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Experimental Analysis CFRP Drill Hole Quality Based on Pre-Hole & Force

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Abstract

Carbon fiber reinforced polymers (CFRP) are stronger and lighter materials in the aerospace industry, instead of titanium and aluminum. The excellent strength-to-weight and stiffness-to-weight properties of composite materials are the main drives of increasing the ratio of the composite parts in aircraft. Less weight on aircraft means less amount of fuel consumption. Subsequently, aircraft can able to fly longer range with higher speeds and more efficiently. As a result, it is a more economical and environmentally friendly condition, which gives the product value and competitiveness for the aircraft manufacturer. During CFRP laminate joining manufacturing activities, delamination is one of the major forms of failure in drilled materials. In this research, a comparative study of drilled hole quality after drilling without pre-hole and pre-hole with three different diameters on CFRP has been made. Two types of different geometrical drill bits were used for the drilling process. The ultrasonic scan images were taken into account to determine the surface delamination.

Keywords
CFRP, Twist drill, Step drill, Ultrasonic Scan, Pre-hole and Hole quality.

1. Introduction
Fiber-reinforced polymers (FRPs) especially CFRP are taking place of conventional materials in applications such as aerospace, automotive, shipbuilding, construction, sports goods, etc. due to its excellent strength to weight ratio, stiffness to weight ratio, and structural integrity. Thus, modern aircraft are being constructed with an increasing number of components made with composite materials reaching up to 50% of the total structure. However, though composite components are intended to create with near-net shape, machining is an unavoidable circumstance. To complete an assembly of a structure like large aircraft, drilling a huge number of holes required. During the drilling process CFRP component face numerous damages in the form of delamination, splintering, thermal damage, geometric deformity (Chen, 1997). Figure 1, shows the fish bone diagram,which indicates the factorsfor affecting the drilling of CFRP. Delamination is considered to be a major driver for generating poor hole quality, which reduces structural integrity as well. As a consequence, ultimately leads to rejection of parts up to 60% in the aircraft industry (Wong, Wu, conference, & 1982, n.d.). Peel up and push out are the two significant types of drilling-induced delamination occurred on the top and bottom side of the laminate (Davim & Reis, 2003). Thrust force generated at the time of drilling plays a major role in these types of delamination (Wong et al., n.d.), and Ho-Cheng and Dharan presented an analytic model to asses critical thrust force (Ho-Cheng & Dharan, 1990). The researchers have been trying to mitigate thrust force till now. Consequently other authors found that the chisel edge of a drill bit is the important contributor of thrust force, it generates during drilling time(Won & Dharan, 2002). The authors showed that drilling on pre-hole reduces the chisel effect and lowers thrust force significantly. Later Tsao and Ho Cheng experiment with varying pre-hole diameter to drill bit ratio showed that, pre-hole diameter close to drill bit

provides better results in terms of thrust force (Tsao & Hocheng, 2003). Though conventional twist drill bit is being used vastly, authors did experimental analysis with special drill bits as well. (Qiu et al., 2018) conducted several experiments with step drill bit and stated that, step drill generates less delamination and produces better hole quality. (G. D. Wang & Kirwa, 2018) conducted a test and compiled results of drilling with twist drill on pre-hole, varying pre-hole to drill ratio, and drilling with a step drill to identify the better methodology.

In this experiment, a similar test with different pre-hole size has been carried out by hand drilling process. Drilling was performed with low feed rate and high spindle speed, as this combination reduces thrust force (Feito, Díaz-Álvarez, López-Puente, & Miguelez, 2018), (C. Wang, Cheng, Rakowski, Greenwood, & Wale, 2017). The constant feed rate and spindle speed were maintained during drilling process.

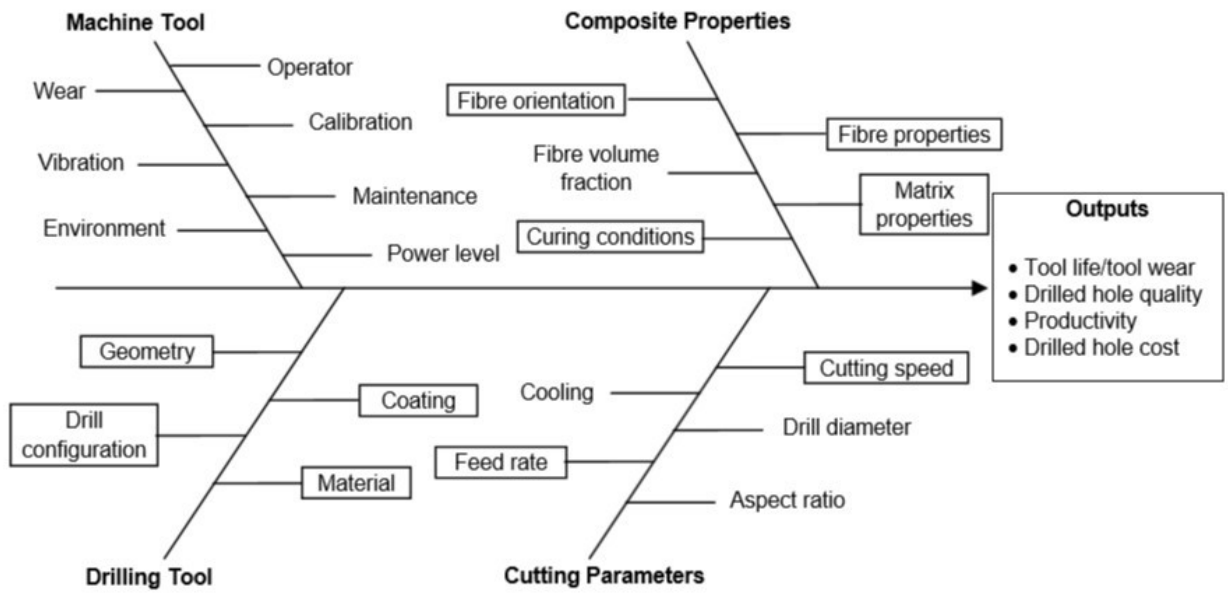

Figure 1. Fish bond diagram detailing factors affecting drilling of CFRP

2. Experimental set up

2.1 Preparing workpiece

Epoxy resin impregnated unidirectional carbon fiber has been used to fabricate the laminate. The laminate consisted total of 16 plies, each ply thickness is 0.125 mm. giving a total laminate thickness of 2 mm, and the plate dimension was 20 cm X 15 cm. The stacking sequence of the laminate was ($0^0/90^0$).

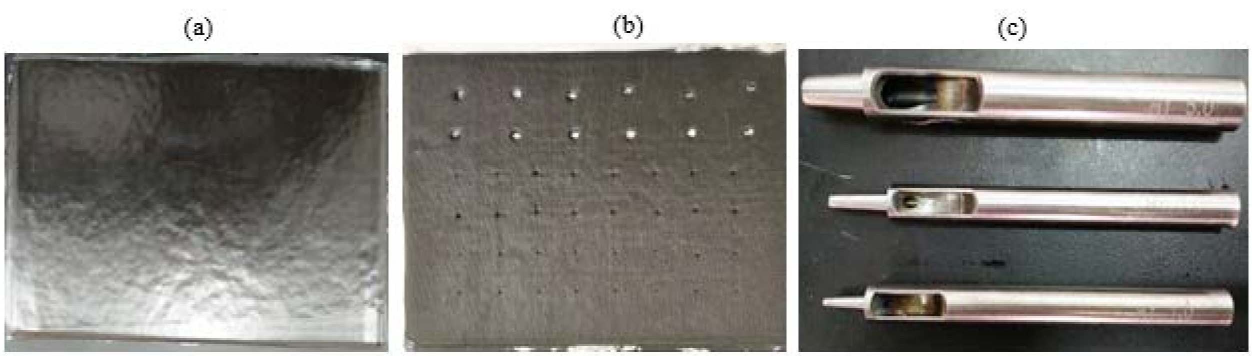

Figure 2. Non-pre-hole CFRP laminate (a), pre-hole CFRP laminate (b), Chisel bit (c)

The workpiece was prepared using vacuum bagging process. Then laminate was cured in an autoclave maintaining optimum temperature and pressure to ensure laminate's integrity. Pre-hole with the diameter of 1 mm, 2 mm, and 5 mm was made using chisel bit before laminate placed into an autoclave. Hole alignment was not possible to maintain accurately because each pre holed ply placed on top of another manually. Non-pre holed laminate, pre-holed laminate, and chisel bit with three different diametersare shown in Figure 2.

2.2 Drilling Tools and cutting parameters

The drilling was carried out with 2 different types of drill bits. One was standard solid carbide twist drill bit, diameter of 8 mm and point angle is 140^0.The drill bit was coated with AlTiN. The other drill bit was solid carbide two-step drill bit diameter of 5mm and 8mm also coated with AlTiN. Drilling tools specifications are shown in table 1. In this experiment, a constant low feed rate of 2.67mm/min and a high spindle speed of 2500 rpm were maintained. No coolant was used during the drilling process. Figure 3, shows the twist and step drill bit.

Table 1. Drilling tools specifications

Tool geometry	Tool material	Point angle	Drill bit diameter (mm)		Coating
Twist drill	Solid carbide	140^0	8		AlTiN
Step drill	Solid carbide	140^0	5	8	AlTiN

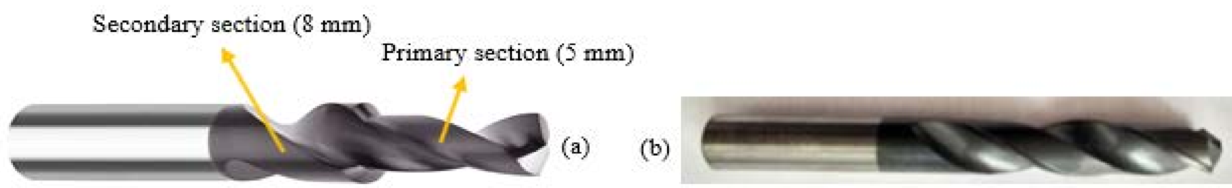

Figure 3. Step drill (a), Twist drill (b)

2.3 Experiment equipment

This experiment was carried out by a manual drilling process using a hand drill gun. A special fixture was designed to hold the workpiece material to perform drilling constraining vibration. The laminate was placed in between of the two-part fixture, and then fastened together. Sufficient drilling space was kept to perform the drilling. Sensors were installed in the fixture to measure thrust force. An amplifier was connected to the sensors to get enlarged electronic signals. Furthermore, this signal converted and displayed as digital form. After that, those data again translated to force manually. The layout of this experiment is shown in Figure 4.

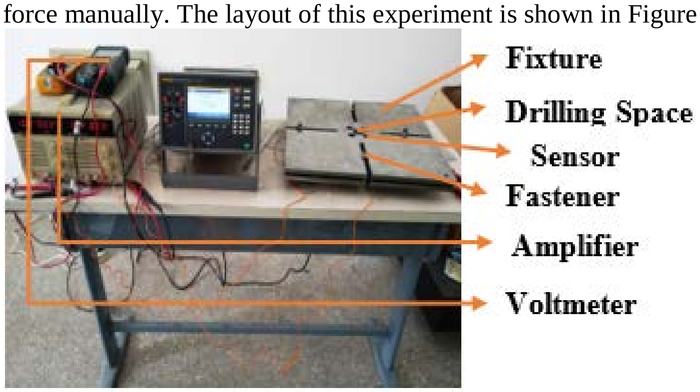

Figure 4. Experimental layout

Figure 5. AM 300 Scanning Acoustic Microscope

The AM 300 scanning acoustic microscope (Figure 5) was used to scan laminates hole quality and identify the delamination area. In this experiment, only the surface layer delamination was observed.

3. Results and Discussions

The provided line graphs plotted as force vs time required to drill laminate's full depth. In the first experiment, 8 mm twist drill bit was used to drill non-pre-holed laminate and laminate pre-holed with diameter of 1mm, 2mm, 5mm.In Figure 6, it is observable that thrust force varies with different sizes of pre-hole/pilot hole and non-pre-hole. Drilling without a pre-hole generated highest thrust force compare to pre-hole.

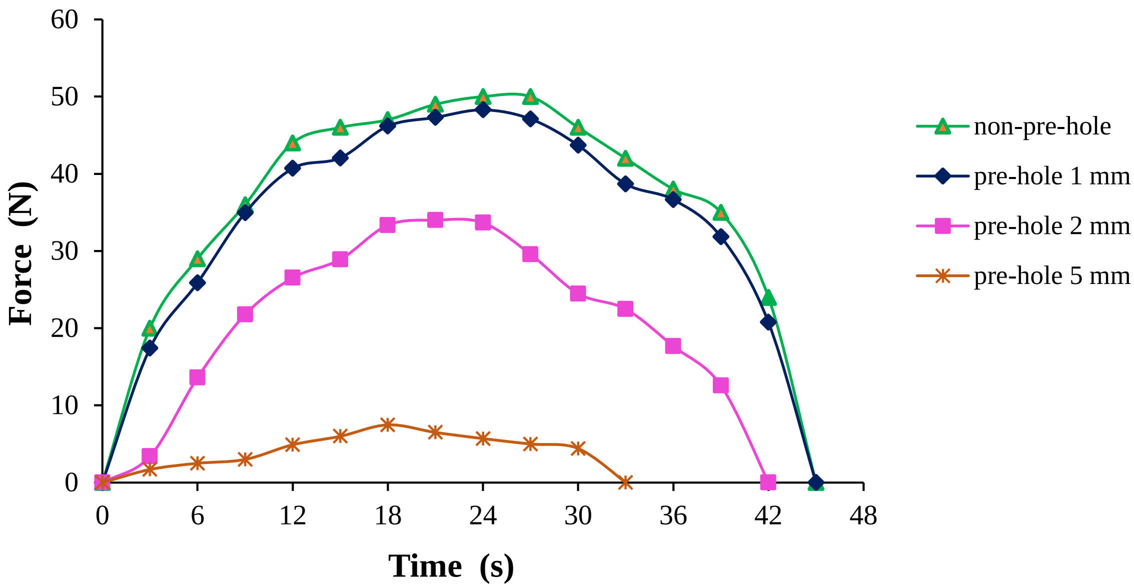

Figure 6. Thrust force comparison between non-pre-hole and different diameters of pre-hole

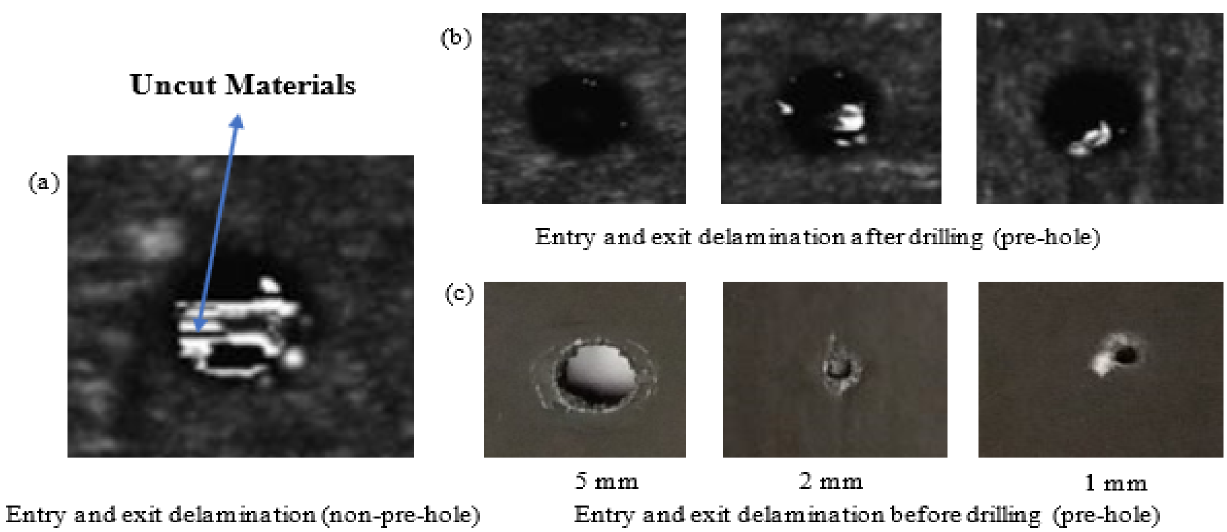

Figure 7. Scan image of laminate before and after drilling

On the other hand, as the ratio of pre-hole diameter and drill bit diameter becomes larger, accordingly thrust force decreases significantly. Hence, providing less delamination and better hole quality. Scan images of the laminate in

Figure 7 also support the result. Figure 7 (a) shows the hole drilled without a pre-hole. A large amount of uncut fibers at the exit of the hole indicates high delamination, resulted from high thrust force. In Figure 7 (b), 5 mm pre-hole shows almost no sign of delamination, where 1 mm and 2 mm pre-hole shows moderate delamination at hole exit. None of the cases shows any significant amount of delamination at hole entry. It is also noticeable that drilling on larger pre-hole requires less time. Since a substantial amount of material has already been cut from the laminate while making pre-hole.

In the second section of the experiment, a step drill bit was used to drill the non-pre-holed laminate. The diameter of the upper part of the drill bit was 5 mm and the diameter of the adjacent part was 8 mm. FromFigure 8, it is noticeable that, 5 mm section of the drill bit generates higher thrust force compare to its 8 mm section. It is because the upper part of the drill bit drills an uncut laminate. Then that hole act as a pre-hole for the 8 mm section, which generates considerably lower thrust force.

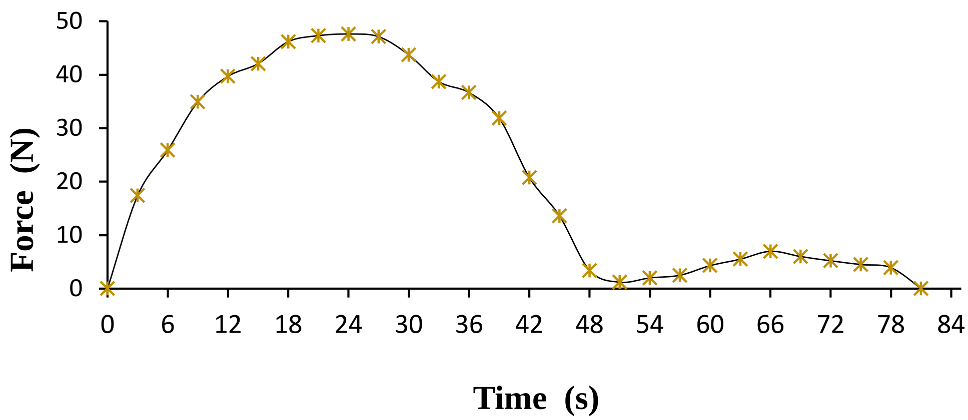

Figure 8. Thrust force of step drill

Figure 9 shows the comparison of maximum thrust generated in drilling on a non-pre hole and different sizes of pre-hole.

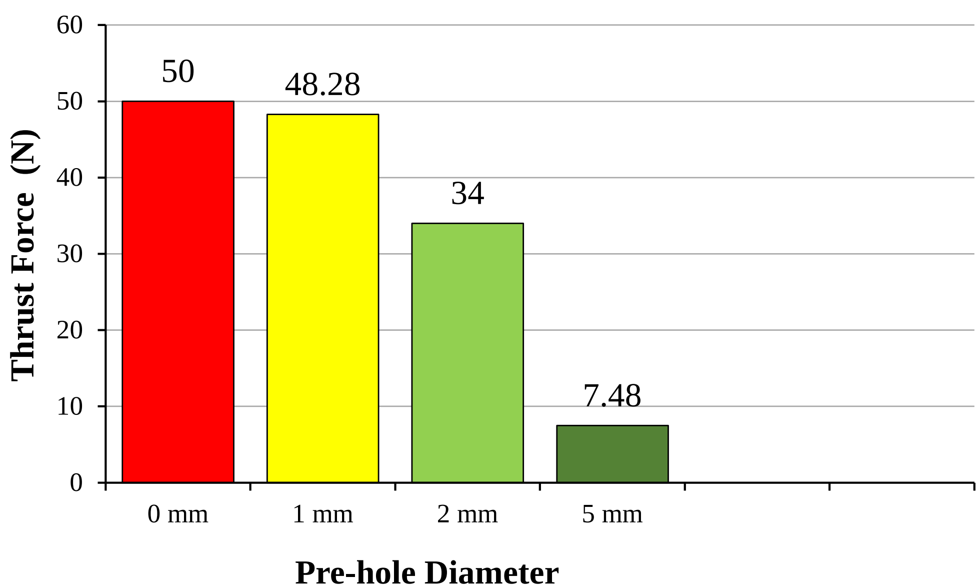

Figure 9. Maximum thrust force comparison

4. Conclusion

Pre-hole means the removal of materials from the composite plate through the entry to exit. During the experiment, drilling speed and feed rate are always maintained in different diameters as well as pre-hole and non-hole conditions. From the experimental results, it has presented that the exponentially increasing level of force; means the delamination rate is high. On the other hand, less force has applied to pre-hole and it gets a better result. Pre-hole diameter closer to a given drill bit diameter, in other words, a higher ratio of the drill bit and pre-hole size ensures the least delamination as it generates the lowest thrust force. Step drill will be the best performer if the chisel section of this drill bit is kept small. At the end of the experiment, results have provided a potential outcome to learn the methodology of reducing the rate of delaminate on and increase the lifetime of composite materials, especially CFRP service operation in the respective engineering industry.

Acknowledgement

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Biographies

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