
10	955	0.10	1.33
11	955	0.15	1.40
12	955	0.20	1.46
13	1273	0.05	1.28
14	1273	0.10	1.32
15	1273	0.15	1.37
16	1273	0.20	1.47

Table 4. S/N response table for delamination factor.

No. of Experiments	Spindle Speed (rpm)	Feed (mm/rev)	Delamination factor	SNRA1
1	318	0.05	1.33	- 2.47703
2	318	0.10	1.37	- 2.73441
3	318	0.15	1.38	- 2.79758
4	318	0.20	1.43	- 3.10672
5	637	0.05	1.30	- 2.27887
6	637	0.10	1.33	- 2.47703
7	637	0.15	1.36	- 2.67078
8	637	0.20	1.41	- 2.98438
9	955	0.05	1.29	- 2.21179
10	955	0.10	1.33	- 2.47703
11	955	0.15	1.40	- 2.92256
12	955	0.20	1.46	- 3.28706
13	1273	0.05	1.28	- 2.14420
14	1273	0.10	1.32	- 2.41148
15	1273	0.15	1.37	- 2.73441
16	1273	0.20	1.47	- 3.34635

Table 5. Response Table for Signal to Noise Ratios.

Level	Spindle speed	Feed rate
1	-2.779	-2.278
2	-2.603	-2.525
3	-2.725	-2.781
4	-2.659	-3.181
Delta	0.176	0.903
Rank	2	1

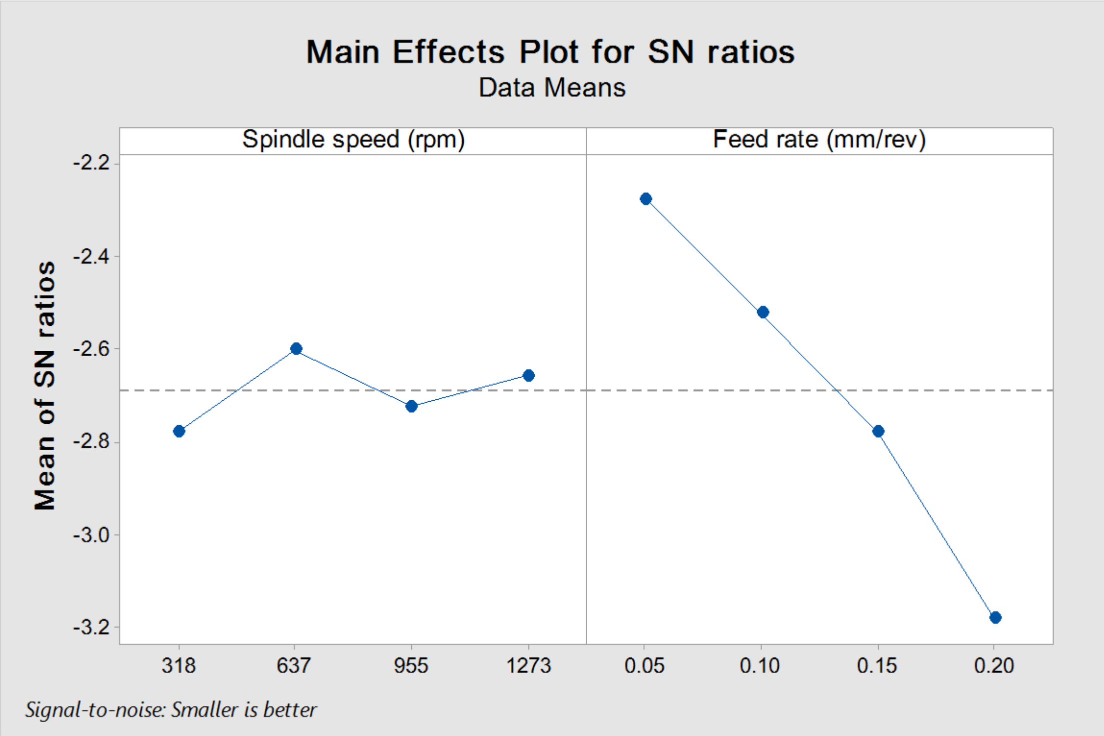

Figure 8. The plot for S/N ratios between delamination and both rotational speed and feed rate using Taguchi Design.