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Computational investigation of both intra-laminar matrix cracking and inter-laminar delamination of curved composite components with cohesive elements

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Abstract

Curved composite components are widely used in engineering applications, such as aircraft wing spars, and subjected to complex 3D loadings. The most critical failure mechanisms of the curved parts are intra-laminar matrix cracking and inter-laminar delamination. A computational approach has been proposed to explicitly model the intra-laminar matrix cracking and inter-laminar delamination in L-shaped cross-ply laminates with cohesive elements. Zero-thickness cohesive elements with a mixed-mode traction-separation damage law are inserted in each 90° lamina to predict matrix cracking and also inserted between neighboring plies to account for inter-laminar delamination. Two laminate stacking sequences with distinguished features of isolating different modes of failure have been investigated. The simulation results confirmed that stacking sequence $[0/90_3/0_2/90_3/0]_s$ trends to highlight the matrix failure mode, while the stacking sequence $[0_3/90/0_3/90/0/90]_s$ trends to highlight the delamination mode. The kinking cracking across 90° plies accompanying the delamination-dominated failure mode during the subsequent crack propagation can be also predicted. The computational results have been compared with the corresponding experimental observations reported in the literature. The good agreement with the reported experimental results verified the capability and effectiveness of computational modelling approach.

Keywords: L-shaped, Matrix cracking, Delamination, Cohesive elements, Stacking sequence, Kinking cracking.

1. Introduction

Along with high demand of light weight structures and considerable progress in composite technology, advanced fiber reinforced composites due to their high strength and high stiffness have been used in a wide variety of engineering applications as primary load carrying components [1]. Curved composite components commonly used in commercial aircraft structures such as spars and ribs as well as fuselage panel to frame connection angles [2] which are subjected to complex loading exhibit a relatively unique mechanical behavior and poor damage resistance. It is therefore of critical importance, in particular for certification of commercial aircraft, to be able to predict where and when such components will suffer damage as well as how the damaged region evolves under continued loading to ensure structural integrity and safety [3].

Damage in such curved composite components may be a complex progression involving intra-laminar matrix cracking, inter-laminar delamination, and fiber failure [2]. In general matrix cracking and delamination are the main initial forms of damage in advanced laminated composite components due to the resin dominated characteristics [4]. The transverse matrix cracking in off-axis plies of a laminate usually does not give rise to ultimate failure but can reduce the stiffness and strength of composites and lead to other damage modes such as delamination. Consequently, delamination may result in fiber breakage in the primary loadbearing plies [5] and lead to the loss of the load-carrying capacity of the whole laminated components. Therefore, there are some interaction between the intra-laminar matrix cracking and the inter-laminar delamination during the damage initiation and crack propagation of laminated composite components. Thus, it is crucial to understand the damage mechanisms and critical failure modes of intra-laminar matrix cracking and inter-laminar delamination and their interactive effects on load-carrying capability of curved laminated composites.

Intra-laminar matrix cracking and inter-laminar delamination in L-shaped laminates have been observed experimentally [3, 4, 6-8]. Sun and Kelly [4] performed sets of experimental studies in which L-shaped

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