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EXPERIMENTAL INVESTIGATION OF SURFACE DAMAGE OCCURRED ON THE SIDES OF HOLE ENTRANCE IN DRILLING OF GLASS-FIBER REINFORCED POLYMER COMPOSITE MATERIALS

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Abstract

Glass-fiber reinforced polymer composite (GFRP) materials have been started to get extensively used at the industry of space, aviation, ship, chemistry and automotive nowadays. Although GFRPs are generally fabricated to near-set-shape, there often is a need to conduct some additional machining operations. Drilling of composite materials is a very common and an additional machining operations used in industry to perform the assembly of composite metarials. However, drilling of composite materials present a number of problems such as delamination associated with the characteristic of the material. In this study, during the process of drilling, because of the high tensile forces surface damage occurred on the sides of hole entrance has been examined. During the investigation, the glass fiber reinforced polymer composite materials have been drilled under the different cutting parameters such as cutting speed, feed, and tool point geometry, and measuring the damage factors at hole entrance have been carried out. Explaining the results, suggestions have been mentioned about the optimum cutting parameters which requires to get preferred for less damage of surface.

Keywords: Machinability, glass-fiber reinforced polymer composite, surface demage.

1.Introduction

Glass-fiber reinforced composite (GFRP) materials are nowadays being commonly used in aircraft and space industry due to their high specific resistance, hardness, lightness, excellent corrosion and heat resistance compared to the other engineering matrerials (1-3). Since the composite materials can be produced in any desired shapes the common process during mounting of the parts is drilling operation (2-4).During drilling operation, because of the cutting forces damages occur on the sides of hole entrance and hole exits. Due to these damages occurring in industry, lots of mechanical parts can not be used. For instance in the aircraft industry 60% of the parts are being refused only because of these damages (5).

In the drilling of composite materials some unconventional methods (water jet, laser, electro erosion) have been tested but because of the heat and mechanical properties of the material, conventional methods have been preferred in the economical drilling of holes with less damage (6). Several researchers in their studies on the drilling of composite materials specified that the damages occurring at the drilling operations were due to cutting parameters, tool geometry and cutting parameters (7-11).

Davim and his colleagues investigated the effects of drilling glass-fiber reinforced composite layers (produced by hand lay up) with different tool geometries on the damage factor and obtained the damage factor by dividing the maximum damage diameter to drill diameter (12). Abrao (13), Tsao (14), Velayudham and Krishnamurthy (15) determined that cutting parameters and tool geometry have a considerable effect on the drilling of composite materials. Mohan and his colleagues claimed that the damage factor decreased at

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low feed rates and high cutting speeds (16). Arual investigated the effects of coating on the tool wear in the drilling of glass-fiber reinforced composites and specified favourable effects (17).

In this study, the surface damage occurring in the drilling of oriented GRP materials was tried to be minimized and to provide this, appropriate cutting parameters and necessary tool geometry were examined.

2. Material and Method

In this study, glass-fiber reinforced polymer (GFRP) composite plates were drilled under different tool geometry and cutting conditions and the damages on the sides of hole entrances were measured.
In the experimental study, 14 layered GFRP material of 200x100x10 mm plates containing 81 % glass-fiber and 19% polyester resin was used. The GFRP material having an angle of 90^0 in between the fibers has an unisotropic structure. The mechanical properties of the GFRP material manufactured in the oriented form are given in Table 1.

Table 1. Mechanical properties of GFRP composite

Mechanical properties	Value
Tensile modulus (DIN 53457)	3450 N/mm2
Tensile strength (DIN EN 61)	48 N/mm2
Tensile elongation (DIN EN 61)	5%
Cure contraction (DIN 16946)	65%
Temperature of deflection (DIN 53461)	70°C
Martens temperature (DIN 53458)	50°C
Thermal conductivity (DIN 52612)	0.15 W/m°C

In the drilling of GRP material, 2,3,4 flute number drills of 8 mm diameter with 60^0 , 90^0 and 120^0 tip angles were used. 9 experiments for each tip geometry and a total of 81 experiments were carried on. During the experimental study TAKSAN TMC 500 vertical machining center with maximum revolution of 6000 rev/min and spindle power of 5.5 KW was used. In order to determine the effects of the change of cutting parameters on the damage, the cutting parameters given in Table 2 were used.

Table 2. Cutting parameters

Cutting speed (Vc), [m/min]	Feed rate (f), [mm/rev]	Flute number (G)
50	0,06	2
70	0,12	3
90	0,18	4

The GRP plates were tied up (as seen in Fig 1) with the aid of the test setup free of vibration and slidings.

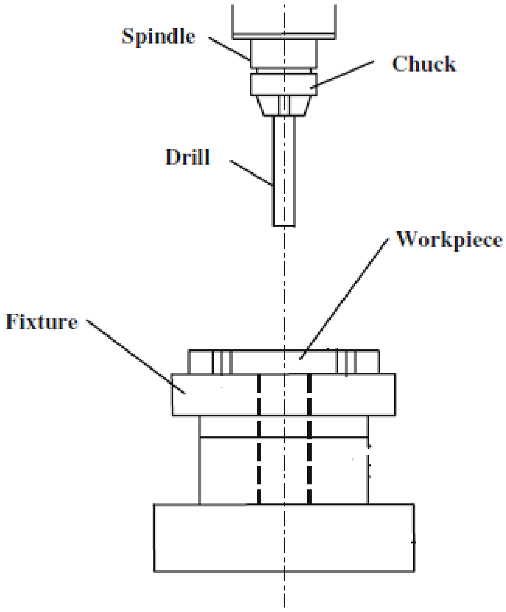
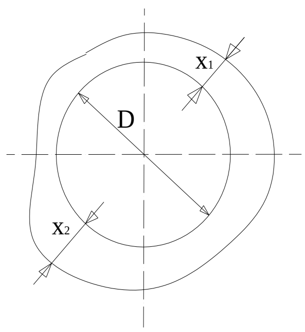


Figure 1. Schematic of drilling set-up. [10]

The digital pictures were taken at the entrances of glass-fiber reinforced layers which were drilled in accordance with the cutting parameters specified in the study and this way the maximum damage zone was identified. Thus the damage factor occurring at the side of the hole entrance was calculated accordingly. In the determination of damage factor (DF), the conventional method of division of damage diameter to drill diameter which was used by Davim and his colleagues (11) was preferred. In the application of this method, a circle is made passing through the minimum points at which the damaged sides around the hole spread intensively and the maximum damage diameter (D_m) is specified. As seen in Fig 2 the biggest values X_1 and X_2 of damaged sides on the same line passing through the center are obtained and D_m is determined by the Formula $D_m = X_1 + X_2 + D$.



D_m = Maximum damage diameter

D = Drill diameter

x_1 , x_2 = Damage width

$D_m = D+x_1+x_2$

HF = Damage factor

$HF = D_m/D$

Figure 2. Determination of minimum damage diameter.

The maximum damage diameter was determined from the digital pictures and then the damage factor was calculated by dividing the maximum damage diameter (D_m) to drill diameter (D). In Fig 3 the determination of damage diameter is shown.

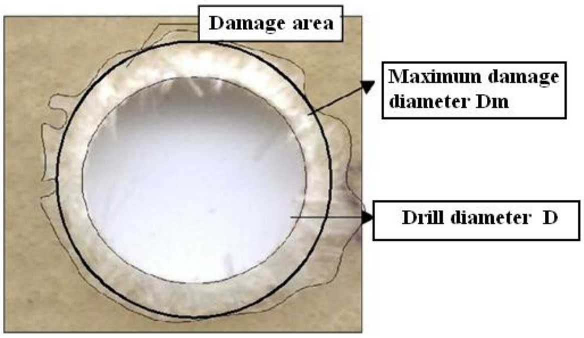


Figure. 3. Scheme of delamination factor determine.

3. Result and Discussion

The tests were made with the specified cutting parameters by using the 2,3,4 flute number and 60^0, 90^0, 120^0 tip angled drills and it was determined that the damage factor decreased with the increase of cutting speed,feed rate and the mouth number whereas it increased with the increase of tip angle.

3.1 The relationship between damage factor and cutting speed

It was observed that the damage factor occurring at the entrance zone decreased with the increase of cutting speed. When the cutting speed increases there is an active cutting and the rupture is minimized. In the drilling of oriented polymer composites the delamination factor occurring at the entrance zone by the effect of radial force is shown in Fig 4.

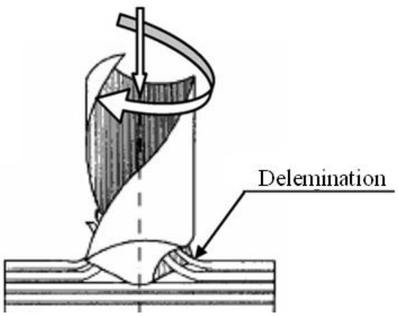


Figure 4. Delemination factor. [18]

With the decreasing of delamination factor the damage occurring at the entrance zone decreases. In Fig 5, it is seen that parallel to the increase in the cutting speed the damage factor decreases. The highest damage factor value, HF= 1.146 , was obtained with the 3 flute number, 90^0 tip angled tool at 50 m/min cutting speed and 0.06 mm/rev feed rate. Whereas the lowest damage factor value was reached with the 4 flute number, 60^0 tip angled tool at 90 m/min cutting speed.
The obtained results showed parallelism with the studies of Khashaba (5) and Mohan (16) but conficted with Dayim's (11-12).

3.2 The relationship between damage factor and feed rate

It was observed that the damage occurring at the entrance zone decreased with the increase of feed rate. In the drilling of GRP due to the abrasive and brittle property of glass, continuous chip formation is not observed and with the increase of feed rate feed cutting force becomes utmost. Fibers are bent over before moving towards X-axis. Material is taken to the helix channel towards the Z axis and thrown out. This way less damaged holes are obtained. As shown in Fig 6 a decrease in the damage factor parallel to the feed rate was observed. The highest damage factor value, HF= 1.139, was obtained with the 2 flute number, 120^0 tip angled tool at 50 m/min cutting speed and 0.06 mm/rev feed rate. Whereas the lowest damage factor value was reached with the 4 flute number, 120^0 tip angled tool at 0.18 mm/rev. The obtained results conflict with the results of many researchers namely with Dayim's (11-12).

3.3 The relationship between damage factor and tip angle

It is known that cutting tool geometry is one of the effective parameters in drilling process. During the drilling of glass-fiber of oriented structure, with the increase of tip angle it was observed that the damage occurring at the entrance zone increased. With the increase of tip angle, radial cutting force starts to play a more effective role than the feed cutting force. Due to the pressures of radial forces at the deformation zone, chips are pushed towards the X and Y axis and less damaged holes are obtained. As shown in Fig 7, paralel to the tip angle an increase in the damage factor was observed. The highest damage factor value was obtained with the 2 flute number, 120^0 tip angled tool at 50 m/min cutting speed and 0.06 mm/ rev feed rate. This shows a parallelism with the studies of Rubio and his colleagues (9).

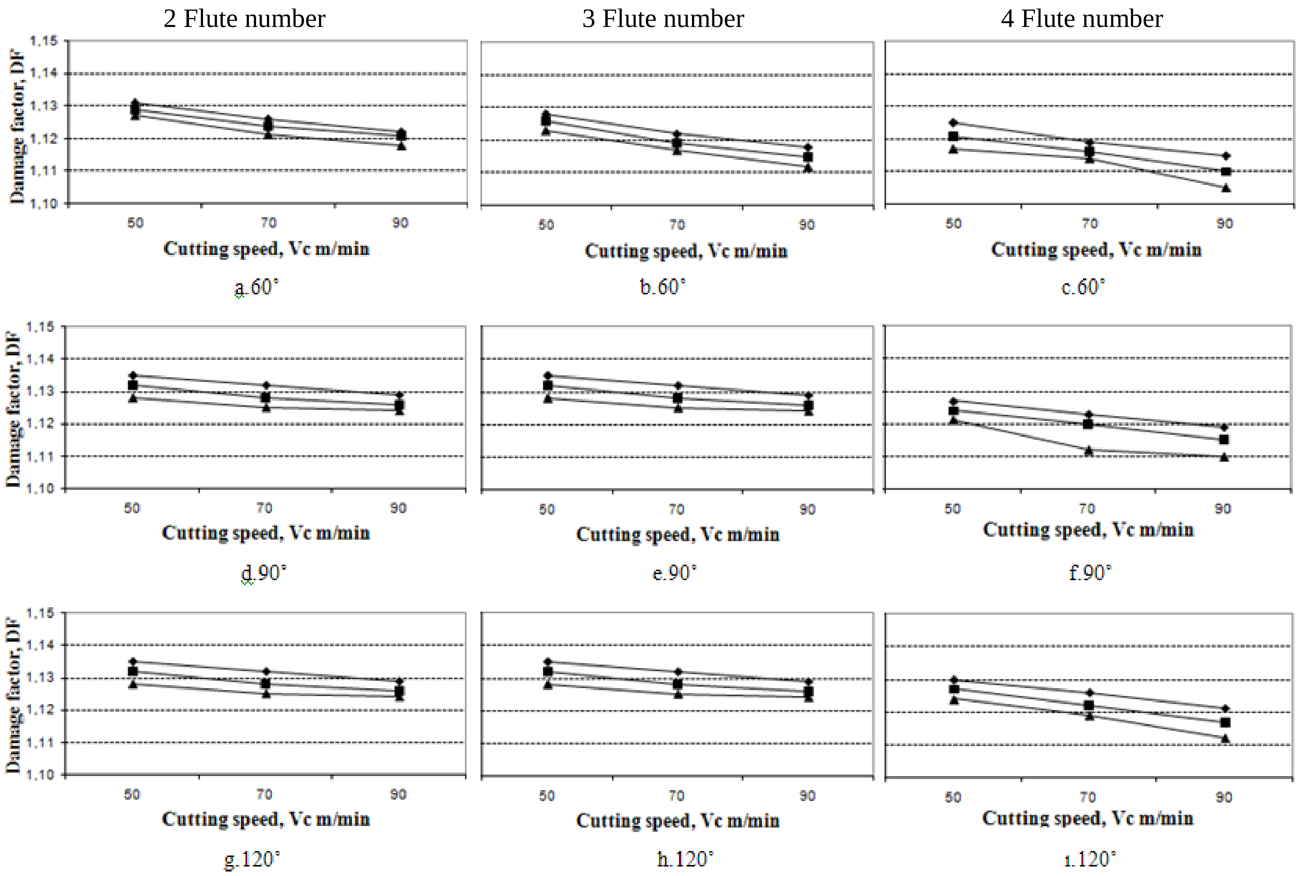


Figure 5. Damage factor – cutting speed comparison graphics.

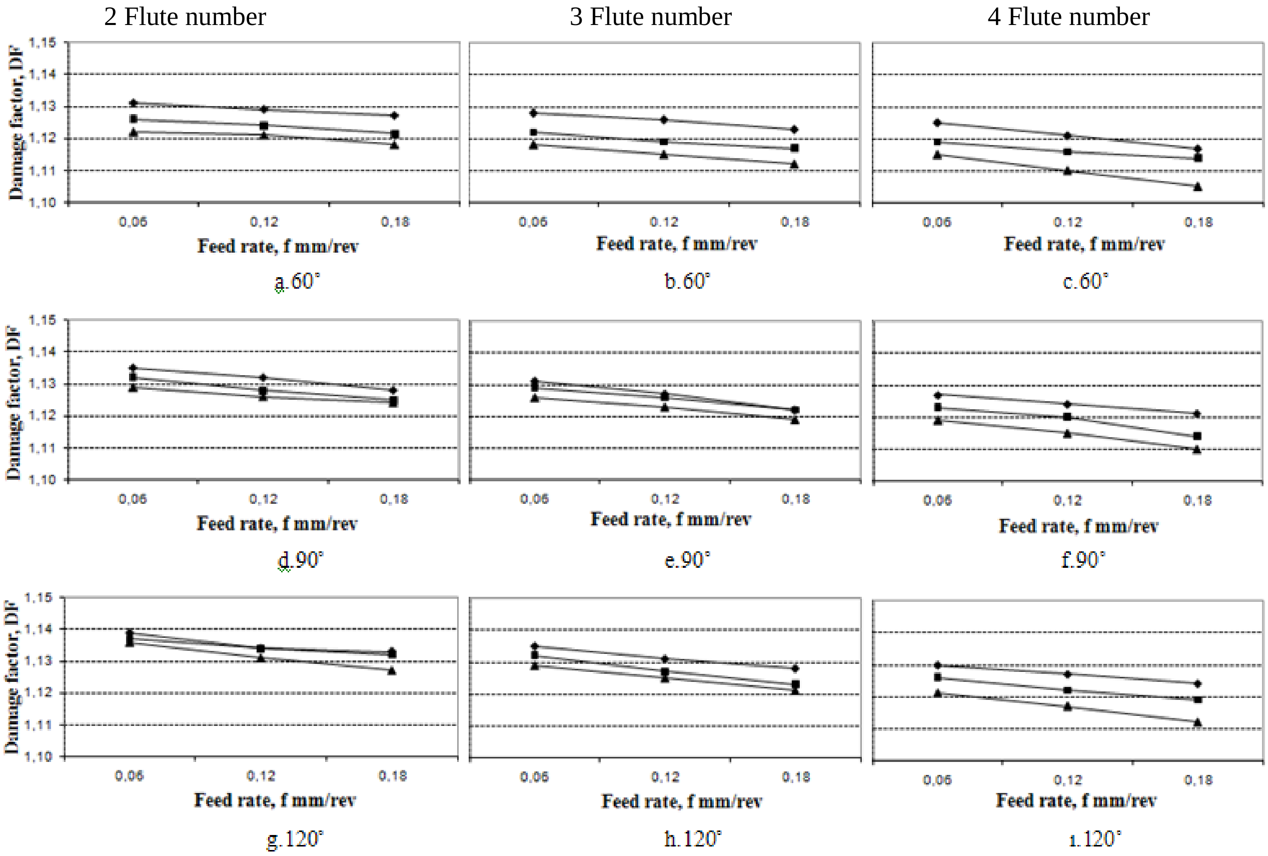


Figure 6. Damage factor – feed rate comparison graphics.

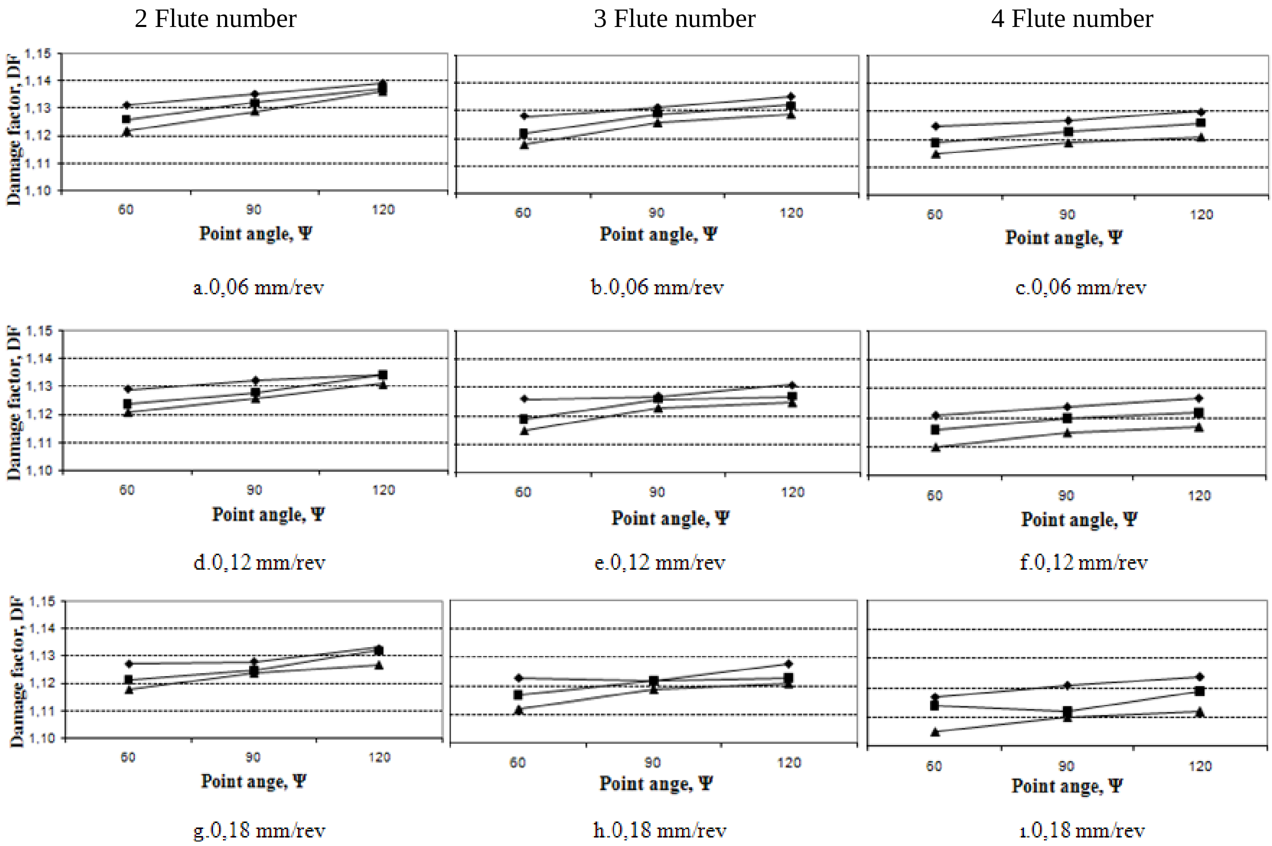


Figure 7. Damage factor – point angle comparison graphics.

3.4 Tool wear

In the cutting tools, flank wear occurred when the glass pieces came in between the working piece and tool surface. In order to obtain good experimental results tools were changed once in every three experiments thus avoiding serious wearing losses.

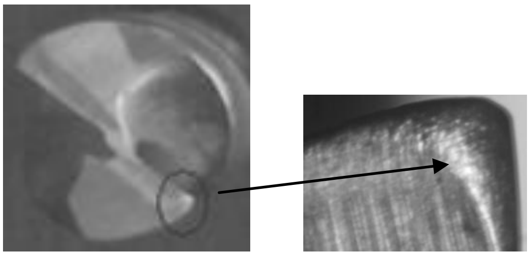


Figure 8. Tool wear on the drills.

4. Conclusion

According to the results obtained from the experiments, the recommended cutting and tool parameters are listed below ;

- 90 m/min high cutting speed,
- 0.18 mm/ rev high feed rate,
- Multiple flute number cutting,
- 60^0 tip angled tool.

By employing the above list the lowest damage factor has been obtained.
To conclude, general results are given below :

- It is possible to obtain less damaged holes with high cutting speeds,
- High feed rate values help the damage factor to decrease,
- Parallel to the increase of tip angle of cutting tool, damage factor increases too.
- The increase in flute number is effective on the decreasing of damage factor.

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