SIGNIFICANCE OF DRILLING PARAMETERS ON DELAMINATION FACTOR IN GFRP: AN IMAGE ANALYSIS APPROACH

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ABSTRACT

Drilling is one of the machining processes most widely applied to composite materials; nevertheless, these materials are prone to delaminate when subjected to stress concentration during machining operations. The damage induced by this operation may reduce the component performance drastically. The present study aims to realize drilling of glass fibre reinforced plastics (GFRP) with reduced delamination. The effects of feed rates, spindle speeds and the geometrical characteristics of the drill on the resulting delamination factor values were compared. A plan of experiments, based on the orthogonal array, was established considering drilling with prefixed cutting parameters in hand lay-up GFRP material. The digital image of the induced damage is analyzed to find delamination factor.

Keywords: GFRP, Delamination, Design of experiments, Image analysis.

INTRODUCTION

Fibre reinforced composites are widely recognized for their superior mechanical properties and advantages for applications in aerospace, defence and transportation sectors [1]. Machining operations in composites can be accomplished using conventional machinery with some adaptations. Among the usual machining processes used on composite materials, drilling is one of the most frequently adopted to make holes for screws, rivets and bolts. As composites are neither homogeneous nor isotropic, drilling raises specific problems that can be related with subsequent damage in the region around the drilled holes. The most frequent defects caused by drilling are delamination, fibre pull-out, interlaminar cracking or thermal degradation [2]. Among the various defects that are caused by drilling, delamination is recognized as the most critical. Delamination is defined as “the separation of the layers of material in a laminate.”
Several techniques have been employed to measure delamination after drilling composites, as shop microscope [3, 6], S-Can [1, 7] and digital photography [4, 8–11]. Generally speaking, a quantitative evaluation is required in order to assess the effect of both the principal cutting parameters and the geometry of the drill [1–11].

Damage Models on composite delamination giving a closer look on delamination; it should be divided into two types, according to their grounds and consequences: one is commonly known as peel-up delamination and the other as push-down delamination. Peel-up delamination is caused by the cutting force pushing the abraded and cut materials to the flute surface – Figure 1. At the beginning of the contact, the cutting edge of the drill will abrade the laminate. As the drill moves forward it tends to pull the abraded material along the flute and the material spirals up before being effectively cut. A peeling force pointing upwards is introduced that tends to separate the upper laminas of the uncut portion held by the downward acting thrust force. Normally, a reduction in the feed rate adopted can reduce this effect.

![Figure 1 Peel up Delamination.](image1)

![Figure 2 Push out delamination.](image2)

On the other hand, push-out delamination is a damage that occurs in interlaminar regions, so it depends not only on fibre nature but also on resin type and respective properties. This damage is a consequence of the compressive thrust force that the drill tip always exerts on the uncut laminate plies of the work piece. At some point, the loading exceeds the interlaminar bond strength and delamination occurs, before the laminate is totally penetrated by the drill – figure 2.

All these defects are unwanted and lead to rejection or rework of the composite part involved. Both options are very costly and time consuming. These damages are especially difficult to detect by visual inspection and reduce severely the load carrying capacity of the laminate part, in particularly under compression loading [12], as already mentioned.

Delamination factor is defined by ratio of maximum diameter (of damaged area around hole) to actual hole area as shown in figure 3. The present work investigates the influence of the cutting parameters and tool geometry on delamination factor.
MATERIALS AND METHODS

Specimens of 5 mm thickness were prepared using the hand lay-up process as shown in figure 4. The reinforcement was in the form of uni-directional E-glass fiber and the matrix was polyester. The fiber volume fraction of 0.56 was achieved for prepared specimen.

DESIGN OF EXPERIMENTS

Based on the literature [1-11] it was decided to study the effect of point angle, feed rate, speed and diameter. This design models have been prepared by choosing three levels.

Taguchi design was used for experimentation by applying L27 orthogonal array, taking three levels for each factor as depicted in Table 1.
Table 1 Input parameters

<table>
<thead>
<tr>
<th>CONTROL FACTOR</th>
<th>UNIT</th>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>mm/rev.</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Speed</td>
<td>Rpm</td>
<td>600</td>
<td>900</td>
<td>1200</td>
</tr>
<tr>
<td>Point angle</td>
<td>Degree</td>
<td>90</td>
<td>104</td>
<td>118</td>
</tr>
<tr>
<td>Diameter</td>
<td>Mm</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

The standard HSS twist drills of 2 mm, 3 mm and 4 mm diameter with different point angles were used in the present investigation. Drilling tests were carried on vertical machining centre (maximum rpm, 12000, figure 5).

Damage Area Determination

Different techniques are used to analyse and calculate the damage area of drilled composites [1-11]. For example, Gao and Kim [13] presented a comparative study on destructive and non-destructive evaluation techniques for characterizing the impact damage in carbon-fibre-reinforced composites. They concluded that visual inspection has a considerable drawback associated to the difficulty in accurately obtaining the profile and depth of the damage. In present work, the digital image of the damage area is used to characterize its extension at the drill entrance and exit.

The image of damage which is shown in figure 6 was taken using a shop microscope Mitutoyo QS – L 2010 ZB. The images were captured by improving contrast to have clear separation of delamination. The damaged area was measured by image analysis using MATLAB as per following steps:

1. Read the image.
2. Convert RGB to gray scale image.
3. Convert greyscale image to binary image.
4. Remove noise using “imfill” instruction.
5. Calculate the hole area using “regionprops” instruction.

Figure 7 shows the image area calculation.
RESULTS AND DISCUSSION

A L27 orthogonal array with, total of 27 experimental runs were carried out. Table 2 shows the results of delamination factor, for various experimental runs of drilling.

Table 2 Experimental Results.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Feed (mm/rev.)</th>
<th>Speed (rpm)</th>
<th>Point Angle (degree)</th>
<th>Diameter (mm)</th>
<th>Delamination Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>600</td>
<td>90</td>
<td>3</td>
<td>1.4551</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>900</td>
<td>104</td>
<td>4</td>
<td>1.2330</td>
</tr>
<tr>
<td>3</td>
<td>0.3</td>
<td>1200</td>
<td>118</td>
<td>2</td>
<td>1.1826</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>600</td>
<td>90</td>
<td>4</td>
<td>1.0099</td>
</tr>
<tr>
<td>5</td>
<td>0.2</td>
<td>900</td>
<td>104</td>
<td>2</td>
<td>1.6155</td>
</tr>
<tr>
<td>6</td>
<td>0.3</td>
<td>1200</td>
<td>118</td>
<td>3</td>
<td>1.4270</td>
</tr>
</tbody>
</table>
Figure 8(a) – 8(c) shows the effect of delamination factor with different speed and point angle at various drill diameters. It is observed that with increase in speed the delamination factor decreases and with higher point angle it increases.
Figure 8 Effect of speed and point angle on delamination factor.

Figure 9(a) – 9(c) shows the effect of delamination factor with different feed rate and point angle at various drill diameters. It is observed that with increase in the feed rate the delamination factor increases and is maximum for the 4 mm drill diameter.
The main effect of feed rate, spindle speed, point angle and drill diameter on delamination factor is represented in figures 10 which indicates that the increase in feed rate increases the delamination factor, whereas the increase in speed decreases the delamination factor. It is observed that the $90^\circ$ point angle gives minimum delamination factor.

Figure 9 Effect of feed rate and point angle on delamination factor.
Figure 10 Main effect plots for delamination factor.

CONCLUSION

Based on the experimental results obtained and concerning the damage induced after drilling GFRP using drills with different geometries, the following conclusions are extracted:

- Within the cutting range tested, delamination factor decreases as the spindle speed is elevated.
- At high spindle speed with higher drill diameter the delamination factor increases.
- With increase in the feed rate the delamination factor increases.
- The delamination factor is lower for the 90° drill point angle and increases with increase in point angle.

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