Delamination and matrix cracking in L-shaped cross-ply composite laminates under four-point bending

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Abstract

New advances in composite manufacturing technology and high demand of light weight structures are fostering the use of composite laminates in a wide variety of shapes as primary load carrying elements. In this context, L-shaped composite laminates start to replace metallic counter-parts in aerospace and wind energy industries. The L-shaped geometry is frequently encountered in aerospace applications as flanges of ribs/spars in aircraft wings and in wind energy applications as corners of turbine blade spars. These L-shaped structural components made from composites exhibit a relatively brittle behavior and poor damage resistance when they are subjected to tensile, compressive or mixed-mode loading conditions, which may present critical issues for their implementation, with potentially catastrophic consequences. It has been analytically shown that once a moderately thick laminate takes a curved shape, the matrix failure appears within individual plies in addition to the well-known interlaminar delamination between neighboring plies. The transverse matrix cracking and interlaminar delamination in L-shaped cross-ply composite laminates have been studied by the experiment and finite element (FE) method in this paper.

A four-point bending test (ASTM Standard D6415/D6415M, 2006) has been performed to provide a pure bending moment for L-shaped specimens. Three laminate stacking sequences [010] s, [90/03/902/03/90] s, and [903/0/903/0/90/0] s were designed with the intention of isolating different modes of failure. Among them, the stacking sequence [90/03/902/03/90]s, trends to highlight the transverse failure mode, while the stacking sequences [010]s, and [903/0/903/0/90/0]s trend to highlight the delaminate mode.

In order to model the crack initiation and growth behavior, a numerical method was developed for this current study using cohesive elements with traction-separation damage criteria. Cohesive elements have been inserted between the interfaces of every neighbouring element along the fibre orientation for all 0° and 90° plies to predict the matrix cracking and splitting at predetermined crack spacing based on experimental observations.

The simulations and experiments are found to be in good agreement at the macro-scale in terms of load-displacement behavior, and at the meso-scale in terms of delamination initiation location and crack propagation path. The proposed numerical method has thus proved to be a valuable tool in modelling transverse matrix cracking and delamination in L-shaped laminates and for understanding the damage mechanisms in composite laminates.

Keywords: Delamination; Transverse Crack; Four-point bending; L-shaped; Cohesive Zone Element.