Drilling induced delamination in aeronautical carbon fibre reinforced polyetherketoneketone (CF/PEKK) composite

DRILLING INDUCED DELAMINATION IN AERONAUTICAL CARBON FIBRE REINFORCED POLYETHERKETONEKETONE (CF/PEKK) COMPOSITE

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Abstract: *The excellent mechanical and thermal properties of thermoplastic carbon fibre/polyetherketoneketone (CF/PEKK) composite has led to its increased utilisation in various manufacturing sectors, particularly in the aeronautical industry. However its machining performance, especially the performance under drilling, has rarely been reported. In this study, the drilling performance of CF/PEKK composite is investigated in detail. The effect of different feed rates on the resulting thrust force, machining temperature and delamination damage has been elucidated. Through monitoring of thrust force and machining temperature, the effect of thermo-mechanical interaction on the delamination damage formation was revealed. This study provides an important insight into the damage mechanism in drilling of CF/PEKK and can provide parametric guidance on practical drilling of such material in aircraft manufacturing industry.*

Keywords: CFRTP; Aeronautical composites; Drilling; CF/PEKK; Delamination damage

1. Introduction

In recent years, continuous carbon fibre-reinforced thermoplastic (CFRTP) composites have received much attention in a wide range of industrial applications, such as aircrafts, automobiles, wind energy and sport equipment. Compared to traditional carbon fibre-reinforced thermosetting plastic (CFRP), CFRTP exhibits higher toughness, faster manufacturing turnover and improved recyclability [1], hence is considered as a more sustainable composite material for future aircraft and automobile manufacturing.

Mechanical joining through riveting is the still most deployed joining method for load bearing composite structures [2], especially in aircraft assembly. However, the studies in the literature mainly focus on investigating the drilling performance of thermoset CFRP, especially CF/epoxy composites. Andreas Haeger et al. [3] conducted a comparative experiment on the effect of the drill point angle on the delamination factor using twist drills with point angles of 70°and 100°. Results showed that the delamination factor of the CFRP drilled with 70° drill bits is 30% smaller compared to that with a point angle of 100°. Tsao and Hocheng [18] compared the influence of different drill bit geometries on the delamination of CFRP using Taguchi analysis. The experimental results revealed that the saw drill and brad spur drill resulted in a reduced delamination factor compared to conventional twist drill bit. The influence of step drill on the delamination factor was investigated by Qiu et al. [4] and a corresponding relationship between the ratio of the pilot section diameter to the sizing section diameter and delamination was obtained. Ramirez et al. [5] conducted drilling experiments on unidirectional (UD) CFRP and found the surface roughness deteriorated for fibre orientation of $\theta = 135° \pm 18°$. This can be explained by the uncut fibres around 135 ° fibre orientation. Similar results were also demonstrated by others [5–8]. This can be explained by the material removal mechanism in the region with a fibre orientation of $90° < \theta < 180°$. The bending and subsequent breaking of carbon fibres resulted in voids and pits on the finished surface. Apart from drill bits geometries and fibre orientation, cutting speed and feed rate are two significant factors that considerably influence the hole quality in drilling of CFRP. Heidary et al. [9] and Krishnaraj et al. [130] revealed that the feed rate has a greater influence on the drilling delamination factor as compared to the cutting speed. Similar results were reported by Krishnaraj et al. [10] where contribution of feed rate on push-out delamination (51.4%) was much greater than that of the spindle speed (35.42%) during high speed drilling of CFRP. Eneyew and Ramulu [8] conducted drilling experiment in UD CFRP and a lower surface roughness can be obtained when employing higher cutting speed and lower feed rate. Liu et al. [11] further validated such correlation using finite element analysis (FEA) method.

Compared to the large body of works available on drilling of CFRP, only a few studies have been carried out on drilling of CFRTP. In this paper, the drilling performance of thermoplastic carbon fibre reinforced polyetherketoneketone (CF/PEKK) composite is reported. The effect of different feed rates on the resulting thrust force, machining temperature, delamination damage will be discussed.

2. Experiment setup

2.1 Materials and drilling experiment

CF/PEKK laminates used in this study were fabricated from 22 lies of unidirectional prepregs with a stacking sequence of $[0/90]_{11}$ and a nominal thickness of 3 mm. The coupons used for drilling experiment has a dimension of 120 mm x 120 mm x 3 mm.

Two-flute 6 mm diameter drill bits (point angle = 104°) with TiAlN coating were supplied by Changzhou Aitefasi Tools Co. Ltd. Drilling experiment were carried out under dry condition with Deckle FP3A 3 axis CNC machine, at different feed rates shown in Table 1. During drilling, the thrust force was measured with a Kistler 9272 dynamometer and the hole wall temperature was captured by a FLIR A6751 thermal camera. Three holes were produced for each set of parameters to endure repeatability.

Table 1Drilling parameters used in this study

Parameters	Values
Feed rate F (mm/rev)	0.025, 0.05, 0.1, 0.15, 0.2
Cutting speed V_c (m/min)	50

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The hole delamination damage was analysed using Alicona infinite focus G5 microscope (Uruker, UK) and quantified by delamination factor F_{da} following established method [15].

3. Results and discussion

3.1 Thrust force and hole temperature

For drilling of CF/PEKK, thrust force is the main reason causing delamination damage at the hole exit, as a result of Mode-I opening fracture [16]. On the other hand, the high machining temperature can soften the CF/PEKK plies and induce thermal-related damage to the hole. The thrust force and hole temperature at different drilling feed rates are shown in Figure 1. The results showed that the thrust force significantly increased with feed rate, while the hole wall temperature followed the opposite trend which showed a clear decline with feed rate.

The thrust force in drilling of CF/PEKK showed 224% increase when the feed rate increased from 0.025 mm/rev to 0.2 mm/rev. The drastic increase can be attributed the thicker material removed per tool revolution under the higher feed rate. The thrust force showed a linear correlation with feed rate, which is similar to the report by Guo et al. [19] in their thrust force mathematical models for drilling of CF/epoxy composite. The hole wall temperature decreased from 201 °C to 85 °C as the feed rate increased from 0.025mm/rev to 0.1 mm/rev. The hole wall temperature stabilized at ~ 80 °C for feed rate > 0.1 mm/rev. The decrease of hole wall temperature can be attributed to the reduced tool-workpiece contact time at high feed rate, which creates less thermal energy accumulation.

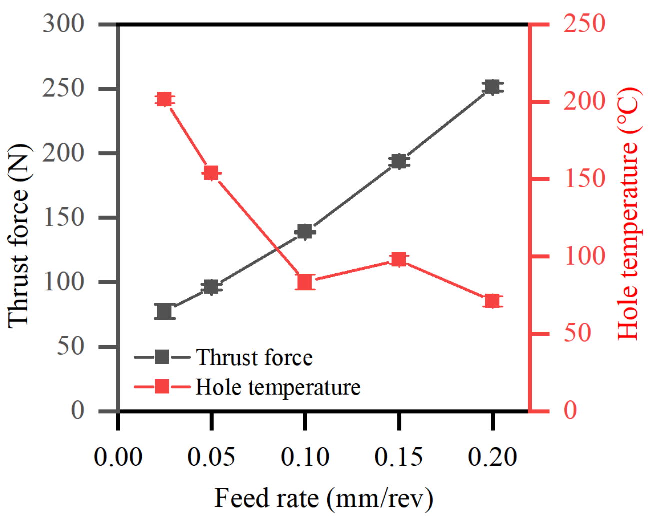


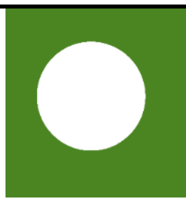
Figure 1 Thrust force and hole wall temperature at different drilling feed rates

3.2 Delamination damage

Delamination damage is mostly induced at the last uncut ply of the laminate during the drilling process, due to lack of mechanical support underneath. Hole delamination can weaken the components' strength and reliability, and therefore should be controlled and minimized whenever possible. Table 2 shows the delamination damage of CF/PEKK at hole-exit under different feed rates. The variation of delamination factor with feed rate is shown in Figure 2. The delamination factor F_{da} first decreased from 1.16 to 1.02 with the feed rate increasing from 0.025 mm/rev to 0.1 mm/rev. Then F_{da} started to show increasing trend with feed rate and reached the highest value 1.47 at the highest feed rate F = 0.2 mm/rev.

The initial declining trend seen for delamination damage can be associated to the decreasing trend of the hole wall temperature. Under a low feed rate (F < 0.025 mm/rev), the high machining temperature can soften the CF/PEKK ply and weaken its resistance to bending deformation. Under high feed rate (F > 0.1 mm/rev), the high trust force can cause severe Mode-I opening fracture and take over the predominant influence on the delamination damage. As such, the delamination damage in drilling of CF/PEKK is strongly influenced by the thermal-mechanical interaction at the tool-workpiece interface.

Table 2 Typical hole exit delamination image produced under different feed rates

Feed rate (mm/rev)	0.025	0.05	0.1	0.15	0.2
CD					

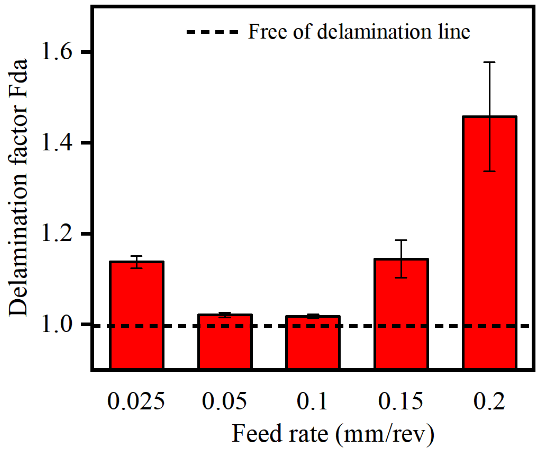


Figure 2 Variation of delamination factor F_{da} with feed rate

4. Conclusions

This paper investigated the drilling characteristics of high-performance thermoplastic CF/PEKK composite. The effect of feed rate on the resulting thrust force, machining temperature and hole delamination damage has been revealed. Experimental results suggested that drilling thrust force increases significantly with feed rate while machining temperature showed clear decreasing trend with feed rate. The composite's delamination damage is a result of combined mechanical –thermal interaction caused by the thrust force and high machining temperature.

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5. References

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