Analysis of hole quality errors in drilling of GFRP composite

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Abstract. Glass Fiber Reinforced Polymer (GFRP) composites applications are widely used now a day due to its greater mechanical, structural and thermal properties. Drilling is the most extensively used manufacturing process in fabrication of composite components. It is commonly used in the final stage of manufacturing or assembling of components. In the process of drilling, various undesirable effects occur such as matrix cracking, fiber damage, delamination, increased surface roughness of hole, circularity and thermal damage, etc., which reduce the quality of hole. Delamination is the major concern among all the undesirable effects. The appropriate selection of cutting parameters and drill bit type can minimize the delamination and improve the hole quality. In the present work, the influence of three types of drill bits and cutting parameters such as feed rate and spindle speed on the hole quality parameters assessed which includes delamination, circularity, diameter deviation and surface roughness. The obtained results conclude that for high spindle speeds, the spur drill gives better hole quality. The assembly accuracy of the drilled hole can be enhanced by the proposed hole quality parameters.

1. Introduction

Glass Fiber Reinforced Polymer (GFRP) is used in the area of aerospace, automotive and machine tool industry. It has good properties like durability, light weight, more specific strength, specific modulus, chemical and corrosion resistance. The GFRP composites are fabricated by various methods like filament winding, hand lay-up, resin transfer molding, etc., [1-6]. Drilling is mainly performed for assembling the subcomponents. Due to anisotropic nature and heterogeneity of composite materials, the drilling operation can damage the peripheral regions of the drilled holes [7]. Drilling within tolerances, good surface quality and suitable circularity without affecting the strength are the requirements for defense and aerospace industry. Delamination is a critical problem in the process of drilling GFRP composites which reduces the structural integrity of the material, causes deficient assembly tolerances. There are two types of delamination mechanisms are present namely: peel-up and pullout. Peel-up delamination is occurring at doorway of the outlet and push-out delamination is occurring at the exit. [8]. The quality of hole is
strongly affected by the machining parameters. Circularity error, roughness and diameter deviation are some of the important parameter for assessing quality of hole [9].

2. Literature Review

Jalumedi Babu et al. [8] conducted a detailed review about delamination factor and its assessment methods. Delamination factor was influenced by damage area contribution and crack length. Several techniques were available to determine delamination and values different from one method to another technique. Akhil et al. [9] used GRA to optimize the process parameters during drilling of composites. Surface quality and delamination error were the responses. Taguchi L27 orthogonal matrix was used to perform the experiments. ANOVA was used to find out influencing parameters. Grilo et al. [10] assessed about delamination error with different drill tools. Drill tools were considered spur drill, flute drill, helicoidal drill. The result mentioned that spur drill provides better performance. Mudhukrishnan et al. [11] investigated that the influence of operating parameters and types of drill tool on the surface quality and oversize of drilled hole in GFRP composite. Improved response values were noticed with high spindle speed and minimum feed rate. Ashrafi et al. [12] studied the effect of different drill speeds and feed rates surface roughness, hole roundness and fiber pull out geometries. The result revealed that selected output parameters significantly influenced by operating variables. Palanikumar et al. [13] formulated a regression model of delamination error and surface quality during GFRP composite drilling. Drill diameter, feed rate and speed were considered as operating variables. The results indicated that delamination factor was influenced by drill diameter. Feed rate influences surface quality and also delamination factor. The developed model had potential to evaluate factor and surface quality and ANOVA was used to estimate for developed mathematical model. Wang and kirwa [14] investigated the influence of pilot hole, twist drill, and step drills, speed and feed rate during on the quality of the drilled hole and force involved in CFRP composite. The result revealed that feed rate and drill types were influenced the machining performance. From the previous studies, it is noticed that surface roughness, diameter deviation, circularity error and delamination factor of drilled hole play an important role for assembly accuracy. Hence, an effort has been made to investigate hole quality parameters in GFRP composite drilling.

3. Materials and methods

Hand lay-up method is used to make GFRP laminate of 16 layers of woven roven glass fiber of stacking order zero degree with 58.63% fiber volume fraction. Epoxy (LY566) resin and 5200 hardener is used in the preparation of laminate [15, 16]. Prepared laminate thickness is 5 mm. The prepared GFRP laminate is drilled using vertical CNC milling machine. Figure 1 shows the machine setup. The drilling operation is performed on the laminate by using different speed, feed rate and drill bits (Twist, Slot & Spur). Drilling is performed by three different drills of 8 mm diameter namely twist, slot and spur dill bit of HSS material. The parameter values and levels are chosen from previous research studies and pilot experiments. Experiments are performed using L9 orthogonal matrix [17, 18]. Table 1 shows the values of process parameters used in this research. Figure 2 and 3 shows the machined sample and drill tool.

The delamination of fibers (Figure 4) of drilled hole is investigated with microscope. The delamination factor is evaluated as follows:

\[ F_d = \frac{D_{\text{max}}}{D} \]  

Where, \( F_d \) = delamination factor; \( D_{\text{max}} \) = maximum damaged zone diameter, mm; \( D \) = hole diameter, mm
Table 1. Experimental process parameters and their levels

| Parameters         | Levels | Level 1 | Level 2 | Level 3 |
|--------------------|--------|---------|---------|---------|
| Drill types        | Twist  | Slot    | Spur    |
| Spindle speed, rpm | 1000   | 1500    | 2000    |
| Feed rate, mm/rev  | 0.10   | 0.15    | 0.20    |

Figure 1. Machine setup

Figure 2. Drill tool

Figure 3. Machined sample
Figure 4. Microscopic images for delamination

Surface roughness (Ra) is measured using Talysurf tester at three places and the average value is calculated [19]. Circularity is also known as roundness error. It can be measured from the minimum confine circle to the maximum confine circle diameter. It is measured using Coordinate Measuring Machine (CMM). Diameter error is the difference between actual size and drilled size. It is also measured using CMM. [20, 21]. The experimental results are shown in table 2.

Table 2. Experimental results

| Sl. No | Drill type   | Spindle speed, rpm | Feed rate, mm/rev | Diameter deviation, mm | Circularity error, mm | Surface roughness, microns | Delamination Factor |
|--------|--------------|--------------------|-------------------|------------------------|-----------------------|-----------------------------|-------------------|
| 1      | Twist drill  | 1000               | 0.1               | 0.27                   | 0.048                 | 4.05                        | 1.463             |
| 2      | Twist drill  | 1500               | 0.15              | 0.25                   | 0.047                 | 3.28                        | 1.475             |
| 3      | Twist drill  | 2000               | 0.2               | 0.038                  | 0.072                 | 3.15                        | 1.375             |
| 4      | Slot drill   | 1000               | 0.15              | 0.026                  | 0.12                  | 1.56                        | 1.275             |
| 5      | Slot drill   | 1500               | 0.2               | 0.014                  | 0.092                 | 1.56                        | 1.265             |
| 6      | Slot drill   | 2000               | 0.1               | 0.039                  | 0.069                 | 1.35                        | 1.219             |
| 7      | Spur drill   | 1000               | 0.2               | 0.033                  | 0.067                 | 2.9                         | 1.475             |
| 8      | Spur drill   | 1500               | 0.1               | 0.021                  | 0.064                 | 2.08                        | 1.275             |
| 9      | Spur drill   | 2000               | 0.15              | 0.029                  | 0.054                 | 1.15                        | 1.354             |
4. Results and discussion

The GFRP composite drilling experiments are carried out with different drill types and process parameters based on Taguchi L9 orthogonal array. Hole quality responses such as diameter deviation, surface roughness, circularity error, and delamination factor are investigated. Diameter deviation is the difference between actual diameter made and actual diameter expected. Surface roughness indicates machinability and functional life. Circularity error is the error which is used to enhance the hole accuracy. Delamination factor influences surface integrity and assembly tolerances. Figure 5-8 show the main effect plot of responses.

![Figure 5. Main effects plot for diameter error](image1)

![Figure 6. Main effects plot for circularity error](image2)
Diameter deviation is decreased with increase of spindle speed. Interfacial friction is decreased with higher spindle speed. Hence, low value of diameter error with higher spindle speed. Circularity error is influenced by feed rate. This is due to high dynamic stability at lower value of feed rate. Spindle speed influences the circularity error. Circularity error has reduced with increase of spindle speed. At high value of spindle speed, rotational stability might be higher [9, 11]. Machined hole surface roughness is less with high value of spindle speed. At low value of spindle speed, can lead to built-up edge formation and deteriorate the machined surface. Delamination factor is reduced at higher spindle speed, this is leads to high temperature and followed by soft matrix and induce less delamination. Conventional drill tool is noticed that higher delamination than spur and slot drill [12-14].
5. Conclusions

The findings of GFRP composite drilling with different drill bits are summarized as follows:

- Hole quality response parameters influence the assembly accuracy and these responses are measured by surface roughness tester and CMM.
- Delamination is influenced by spur drill, greater speed and lower feed rate.
- Surface roughness is lowered with increased speed and lower feed rate values.
- Lower circularity error values are obtained at increased speed and lower feed rate.
- Hole diameter error has lowered with increased feed rate and increased with increase in speed.
- The hole quality parameter investigation can be used to predict assembly accuracy of drilled hole in advance. Also, the future work is to perform with other kind of drilling tools.

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