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The Study of Tensile Failure on Thin Plate Hybrid Composites with Drilled Holes

Mohd Azuwan Bin Maoinser, Faiz Ahmad and Muhammad Hatta Bin Mohd Junaidi
Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

Corresponding Author: Mohd Azuwan Bin Maoinser, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

ABSTRACT

Increasing usage of hybrid fiber composite in structural application such as aircraft body has increased the drilling holes application to assemble the complex structure. The objective of this study is to investigate the tensile properties of hybrid fiber composite with the drilled holes. The samples were drilled using the feed rate of 0.05 and 0.15 mm/rev and spindle speed of 690, 790, 1250, 1340, 2500 and 2700 rpm. The damage factor is analyzed using 3D non-contact machine to study the effect of different drilling parameters on the drilled holes. The correlation between damage factor and tensile results were studied in order to observe the influence of damage factor on the tensile properties of the drilled holes. In conclusion, the damage factor variations affected by different drilling parameters do not have any influence on the tensile properties of hybrid fiber composite with drilled holes.

Key words: Hybrid fiber composite, drilling, damage factor, tensile properties and delamination

INTRODUCTION

Hybrid fiber composites are attractive for application to provide synergy effect in achieving properties such as tensile strength stiffness, reduced weight or cost and improved fatigue or impact resistance. Although composites components are produced to near-net shape, machining is often needed, as it turns out necessary to fulfill requirements related with tolerances or assembly needs. Among the several machining processes, drilling is one of the most frequently used for the production of holes for screws, rivets and bolts. When composites parts are subjected to drilling operations, the defects that are likely to appear differ from metallic parts, making evaluation of hole quality more difficult. Besides process related problems in composites fabrication, drilling can cause several defects like, delamination, intralaminar cracks, fiber pull out and thermal damage. These problems can affect the mechanical properties of the produced parts, hence, lower reliability by Durao (2005).

Tagliaferri *et al.* (1990) carried out drilling tests on a Glass Fiber Reinforced Epoxy (GFRE) composite obtained from prepreg in a quasi-isotropic stacking sequence using High Speed Steel (HSS) drills without backing or cutting fluid. They concluded that, if feed remains constant, damage reduction is accomplished by an increase in cutting speed and if speed remains constant, lower feeds show better results in terms of damage reduction. Persson *et al.* (1997) have studied the effect of hole machining defects on strength and fatigue life of Carbon Fiber Reinforced Epoxy

(CFRE) composites. They concluded that fatigue testing results yielded 8-10% lower for PCD and Dagger drills as compared to orbital drilled patented by NOVATOR AB. Park *et al.* (1995) applied the helical-feed method to avoid fuzzing and delamination. Different tools such as cast iron with bonded diamond and tungsten carbide were used in this study and concluded that tensile tests performed on specimens drilled in different conditions did not show dependency of drilhng methods on test results. The objective of this study is to correlate between the effects of damage factor (F_d) due to varying drilling parameters on the tensile properties of the Hybrid Fiber Reinforced Polyester (HFRP) composite.

MATERIALS AND METHODS

Hybrid Fiber Reinforced Polyester (HFRP) composite was fabricated using hand lay-up technique. In this study, glass fiber and carbon fiber are formed together in a single matrix in order to produce an advance composite with hybrid application. HFRP composite was designed in 2 mm thickness consist of 4 layers of carbon fiber and 4 layers of glass fiber (as shown in Fig. 1). The 55% Fiber Volume Fraction (FVF) HFRP composite is cured under the room temperature for 8 h. The samples was fabricated in 185×270 mm dimension an was then cut to 25×250 mm according to ASTM D3039 standard for tensile testing purpose after drilling process.

The hole were drilled at the center of the 25×250 mm specimen using High Speed Steel (HSS) twist type drill bit with various cutting speed and feed rate (Table 1). Computer Numerical Control

Table 1: Drilling parameters used in drilling process

Sample name	Feed rate (mm/rev)	Spindle speed (rpm)
A	0.05	690
B		790
C		1250
D		2700
E		2500
F		2700
G	0.15	690
H		790
I		1250
J		1340
K		2500
L		2500

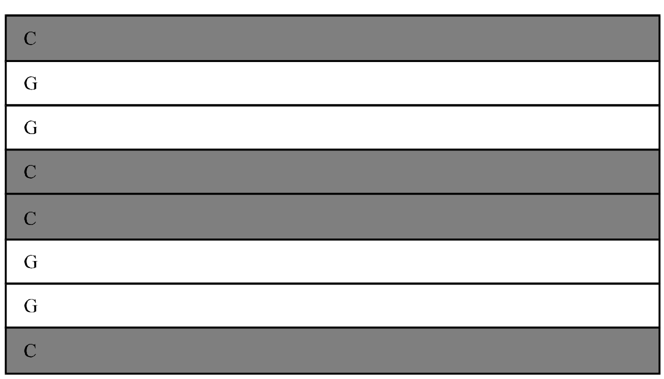

Fig. 1: Symmetrical design of HFRE composite

(CNC) machine was used to drill the specimens in order to control the feed rate and as a safety precaution due to hazardous fibrous material produce during drilling process. Figure 2 shows the HFRP composite specimen was drilled by using a jig to reduce the time consumed in drilling process.

Damage factor (Fd) employed by Tsao and Hocheng (2004). was used to evaluate the maximum damage occurred on top of the drilled holes and compared with the drill bit diameter (Fig. 3). It was calculated by using the formula (1).

$$F_d = D_{max}/D_o \quad (1)$$

The study was continued with tensile testing using Universal Testing Machine (UTM) 100 kN guided by ASTM D3039 standard. The specimens were griped using emery cloth at both ends. Then, the UTM was run at the speed of 0.0333 m sec^{-1}. The correlation between damage factor (F_d) and tensile properties of each specimens were studied.

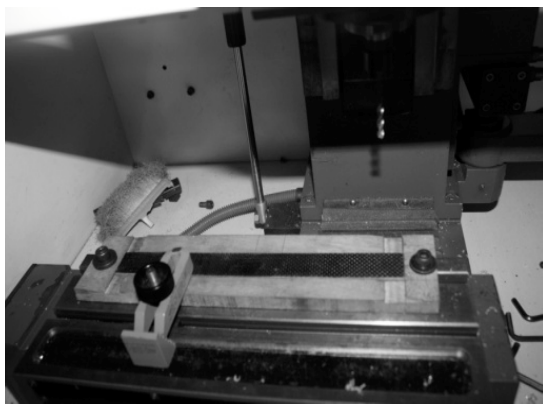

Fig. 2: Drilling HFRE composite specimen using CNC machine with jig

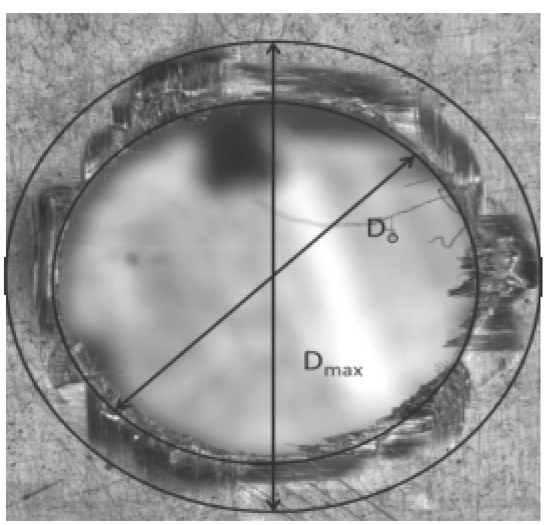

Fig. 3: Damage factor (F_d)

RESULTS AND DISCUSSION

Influence of various drilling parameters on damage factor (F_d): The graph in Fig. 4 shows result of the damage factor calculated and compared with for each group of samples. The comparisons are against variation of spindle speed and feed rate for each group. Spindle speed and feed rate variations involved are 690, 790, 1250, 1340, 2500 and 2700 rpm and 0.05 and 0.15 mm/rev, respectively. In general, these results from Fig. 4 are adequate to identify an optimum domain of parameters combining low feed rates with medium spindle speeds. Higher spindle speed of 1340, 2500 and 2700 rpm increase the risk of thermal damage as it causes the softening of the matrix material by Durao *et al.* (2008). A consequence of that phenomenon can be a loss of mechanical strength of the uncut plies of the laminate, leading to extended delamination.

The optimum spindle speed observed from this experiment was 1340 rpm compared to the other type of spindle speed for drilling hybrid fiber composite using 5 mm diameter HSS drill bit. Meanwhile, drilling hybrid fiber composite of lower spindle speed of 670 rpm resulted in highest damage on top of the drilled holes wall. This is because the spindle speed is too low compared to the feed rate given because bigger thrust force is applied. This too, increase the risk of thermal damage as it causes the softening of the matrix material by Durao *et al.* (2008).

Regardless the drill geometry and the cutting speed, a clear trend was found regarding the effect of feed rate where the optimum way of drilling hybrid fiber composite is observed as low feed rate of 0.05 mm/rev used in drilling process. Regarding the experimental set used in this study, it is not surprising to observe that a feed rate of 0.05 mm/rev has resulted as the best option. However, it must be remembered that a low feed rate of 0.05 mm/rev also increases the heating of the hole machined walls during machining. In some cases, the possibility of matrix softening should be taken into account. The use of CNC machines, enabling a variable feed rate strategy is a good option to consider when drilling laminate plates by Durao *et al.* (2008).

Influence of damage factor (F_d) and tensile properties of the drilled specimens: The graph in Fig. 5 shows the comparison of tensile stress value for each sample. Comparison made between the drilled samples ranging of group A to group L, there are no significant difference of drilling parameters of the samples to the tensile strength. Insignificant trend was found due to the strength of each sample test resulting in random data between 296 to 315 MPa and the strength is not inversely proportional to the damage factor found on each sample. Since, the original tensile strength of GFRP is 278 MPa, the combination of carbon fiber and glass fiber composite have proven that in this study, the boost of mechanical strength is achieved where the strength ranging from 296 to 315 MPa by Kelly (1990). Two different feed rate 0.05 and 0.15 mm/revdid not show

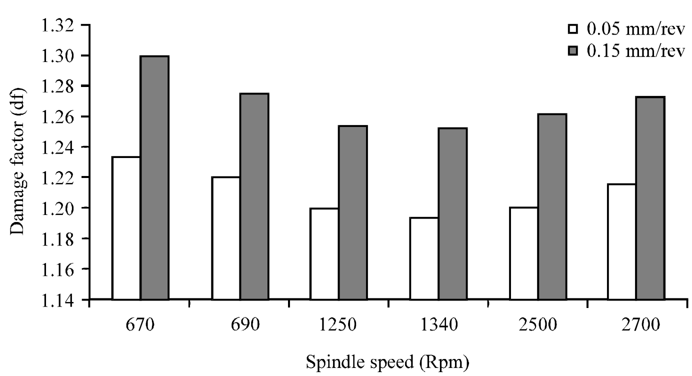

Fig. 4: Damage factor vs. spindle speed graph

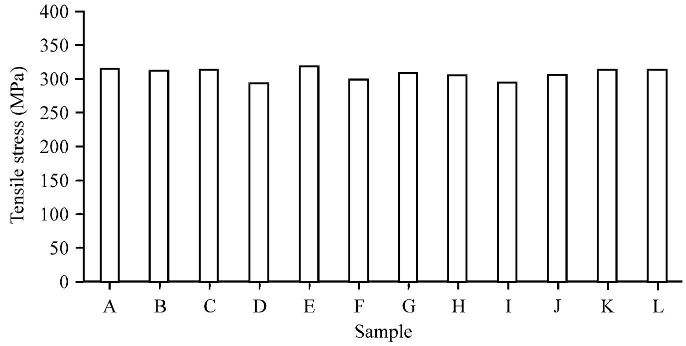

Fig. 5: Tensile properties of each specimen

anysignificant difference in the tensile strength of the samples. This concludes that the feed during drilling process did not show any influence in the strength of drilled composite. However, higher feed rate might create severe damage to the hole that is not practical for its tensile strength.

CONCLUSION

This study concluded that:

- The tensile properties are independent of damage factor (F_d) resulting from different drilling parameters
- Spindle speed of 1340 rpm is the optimum way of drilling HFRP composite laminates due to lowest damage factor (F_d) produced at lowest feed rate in this study
- Damage factor (F_d) of the drilled hole can be reduced by reducing the feed rate of the drilling process

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