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# Parametric study on drilling of GFRP composite pipe produced by filament winding process in different backup condition

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ABSTRACT

Generally, there is a need for machining to complete the process of manufacturing and assembling composite pipes. One of the principal processes of composite machining is drilling. In this process, the mechanical strength of the composite pipes is reduced by the delamination. In this paper, the effect of drilling parameters such as spindle speed, feed rate, diameter and drill geometry on the thrust force and the delamination factor for the composite pipes produced by the filament winding process are investigated in "a without backup state". Then, sample parameters which have the minimum and maximum delamination area are selected and these pipes are drilled in ice supported condition based on the selected parameters, by analyzing the results and determining the size of the delamination area. Then the drilled specimens are loaded under pressure test and their residual compressive strength is obtained. The results show that, thrust force variations and delamination factor decreasing is because of choosing twist drill and reducing feed rate, increasing spindle speed and drill diameter. Also by using ice as a backup, the delamination factor in the twist and brad point drills decreases significantly and the residual compressive strength of the drilled pipes increases meaningfully.

## 1. Introduction

Nowadays, composite pipes made of glass fibers with filament winding process, are used extensively in fluid transfer industry such as refinery, aerospace, military and automotive because of its high strength compared to low weight and corrosion resistance [1,2]. These pipes are made with different matrix and fibers under different orientations and layups. In the meantime, glass fiber is more widely used because of many advantages such as high strength, low price and high chemical resistance [3,4].

In order to complete the construction and assembling the composite pipes, there is a need for their drilling, which is a part of the final and complementary stages. However it has its own problems. The presence of defects in the drilled parts causes the composite parts being rejected, which entails a lot of costs [5,6]. In the other hand, there are few methods for drilling the composite pipes, due to the presence of factors which is strongly effect on machinability [7]. These factors are anisotropy of reinforcing fibers, lack of proper heat transferring and the simultaneous cutting of the soft matrix and hard fibers. Most researches done on the field of composite drilling, are on flat plates and some research has been done on the drilling of composite pipes [8].

The most important damage mechanisms has seen in the drilling of composite pipes are included delamination, the matrix cracking, the fibers pull out, the shrinkage of the hole and burning of the matrix, which effects on the mechanical properties of the components and the reduction of the residual strength of the pipes [9].

One of the most usual defects in composite drilling is delamination, which usually happens at drill entrance, exit and driven by thrust force variations, spindle speed, feed rate and drill geometry. The thickness of the uncut pipe is decreased, when the drill reaches at the end of the specimen. In such situation, the stress caused by the thrust force extends beyond the interlaminar strength, and also an intense delamination occurs [10].

The values of adjusted delamination factor were obtained using Davim et al., approach. The adjusted delamination factor$F_{da}$ is given as:

$$F_{da} = \alpha\frac{D_{\max}}{D_{nom}} + \beta\frac{A_{\max}}{A_{nom}} \tag{1}$$

$$\beta = \frac{A_d}{A_{nom} - A_{\max}} \quad \alpha = 1 - \beta \tag{2}$$

Which $D_{nom}$ is the nominal diameter of the hole, $A_{nom}$ is the area related to nominal hole, $A_{\max}$ is the areas related to the maximum diameter of the delamination zone ($D_{\max}$) and $A_d$ is the delaminated area.

By adjusting the process parameters correctly, such as the speed of

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the spindle, the diameter and geometric shape of the drill, the machining efficiency increases and the potential damage to the components is reduced, and therefore the performance of the operation increases [8]. In the composite drilling process, the feed rate and drill geometry are the critical parameters. Also, the diameter of drill bits, spindle speed, material, and how the fibers are positioned, is very effective in the quality of the hole [11].

Many researchers had studied the effect of input drilling parameters on delamination factor [12–16]. They directed a series of examinations on various composite materials including GFRPs, carbon fiber reinforced plastics (CFRPs), and metal matrix composites to study the effects of drilling parameters on delamination. Their results show that delamination increases with increasing feed rate and cutting speed. In contrast, Khashaba et al., has been reported that, delamination decreases with increasing cutting speed during drilling of woven-ply GFRP composite laminates[17,18]. This also has been reported that during high-speed drilling of thin woven-ply CFRP composite laminates delamination reduces by increasing the cutting speed [19]. They also showed that delamination increases with mounting drill point angles. However, this has been observed by Kilickap that the delamination tendency decreases with increasing point angle of twist drill during conventional drilling of UD-ply GFRP composite laminates [20].

In another work, the effect of cutting geometry on the thrust force and the delamination factor of the GFRP plates were tested by Abrao et al. [21]. The examinations performed by choosing four drills with various geometry and studying the effect of cutting parameters. The outcomes demonstrated, while the drill with three cutting edges had the highest thrust force, applying a saw drill with a lower thrust force will be apperceived. Eventually, they concluded that in the cutting range tested, increasing of the feed rate and cutting speed would increasing the delamination size.

To sum up, increasing of the drilling-induced delamination with mounting feed rate at any different cutting speeds using different drill bits is what almost all researchers agreed, while two different behavior for cutting speed and drill point angle effects were reported.

Few works has been conducted in drilling of composite pipe. In Hochang et al.'s researches, during the drilling of 12 layers of carbon fiber composite pipes with colloid magnetism backup, the amount of delamination was significantly reduced compared to the without backup drilling, and at the same time, the thrust force of drilling has been increased [22,23].

The mechanical virtues of the material, such as residual tensile, compressive and flexural stress, are reduced after machining. The overall results show that, the drilling parameters such as cutting speed, feed rate and drill geometry have an impact on the hole quality, and because of that the residual strength is affected [15].

Zarif et al., examined the effect of drilling parameters including: spindle speed, feed rate and drill point angle on the residual tensile strength of GFPR composite plates. Their results indicate that with increasing delamination, the residual tensile strength decreases. They also showed that increasing the angle of the drill point increases the thrust force, the delamination factor, and decreases the residual tensile strength [24]. The residual compressive stress is one of the mechanical property that is important to measure and determine its behavior after drilling.

In the present study, the effects of machining parameters, such as: spindle speed, feed rate, drill geometry and diameter on delamination factor have been investigated in a without backup drilling of composite pipes produced by the filament winding. Three levels of spindle speed and feed rate, two types of drills with different geometric shapes are used in two different drill diameters. Finally, by analyzing the results and determining the size of the delamination area, sample parameters that have the least and the most delamination area are selected and two pipes are drilled in ice supported condition based on selected parameters. Then the drilled specimens are loaded under pressure test and their residual compressive strength is obtained.

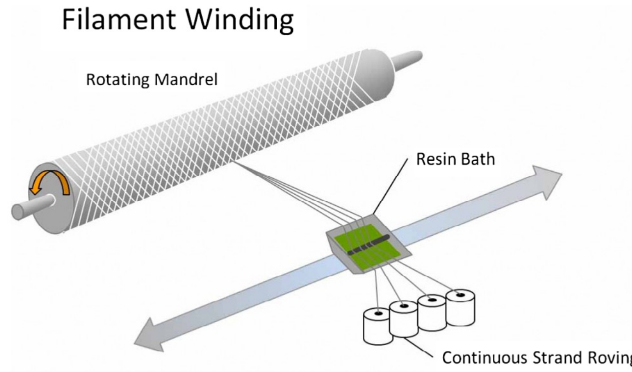


**Fig. 1.** Schematic sketch of filament welding method.

## 2. Experimental research

### 2.1. Specimens

Composite pipe samples are prepared using a filament winding method. In Fig. 1, a schematic representation of a filament winding device is presented. In this method, the fibers are impregnated in a special resin bath and then wounded around the mandrel at various angles. Finally, prepared pipe is cooked in the air or furnace under specific conditions.

In our experiment tests he arrangement and construction of the fiber is like that: first 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, wrapped together with 45-degree angle and the thickness of 2 mm. Fig. 2, shows the pipe made by the filament winding process; Finally, after that the fibers have been wound, the specimens are separated from the filament winding machine and placed in a rotary device to ensure that the curing process of the resin is uniformly carried out at ambient temperature and the pipe reaches its final strength. By this method, the amount of production can be increased and continuous rotation prevents the non-uniform distribution of the resin.

It should be noted that the diameter of the sample is 105 mm and the final thickness of the samples is 3 ± 0.3 mm. Table 1 represents the mechanical properties of the resin and glass fiber which is used for manufacturing of composite pipes in drilling tests.

### 2.2. Equipment

The drill test was carried out by the FP4M Milling Machine, and

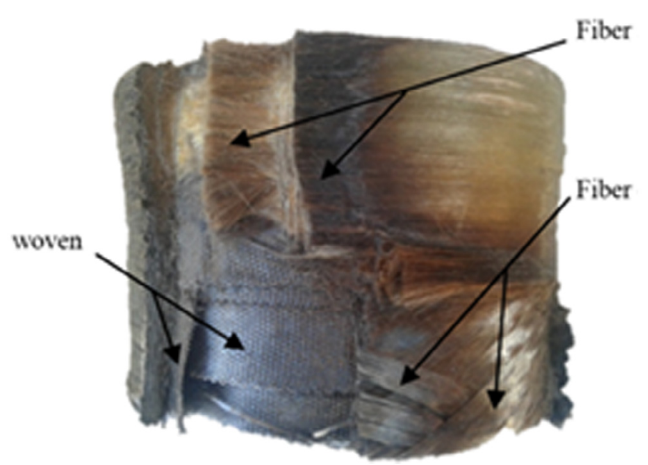


**Fig. 2.** Manufactured pipe by filament winding method.