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AN ELEMENT TEST SPECIMEN WITH PLY DROPS TO STUDY FATIGUE CRACK GROWTH RATES AT GEOMETRY TRANSITIONS

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ABSTRACT

Many advanced lightweight composite structures, such as wind turbine blades, have often a complicated shape, including variable thickness, to optimise aerodynamic efficiency and reduce weight. In composite structures, the varying thickness is achieved by terminating or dropping off plies (ply drops) [1,2]. Ply drops, however, result in material and geometrical discontinuities along composite structures, which induce stress concentrations. Cracks can be potentially initiated at these ply drop sites and evolve to delaminations which can propagate under service loading [3,4] severely reducing the load carrying capability of composite structures.

Tapering of laminates can be realised in many different ways [5] and several studies have been carried out to find the optimal ply drop design. Efficient ply drop designs, e.g. using chamfered plies [6], can significantly delay the occurrence of the delamination initiation. However, once a delamination initiates, then its growth rate under cyclic loading is critical for the integrity of the composite structure.

An element test specimen with several ply drops is used (see Fig. 1) in the present study to investigate damage initiation from a ply drop and its propagation under cyclic loading. The use of an element test specimen, which includes design features (ply drops), can replicate the damages modes of a real composite structure but at the same time more insight to the damage mechanisms can be gained.

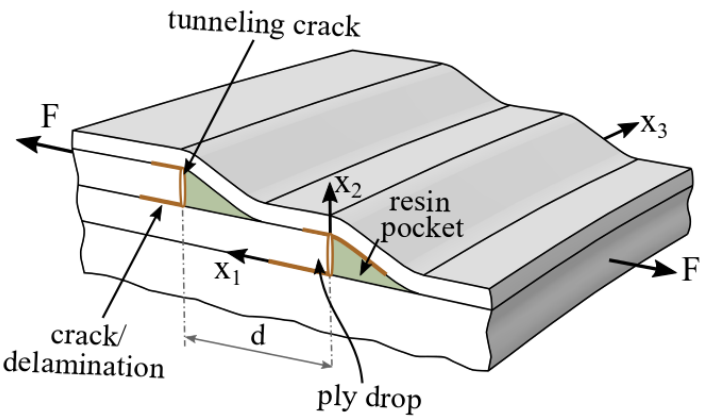

Figure 1: Schematic illustration of an element test specimen showing two ply drops and the possible cracks that can occur under loading.

As can be seen from Fig. 1, both tunnelling and delamination cracks can be potentially formed at the material interfaces. The sequence of damage initiation and propagation will be reported based on optical observations of the ply drop specimens during tension-tension cyclic loading. A schematic illustration of the test set-up is shown in Fig. 2. Photographs were taken at certain number of cycles of the surface of specimen (x_1-x_3 plane – see Fig. 2) and from these images, the delamination crack length could be measured. It will be shown that tunnelling cracks appear very early at the ply drop

locations. Then, delamination cracks initiate from these tunnelling cracks (see Fig. 1). By using specimens with more than one ply drop, as it is commonly reported in literature, it is possible to study the geometry (thickness) effect of the cyclic delamination crack growth rate. It will be shown, that all delamination cracks shown in Fig. 1 will arrest during cyclic loading (each delamination at different number of cycles), except the delamination, which is deepest inside the ply drop specimen.

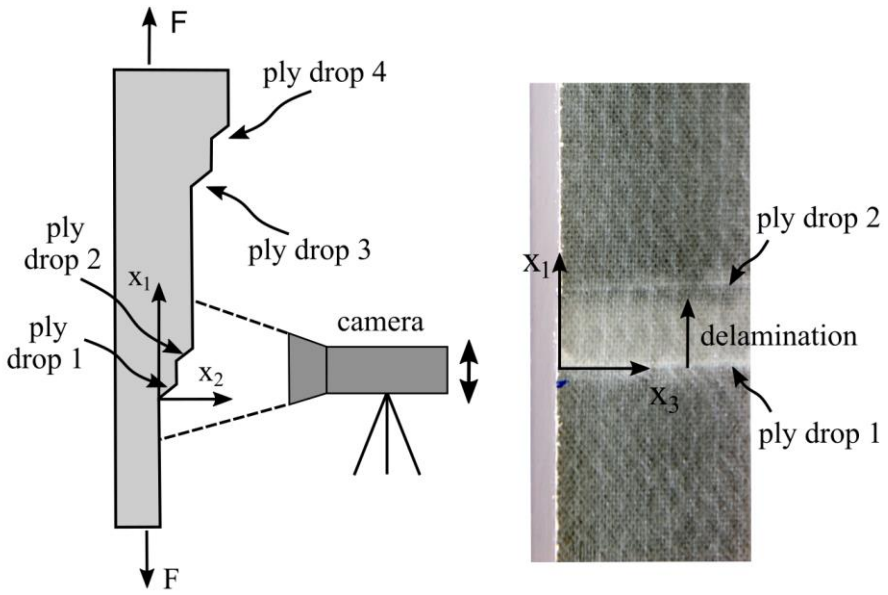

Figure 2: Schematic illustration of test set-up to monitor the damage initiation and propagation under cyclic loading.

When this delamination crack grows further away for ply drop 2 (see Fig. 2), the thickness of the specimen is constant and thus the delamination crack growth rate can be measured for different applied stress levels. It will be shown that in this region (away from ply drops 2 and 3), the delamination growth rate is constant and thus the element test specimen is a steady-state specimen able to provide accurate delamination crack growth rates that can be used in modelling to assess the delamination extension in a real structure.

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