Experimental and numerical study on the delamination behaviour of interleaved composites with automated tape laying (ATL)

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Abstract
Automated Tape Laying (ATL) is one of the key technologies of automated composite manufacturing processes. Typically, prepreg tapes are laid side-by-side onto a tooling surface to generate the composite preform. While the interleaved composites is manufactured by introducing a wider gaps between adjacent tapes (i.e., tape pitching) in each ply, tapes will migrate from one ply to the other and gapping and overlapping are generated in different plies which leads to a complex through-thickness structure. Inconsistencies such as overlapping tapes or gaps between adjacent tapes may also occur. Within this study, the mixed-mode delamination behaviour of interleaved composites has been investigated experimentally and numerically. Single-leg bending (SLB) testing has been carried out on specimens cutting from large interleaved panels with different positions in two directions. X-ray computed tomography and microscope were used to characterise the crack location both before and after the test. Voxel-based FEM framework and compliance based method are presented for the analysis of fracture toughness. With both experimental and numerical analysis, this paper provides a better understanding of the effect of fibre migration and inconsistencies on the propagation behaviour of interlaminar crack.

1. Introduction
Composite materials have been widely used in aerospace industry due to their high specific stiffness and strength. Driven by the need to lower the cost of composite part fabrication, the aerospace and materials industry began to collaborate on research efforts to develop automated fabrication methods. Automated tape laying (ATL) and automated fibre placement (AFP) are the two main technologies that are employed today to produce advanced composite laminates from unidirectional of prepreg. ATL is employed to deliver wide prepreg tape onto a surface while AFP utilises a band of narrow prepreg tows, which are collimated on the head and then delivered together. The prepreg tape ATL head handles is typically 75, 150, or 300 mm wide, and the narrow tows for AFP is between 6.35 mm (0.25 in) and 25.4 mm (1 in). Therefore, ATL can be considered a highly productive process for prepreg layup, especially when manufacturing flat laminates. ATL systems have been used for manufacture of a variety of parts, such as tail planes, wing skins and the centre wing box of the A380.

Delamination is a major failure mode especially when fibre-reinforced composite laminates are impact by a foreign object. Although the interlaminar fracture in unidirectional composites has been studied widely, there are no relevant study on the delamination behaviour of interleaved composites which includes tons of fibre migration and inconsistencies (overlapping and gapping). The aim of this work is to extensively study the delamination behaviour of the interleaved composite by SLB experiments.

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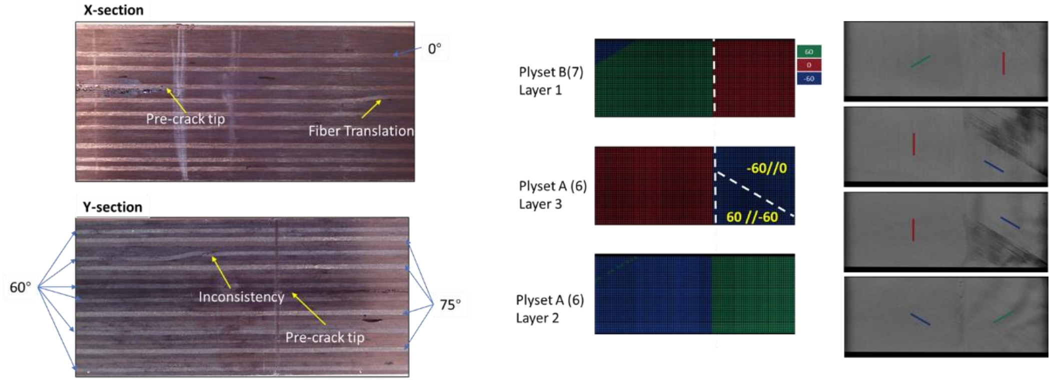
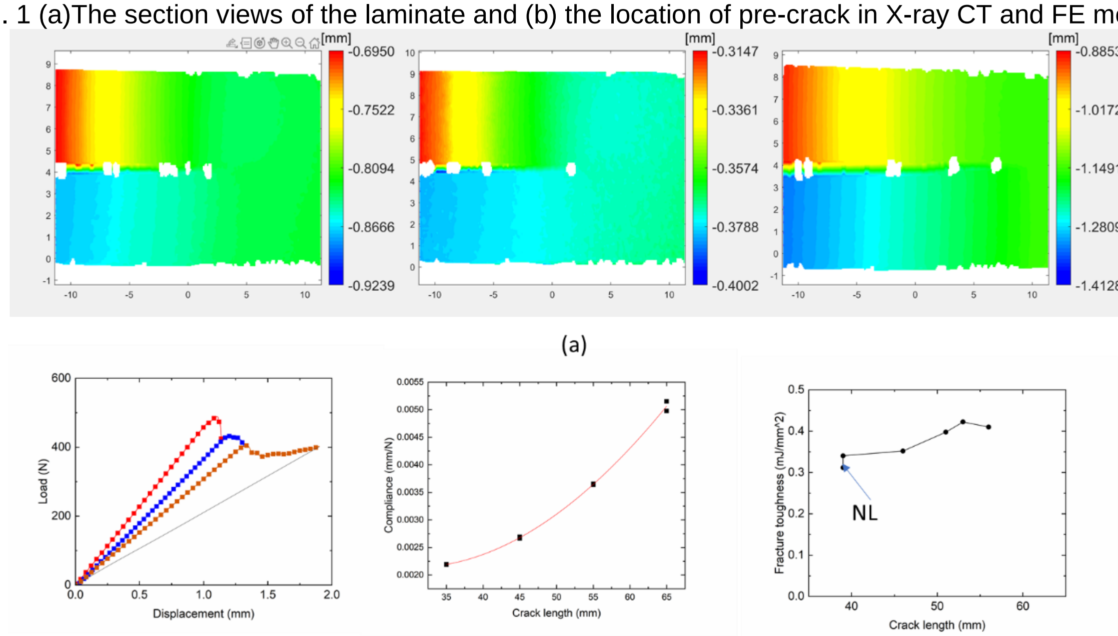
2. Results
Interleaved panels were fabricated according to US 9333710 B2 (GKN Aerospace Services Ltd, Gawn et al, published 10 May 2016) from Hexply Autoclave aerospace carbon fibre / epoxy prepreg. And the panel was manufactured by ATL process. Different from traditional ATL, the distance between two different ply (i.e. ply pitching) is not less than 1mm, but equals to 150mm, which is two times of the tape width. And to disperse the inconstancies in the whole panel, the ply stagger was employed between different ply sets.

There are 10 ply sets in the panel, and the thickness is 8.9mm. It includes two main ply sets and the ply sequences are [60/0/-60] and [75/45/-75/0], respectively. Figure. 1 is the sectional views of the laminate, which shows the ply orientations, fibre translation and some inconsistency. Samples which were 20mm × 175 mm were cut from the panel which has the dimension of 850mm × 650 mm in both X direction and Y direction. The starter crack was introduced into the sample by diamond blade and diamond saw. And to make the crack shaper, three point loading was used. Fig.1 (a) shows the initial crack tip determined by microscope and (b) shows shape of the initial crack by X-ray CT and its corresponding FEM.



(a) (b)

Fig. 1 (a)The section views of the laminate and (b) the location of pre-crack in X-ray CT and FE model



(b) (c) (d)

Fig.2 (a) Displacement calculated by DIC (b) Load-displacement curve (c) the relationship between compliance and crack length and (d) R-curve.

3. Results and Conclusions

The quasi-static tests were performed using an Zwick 50. The span of the specimen is 2L = 140 mm, and the initial crack length is a0 = 39 mm. The crosshead displacement rates ($\dot{\delta} = 0.008$ mm/s) was chosen. The crack propagation was recorded by DIC method. The compliance based method is used to calculate the fracture toughness. And the relationship between compliance and crack length is determined by preloading with a0 varying from 35mm to 65mm. It can be fitted by $C = C + C_3 a^3$. Fig.2 (a) shows the displacement in y direction of SLB sample around the crack tip. And Fig. 2(b) shows the load-displacement curve, (c) shows the relationship between compliance and crack length. The initial fracture toughness at NL point is 0.31 mJ/mm^2. The R-curve increases with crack length which is due to the fibre bridging effect.