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Experimental Study in Drilling Composite Pipes Manufactured by Filament Winding Process Using Full Factorial Design Method

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ABSTRACT: Drilling is one of the major machining processes for assembling process in composite tubes. During drilling, damages such as matrix cracking, fiber pull out and delamination around the hole may cause the loss of residual compression strength of the composite tubes. In this paper, the effect of drilling parameters such as spindle speed, feed rate, diameter and geometry shape of the drill on thrust force and delamination factor with full factorial design method for composite tubes manufactured by filament winding process was investigated. According to the results, the parameters affecting the delamination factor are the geometric shape of the drill, feed speed, drill diameter and spindle speed, respectively. Also, by selecting twist drill tools with a diameter of 12 mm, spindle speed of 1000 rpm and feed rate of 25 mm/min, the amount of delamination factor is minimized. The residual compressive strength of the best and worst specimens according to delamination factor was investigated. According to the results, by decreasing delamination factor, the residual compressive strength increases. Also, if the input parameters in the drilling process are selected correctly, the residual compressive strength would increase around 12%.

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1- Introduction

One of the important processes in completing the construction and assembling of composite tubes is drilling [1]. Unlike metal machining, there are few sources to choose the best cutting parameters for the drilling of composite tubes. Hitherto, studies on the drilling of composites have often been on flat plates and have not paid much attention to the drilling of composite tubes. The most important damages seen in the perforation of the composites include the matrix breakage, delamination, fiber pull out, the contraction of the hole and the burn of the matrix, which has an effect on the mechanical properties of the components and the reduction of the final strength [2]. Delamination is one of the most important damages of composite drilling, which typically occurs when the drill is entering and leaving. They call peel up to the delamination at the entrance and push out at drill exit as shown in Fig.1.

To investigate the drilling of composite tube process, the adjustable parameters such as spindle speed, feed rate, diameter and geometric shape of the drill should be controlled. By the correct setting and proper selection of these parameters, the machining efficiency is increased and the potential damage to the components is reduced, resulting in higher performance when applied to composite structures [3].

2- Delamination Factor Measurement

After scanning the drilled composite specimens, the maximum diameter and area of the delamination zone are determined by the image processing software as shown in Fig.2. A novel approach was proposed by Davim et al. to obtain the values of adjusted delamination factor expressed in Eq.(1). In this equation, the effect of crack size and the damaged area are considered.

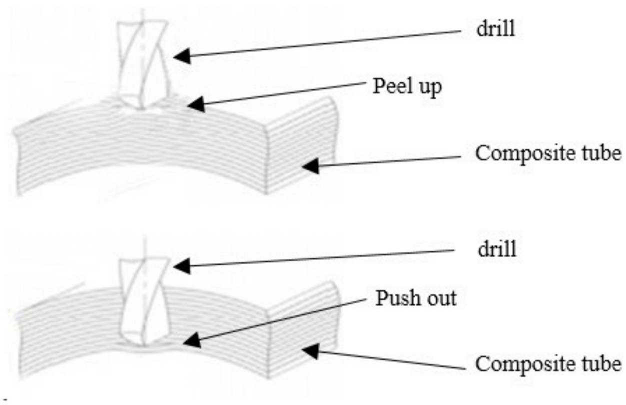

Fig. 1. Peel up and push down Delamination

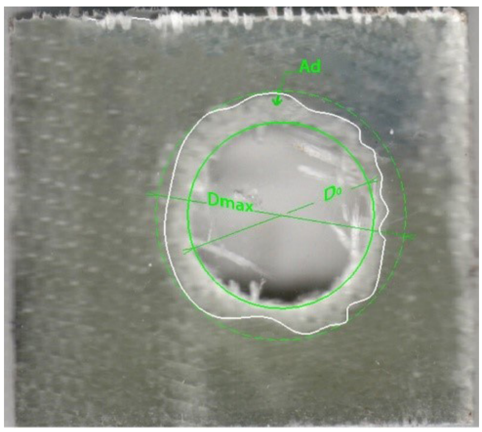

Fig. 2. Measurement of the delaminated area A_d

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$$F_{da} = F_d + \frac{A_d}{A_{\max} - A_0}\left(F_d^2 - F_d\right) \quad (1)$$

where A_0 and A_{max} are the areas related to the nominal hole and maximum diameter of the delamination zone, respectively and A_d is the delaminated area.

3- Experiments

Composite tubes are prepared using a filament winding method. In this method, the impregnated fibers are wound on a special Mandrel resin at various angles and then cooked in the air or in a furnace under specific conditions.

The diameter of the tube is 105 mm and the final thickness of the samples is 3 ± 0.3 mm. Table 1 shows the mechanical properties of the resin and fibers of composite tubes that have been tested for drilling. The fibers are E glass fibers. The composite tube has a specific layup. Firstly, the woven glass fiber is wound up as a base in three layers with a thickness of 1 mm on the mandrel, then the fibers impregnated with the epoxy resin 828, with a 45o angle of 1 mm thick on the woven, then the fibers at different angles are wrapped around each other at a thickness of 1 mm.

Table 1. Mechanical properties of fiber and matrix

material	tensile strength MPa	Young's modulus GPa	Poisson coefficient
Fiber glass	2400	73	0.2
epoxy	69	2.75	0.3

The drill test is done by the Universal Milling Machine making Tabriz, the FP4M model, and a special jig and fixture is used for the drilling process. To measure the thrust force, the DEE-C3 load cell model with a capacity of 100 kg has been used. The twist drill with point angel 118o and brad point drill are used for testing in 8 and 12 mm diameter with HSS material.

4- Design of Experiments

In this paper, the design of the experiment was carried out using full factorial design. The spindle speed and feed rate with three levels, the diameter and geometric of the drill with two levels are considered as an input parameter, axial force and delamination factor are considered as the most important output responses.

5- Effect of Machining Parameters on Thrust Force and Delamination Factor

As shown in Fig.3, the spindle speed and feed rate have the greatest impact on the thrust force. But unlike to composite plate drilling, controlling the thrust force under critical value is not achieved to the minimum damage because different mechanisms are involved in the drilling of composite tubes. It is believed that these factors are related to the dynamics of the work piece, the conditions of production, and the instrument in which the force is applied [4].

Regarding the values of Fig.4, the geometric shape of the drill has the greatest impact on the delamination factor, then the feed rate and diameter are the most affecting parameters on delamination.

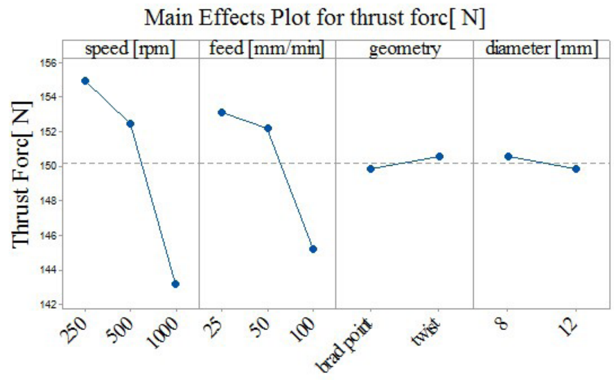

Fig. 3. Main effects plot for thrust force

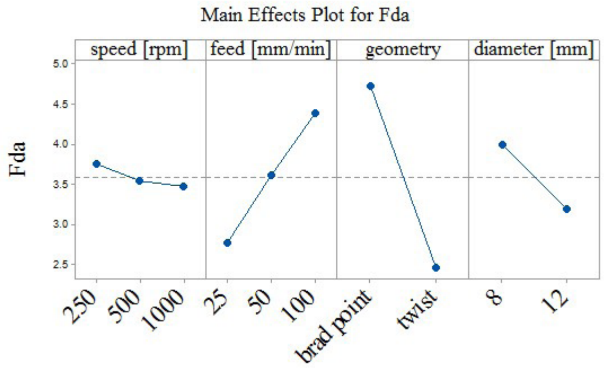

Fig. 4. Main effects plot for F_{da}

6- Residual Compressive Strength

In order to compare the compressive strength of the composite specimens, three samples were selected as specimens without a hole, with hole by the least delamination factor and with hole by the maximum delamination factor. As shown in Fig.5, by a proper selection of drilling parameters, compressive residual strength can increase around 12%

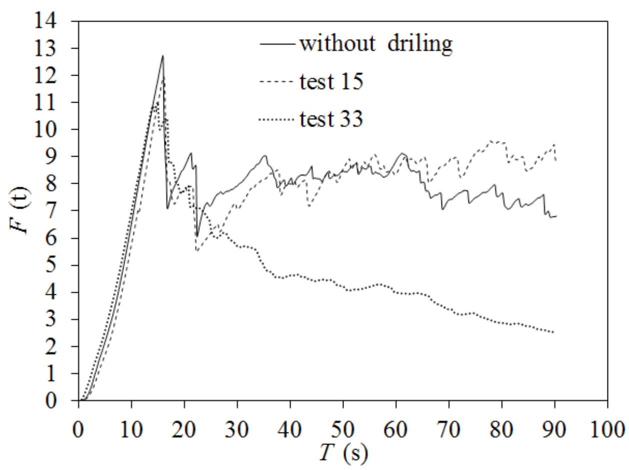

Fig. 5. Residual compressive strength

7- Conclusions

In this paper, the effect of input parameters such as spindle speed, feed speed, diameter, and geometric shape of the drill on the thrust force and the delamination factor are investigated by a full factorial experimental design. An example of the best and worst cases is selected and their residual compressive strength is obtained, whose results are presented below:

- By investigating the intersection plot of input factors and delamination factor, it was found that twist drill has less damage than the brad point drill bit.
- In this research, with the choice of a twist drill tool with a diameter of 12 mm, spindle speed of 1000 rpm and a speed of 25 mm/min, the bending of the tube during drilling is minimized and the drill performs the cutting correctly. As a result, the delamination factor is as low as possible.
- According to the vertical pressure test diagram of the perforated tubes, it was found that if the best drilling parameters were selected for composite tubes, a higher compressive strength is achieved.

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