Optimization on Delamination Factor During Drilling CFRP Composites Using HSS Tool

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Abstract: -

Delamination is the major defect occurs during drilling process of composite materials. In this paper, it has been studied the effect of spindle speed and feed rate on delamination factor during drilling carbon fiber reinforced polymer (CFRP) composite using HSS drill tool. Taguchi design is used to optimized the effect of these parameters using MiniTab 17 software. It concluded that feed rate is more effective than spindle speed on drilling CFRP composite. The optimum experiment was no.13 with minimum delamination factor 1.223 at spindle speed 1273 rpm and feed rate 0.05 mm/rev.

Keywords: CFRP composite, drilling process, HSS drill, Taguchi method.

Introduction: -

In the recent time, composites are used in many interesting applications as compared with traditional materials, especially in aircraft, aerospace, automotive, and marine structure. Carbon Fiber Reinforced Plastic (CFRP) are being used in many applications due to their superior properties. CFRP as compared with steel and titanium, is proved that it is stronger and stiffer respectively, also CFRP is lightweight than both of these metals. CFRP used in aircraft in order to reduce weight and increases the load capacity of it.

Basically, drilling CFRP composite is related to defects such as

delamination, fiber pull out, geometric defects, etc. Delamination is considered the most significant defects occur during drilling composite material.

Delamination is the losing of the adhesion of the layers of the composite work part during drilling operations. Delamination is the most common defects that appear in drilling CFRP composites. In order to evaluate the delamination factor, the nominal hole ($D_{nominal}$) and the maximum diameter of the damage around the hole (D_{max}) must be measured, the delamination factor determined (F_d) using the following equation.

$$F_d = \frac{D\ max}{D\ nominal} \qquad (1)$$

Literature survey:-

Chetan and Mahesh **[2]** studied the effect of spindle speed, feed rate, and point angle on delamination as well as hole size during drilling CFRP composite. The optimum experiments with less delamination when spindle speed increase, feed rate decrease and increase in point angle. **Ruslan et al. [3]** concluded that feed rate is the most effective parameter on drilling CFRP composite, it has been recommended to use a minimum value of feed rate when drilling CFRP composites. **Desh et al. [4]** presents the combination of high spindle speed, low feed rates, and the lower point angle produced minimum delamination damage in CFRP composites. Also, they focused on the effect of these parameters when using different tool materials, like using HSS, carbide, and PCD coated drills. **Nagaraja et al [5]** reveals that increases in drill diameter, decreases in feed rate and increases in cutting speed lead to a minimum delamination. It detected the less delamination at speed 1800 RPM, feed rate 10 mm/min, point angle 90º, and drill diameter 4 mm. **Vijayan et al. [6]** determined that feed rate has the most influence parameters on delamination factor. The optimum condition with minimum delamination at lower values of feed rate 0.10 mm/rev and spindle speed 12000 rpm**.**

Experimental works:

Preparation of CFRP composite by hand lay-up method at room temperature, the fiber weight fraction is 36%. It consists an eight layers of woven carbon fiber as the reinforcement and polyester resin as the matrix, using an aluminum roller to distribute the polyester resin at each layer of carbon fiber. **Fig.1** shows the CFRP composite sample.

Fig.1 CFRP composite.

After 24 hours the glass sheet mold was opened and take out the CFRP composite plate with thickness 5 mm. In order to find the mechanical properties of CFRP composite, it was cutting according to ASTM standard size specimens using CNC milling machine, **Table.1** show the mechanical tests and its results.

Table. 1 Mechanical properties of CFRP composite.

Mechanical tests	ASTM	Results
Bending	D790-03	11 MPa
Compression	D695-02a	367 MPa
Hardness	D2240-00	83 shore D
Impact	D256-04	70000 J/ m^2
Tensile	D3039/D3039M-$00^{\epsilon 1}$	185 MPa

A vertical milling machine with spindle motor 7.5 HP and a maximum spindle speed 6000 rpm are used to perform the drilling process with High Speed Steel drill (HSS) with diameter 10 mm. **Fig.2** shows the machine.

Fig.2 Vertical CNC machine.

In this study, two drilling parameters have studied their effect on delamination factor during drilling CFRP composite material; spindle speed and feed rate are selected with four levels for each one. Spindle speed levels are 318, 637, 955, 1273 rpm and feed rate 0.05, 0.10, 0.15, 0.20 mm/rev.

Taguchi approach is a statistical method in Minitab17 software. In this study, it is used to design the value of these parameters and then discovering the effect of them on delamination factor (D_f) with orthogonal array L16 (4^2); two parameter with four levels for each one **[7]**

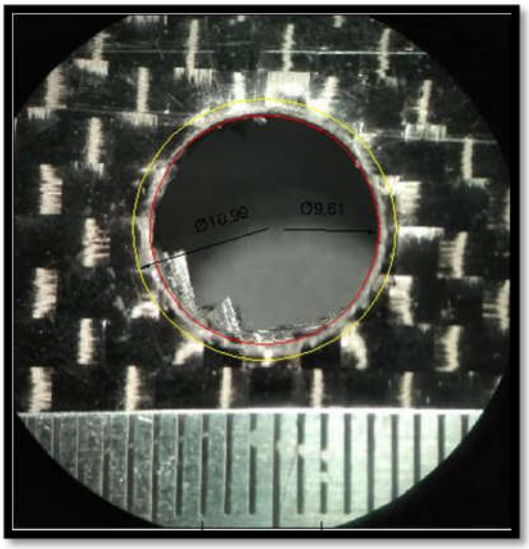
Drilling experiments were done on CFRP composite on dry condition using HSS drill with Ø10 mm, **Fig.3** show the CFRP composite plate after drilling process.

Fig.3 CFRP composite after drilling process.

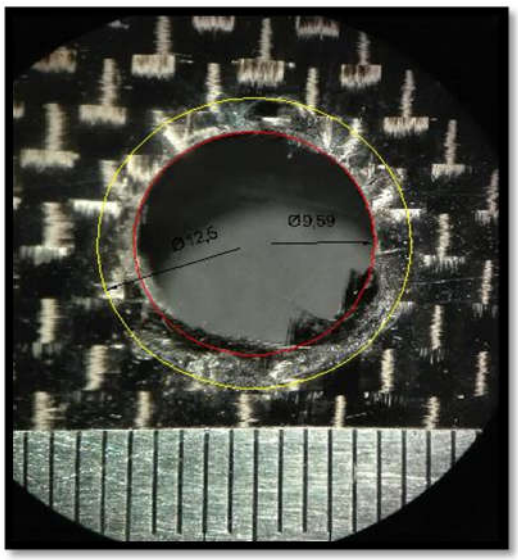
After that, each hole at the exit and entrance are examined by Microscope with magnification 20X as shown in **Fig. 4.** and then taken an image of each hole on the both sides.

Fig. 4 The microscope used in this study.

Then processing the image by AutoCAD 2016 to measure the delamination damage around each hole by drawing a circle around the damage area. **Fig. 5**.



(a)



(b)

Fig.5 Experiment no. 13 (a) the hole at the exit side (b) the hole at the entry side.

The mean of delamination zone diameter at the entrance and exit was taken and calculated the value of delamination factor, according to **equation (1)** the results of each experiment are collected with **Table.2**, the trial no. 13 is the optimal experiment with minimum F_d 1.223 with maximum spindle speed 1273 rpm and minimum feed rate 0.05 mm/rev.

Table.2 The experiments results of delamination factor (F_d).

No. trail	Spindle speed rpm	Feed rate mm/rev	F_d
1	318	0.05	1.274
2	318	0.10	1.382
3	318	0.15	1.404
4	318	0.20	1.413
5	637	0.05	1.281
6	637	0.10	1.286
7	637	0.15	1.321
8	637	0.20	1.348
9	955	0.05	1.275
10	955	0.10	1.347
11	955	0.15	1.374
12	955	0.20	1.414
13	1273	0.05	1.223
14	1273	0.10	1.231
15	1273	0.15	1.246
16	1273	0.20	1.294

The optimization was done by the Taguchi design, L16 array orthogonal and signal to noise ratio (S/N) is the measurement of the quality characteristics, it appointed to measure the variance of the experimental design, which achieves by applying the formula **equation (2)** is for smaller is better and the results of this equation for each trial are collected in the **Table.3.**

$$S/N = -10 \log_{10} \frac{1}{n} \sum y^2 \qquad \textbf{(2)}$$

where: s/n is signal to noise ratio, *n* is the number of observations, y is the data observed.

Table.3 s/n ratio smaller is better

No. trail	F_d	S/N ratio
1	1.274	-2.10339
2	1.382	-2.81016
3	1.404	-2.94734
4	1.413	-3.00284
5	1.281	-2.15098
6	1.286	-2.18482
7	1.321	-2.41806
8	1.348	-2.59380
9	1.207	-2.11020
10	1.347	-2.58735
11	1.374	-2.75973
12	1.414	-3.00899
13	1.223	-1.74853
14	1.231	-1.80516
15	1.246	-1.91036
16	1.294	-2.23869

Fig.6 clarify the relation between delamination factor and both spindle speed and feed rate.

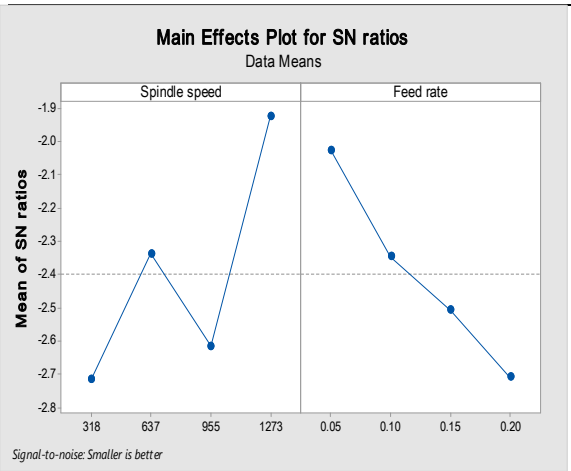


Fig. 6 Main effects plot for s/n rations

The relation between delmination factor and spindle speed, feed rate are illustrated in **Fig. 7**.

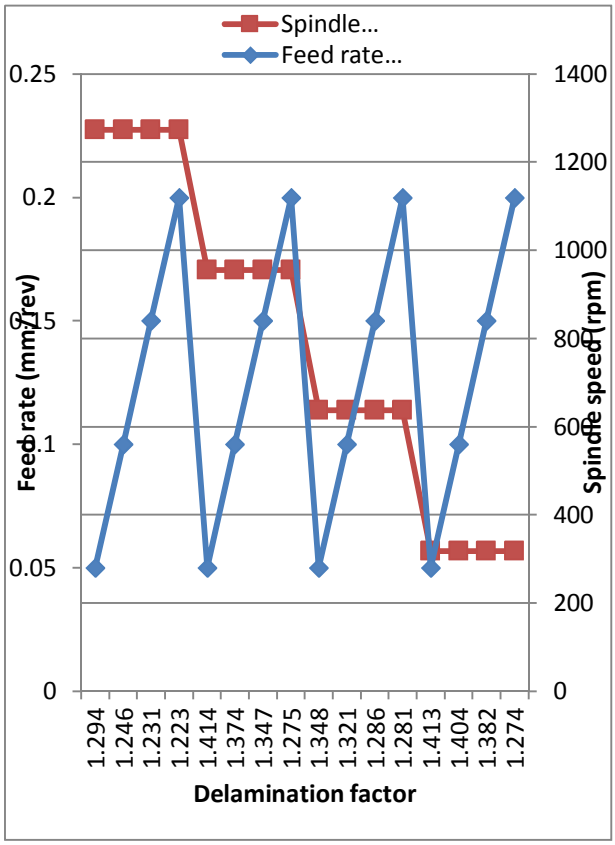


Fig.7 Relation between delamination factor and spindle speed, feed rate.

Conclusions:-

This paper submitted the optimization of drilling process parameters, namely spindle speed and feed rate in drilling CFRP composites using Taguchi application. The conclusions from this study are as follows:

1- Feed rate is more influence parameter than spindle speed on the drilling CFRP.

2- When spindle speed increases the delamination factor decreases, but when the feed rate increases the delamination factor increased.

3- Spindle speed of 1273 rpm, and feed 0.05 mm/rev are found to be the optimal parameters with minimum delamination factor 1.223.

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أمثلية معامل الانفصال الطبقي أثناء تثقيب البوليمر المقوى بألياف الكاربون باستخدام بريمه من صلب السرعات العالية

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الخلاصة: ـ

يعتبر الانفصال الطبقي من اهم العيوب التي تحدث أثناء تثقيب المواد المركبة. في هذا البحث تم دراسة تأثير سرعة عمود الدوران ومعدل التغذية على الانفصال الطبقي الحاصل اثناء تثقيب البوليمر المقوى بالياف الكاربون (CFRP) بأستخدام بريمه من صلب السرعات العاليه (HSS). تم أستخدام طريقه تاكوشي من أجل تحقيق أمثليه النتائج بأستخدام برنامج MiniTab 17. وتبين ان معدل التغذيه أكثرتأثيرا من سرعه عمود الدوران على تثقيب البوليمر المقوى بألياف الكاربون (CFRP). الحالة الامثل لأقل معامل انفصار طبقي وبمقدار 1,223 مع سرعة عمود الدوران 1273 دوره/ دقيقه ومعدل التغذيه 0,05 ملم/ ثا.

الكلمات المفتاحية: ـ البوليمر المقوى بألياف الكاربون، عملية التثقيب، بريمه صلب السرعات العاليه، طريقة تاكوشي.