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Erol Kılıçkap
Burak Yenigün
Yahya Hışman Çelik
Batman University, Batman-Turkey
ekilickap@dicle.edu.tr; burak.yenigun @batman.edu.tr;
yahyahisman.celik@batman.edu.tr

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ORCID ID	0000-0002-7260-3797	0000-0001-5519-2917	0000-0003-1753-7712

THE EFFECT OF DRILLING PARAMETERS ON STRENGTH OF GLASS FIBRE-EPOXY LAMINATES BY PRODUCED HAND LAY-UP

ABSTRACT

In this study, the effects of delamination factor on strength of glass fiber reinforced plastic (GFRP) composite with +45/-45 orientation angle fabrics were investigated. GFRP composite specimens, which contain 36% fiber volume, were produced by hand lay-up. The all specimens were prepared according to ASTM D5766-2002 standards. The experiments were conducted the different drilling parameters such as cutting speeds and feed rates using tungsten carbide (WC) and Brad Spur drill tools. Delamination factors of drilled specimens were determined by optical microscope. The tensile strength values of the drilled GFRP composite specimens were determined by universal tensile testing machine. As results, it was determined that the increasing cutting speed and feed rate increased the delamination factor. The strength of GFRP composites decreased with increasing delamination factor.

Keywords: Delamination, Drilling, GFRP, Tensile Strength, Glass Fibre-Epoxy Laminates

1. INTRODUCTION

Composite materials are used in aerospace, automotive, marine etc. owing to their good mechanical properties such as stiffness, low density, and good corrosion resistance [1 and 2]. The most used among composite materials was GFRP composites due to their economic efficiency. Although GFRP composite parts are producted to a near net shape, a second machining is required. The most common of these machining is drilling. Some problems are encountered in the drilling of GFRP composites [3 and 4]. These problems are delamination, tool wear, surface roughness, whole quality, chip characteristic [5]. Delamination is the most important of these problems [6]. The delamination in the composites reduces the fatigue strength of the material. It also both causes the poor assembly tolerance and affects the integrity in composites structures. Damage such as delamination and defects around of the hole on the drilled composite parts create adverse effect of assembly of parts [7 and 8]. For instance, delamination during drilling causes to adverse effect in 60% of all part of the aircraft industry [9]. It is inevitable to reduce the deformation on the composite material. Delamination and other damages on composite materials are effected with drilling parameters, composite properties, tool materials and its geometry.

The deformation must be reduced or kept at minimum level. Therefore, researchers have focused their studies on reduction in

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delamination. Karimi et al [10] determined that the feed rate and drill point angle had a significant effect on thrust force, adjusted delamination factor and strength of composite. Kishore et al [11] researched influence of cutting parameters on strength while drilling GFRP. They announced that the drilling parameters such as cutting speed, feed rate and the tool point geometry were important parameters. However, cutting speed was the most significant among these parameters. Abdul Nasır et al [12] researched the effects of drilling conditions (feed rate, spindle speed and drill point angle) on residual tensile strength. They noted that feed rate was a significant parameter in affecting the residual tensile strength. Krishnaraj et al [13] analyzed the effects of feed rate and spindle speed on strength and the stress distribution around the hole in the GFRP composite laminates. They found that the strength of composite were affected by cutting speed and feed rate. Stress and damage was obtained as minimum at the high spindle speed and the low feed.

2. RESEARH SIGNIFICANCE

Delamination is one of the most important damages in drilling of composite materials. Delamination causes to a significant decrease in the strength of the material. Hence, the delamination must be kept at minimum level. The aim of this study determined the delamination factor depending drilling parameters and the tensile strength depending delamination factor.

3. MATERIAL AND METHOD

3.1. Workpiece Materials

In this study, GFRP composite produced by hand lay-up method was used. The composite consists of 8 layers of E-glass fiber fabric with a +45/-45 orientation angle and polyester resin. The GFRP composite was produced in the size of 500mmx200mmx4mm. The composite was cut the size of 150mmx27mmx4mm according to ASTM D5766-2002. The physical properties of the composite are shown in Table 1.

Table 1. Physical properties of composites

Properties	Fiber	Resin
Type	+45/-45 E-glass	Polyester
Area Density (gr/m^2)	468	410
Volume Rate	36	64
Density of GFRP(gr/mm^3)	1.75	

3.2. Drilling Tests

The drilling operation was conducted on Brother SPEEDIO S500x1 CNC vertical machining centre with a spindle power of 10.1kW and a maximum speed of 10000rpm. The drilling tests were carried out without the use of cutting fluid. The drilling experimental setup is shown in Figure 1.

The cutting tools were WC and Brad Spur tools which have 6mm drill bit. The drilling parameters are given in Table 2.

Table 2. Drilling parameters

Parameters	Values
V, Cutting Speed (m/min)	10 and 20
f, Feed Rate (mm/rev)	0.1, 0.2, 0.3 and 0.4

Figure 1. Experimental setup

3.3. Determination of the Delamination Factor

In drilling of composite materials, delamination is a major failure mechanism. The delamination was occurred at the entrance and exit of the hole [14]. This factor (Fd) is defined as the ratio to nominal diameter of the hole of maximum diameter in the delaminated area (Figure 2) [15].

Figure 2. Delamination area on the hole

The delamination factor (Fd) around the hole can be determined as empirical. For this, the maximum diameter in the deformation zone (D max) must be found. The delamination factor value is determined from Equation 1 [16 and 18].

$$\text{Fd}=\frac{D_{\max}}{\text{D}} \quad (1)$$

3.4. Determination of Tensile Strength

Tensile tests were carried out through a universal testing machine Shimadzu Autograph AG-X 250KN. The tensile load was applied to the specimen under displacement control with a crosshead speed of 1 mm/min at room temperature. The setup of tensile test is shown in Figure 3.

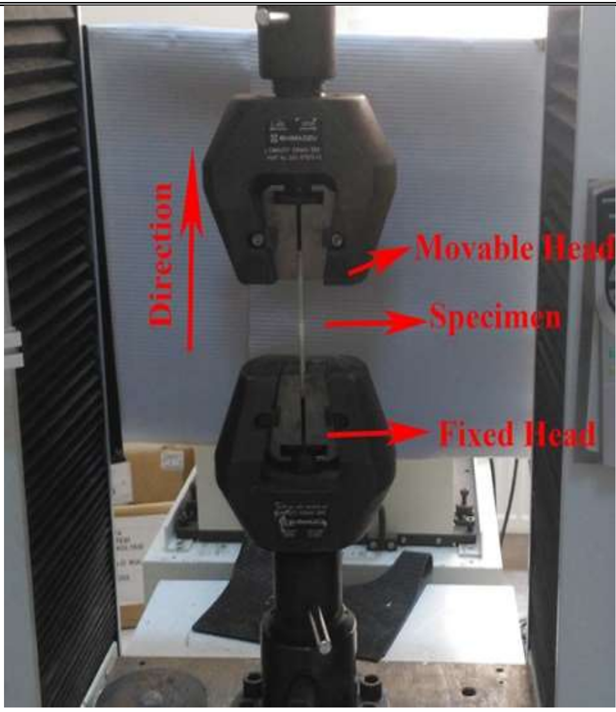


Figure 3. Tensile test setup

4. EXPERIMENTAL RESULTS

4.1. The Effect of Drilling Parameters on Delamination

At the beginning of damage during drilling of the GFRP composites income the delamination. Therefore, it is necessary that delamination must be kept at the minimum level. In the study, to evaluate the effect of cutting speed and feed rate on the delamination at workpiece, a number of drilling test were conducted by WC and Brad Spur tools. The delamination was observed at the entrance and exit of holes during the drilling of GFRP composites. Observed delamination is given in Tables 3 and 4 for WC and Brad Spur tools, respectively. The effect of feed rates and cutting speeds on delamination are given in Figure 4 for WC and Brad Spur tools.

Table 3. Delamination and Fd values for WC tool

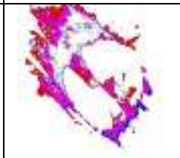
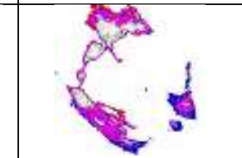
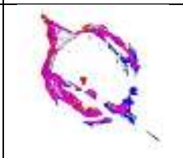
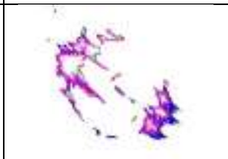
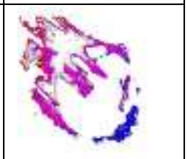
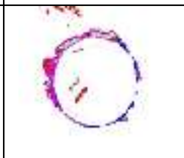
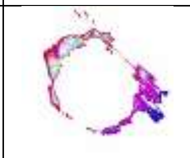
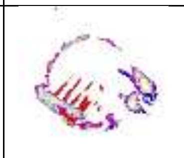
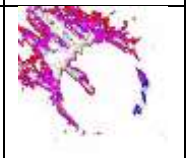
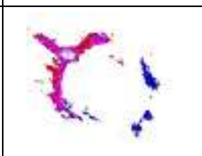
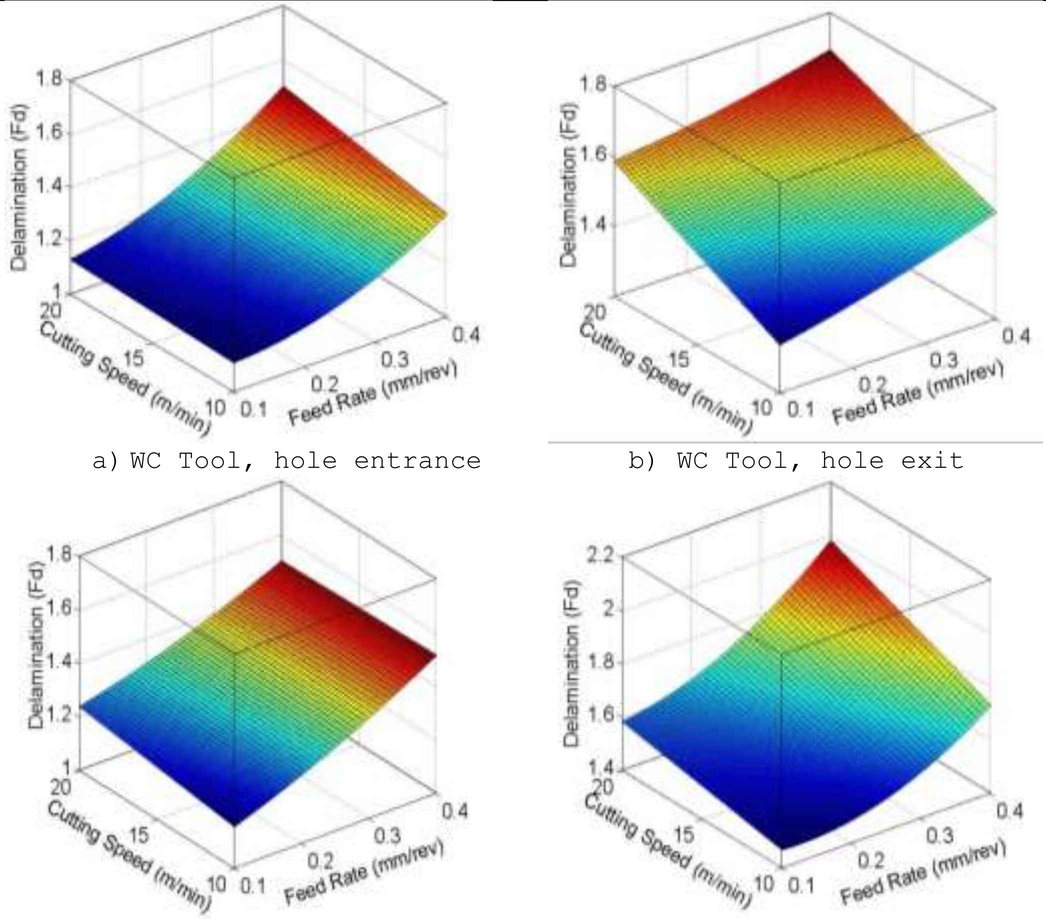
	V=10 m/min		V=20 m/min	
	Entrance	Exit	Entrance	Exit
f=0.1 mm/rev	 1.10	 1.33	 1.15	 1.59
f=0.2 mm/rev	 1.14	 1.40	 1.17	 1.60
f=0.3 mm/rev	 1.28	 1.42	 1.32	 1.66
f=0.4 mm/rev	 1.36	 1.51	 1.51	 1.69

Table 4. Delamination and Fd values for Brad Spur tool

	V=10 m/min		V=20 m/min	
	Entrance	Exit	Entrance	Exit
f=0.1 mm/rev	 1.16	 1.45	 1.21	 1.58
f=0.2 mm/rev	 1.28	 1.51	 1.35	 1.68
f=0.3 mm/rev	 1.31	 1.57	 1.39	 1.72
f=0.4 mm/rev	 1.55	 1.72	 1.49	 2.01



a) WC Tool, hole entrance b) WC Tool, hole exit

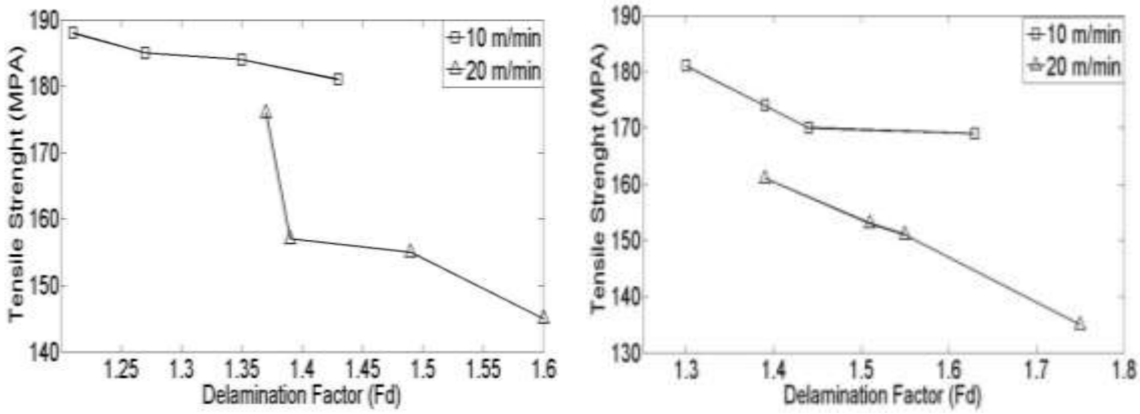
c) Brad Spur, hole entrance d) Brad Spur, hole exit

Figure 4. The effect of feed rates and cutting speeds on delamination

As seen the figures 4, it was observed that the delamination factor increased as the feed rate and cutting speeed was increased. The minimum delamination factor was calculated as 1.10 at the entrance of the hole at a cutting speed of 10m/min and a feed rate of 0.1mm/rev for WC tool. The maximum deformation factor was calculated as 2.01 at the exit of the hole at a cutting speed of 20 m/min and a feed rate of 0.4mm/rev for Brad Spur tool. Under all drilling conditions, it was seen that WC tools create less delamination than Brad Spur tools.

4.2. The Effect of Delamination Factor on Tensile Strength

To determine the effect of the delamination factor on the tensile strength, after the drilling of GFRP composites, tensile tests of all drilled GFRP composites was made. The changes in tensile strength depending on the delamination factor are given in Figure 5 for WC and Brad Spur tools.



a) WC Tool b) Brad Spur Tool

Figure 5. The effect of delamination on tensile strength

As seen figure 5, tensile strength decreased with increasing the delamination factor. The experimental results showed that delamination factor have important an effect on the tensile strength. Low tensile strength does not lead to fulfill the functions of machine parts. Life of machine will be shorter than necessary. This situation increases the operating costs of the machines. For this reason, it is necessary to keep the deformation factor at a minimum level. Minimum deformation factor in drilling of the GFRP composite was obtained from WC tool at low feed rate and cutting speed. For WC tool, the images of the GFRP composites subjected to the tensile test are given in Table 5.

Table 5. The cracking of specimen after tensile test for WC tool

	V=10 m/min		V=20 m/min	
	Entrance	Exit	Entrance	Exit
f=0.1 mm/rev				
f=0.2 mm/rev				
f=0.3 mm/rev				
f=0.4 mm/rev				

5. CONCLUSIONS

The effects of both the drilling parameters on delamination factor and the delamination on tensile strength were investigated in drilling of the GFRP composite. The obtained results are given below.

- It was seen that feed rate, cutting speed and tool type affected delamination factor.
- Delamination factor increased at high feed rate and cutting speed. Feed rate and cutting speed must be kept at low level to obtained minimum delamination.
- The lower the delamination factor, the greater the tensile strength.
- WC tools should be preferred than Brad Spur tools to obtain the minimum delamination and the maximum tensile strength.

NOTE

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