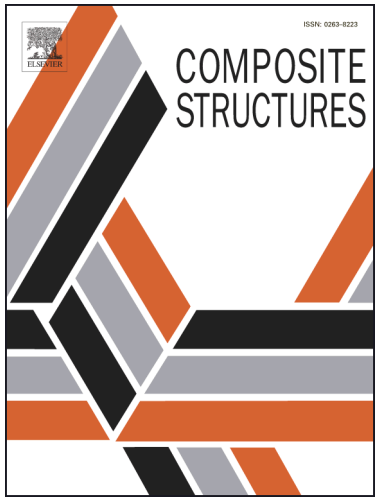

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Open Hole and Filled Hole Progressive Damage and Failure Analysis of Composite Laminates with a Countersunk Hole

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Abstract

Countersunk holes are used in bolted joints for creating non-protruding smooth surfaces. As a first step towards a detailed progressive damage and failure analysis of bolted joint configurations, a new model referred to as the Intra-inter crack band model (I2CBM) is used to study open hole tension/compression and filled hole tension/compression progressive damage and failure. The I2CBM is a unified approach for modeling intralaminar and interlaminar progressive damage and failure in polymer matrix composites. 3D finite elements in the I2CBM formulation can be adapted for modeling individual lamina elements or to model interface delamination elements. A path for communication between the intralaminar and interlaminar failure mechanisms is enabled in the model to overcome limitations associated with homogenized element modeling and to capture complex interactions in a physically correct manner. A non-local crack spacing method is implemented for tracking matrix cracks. Comparisons between test results and I2CBM prediction for the open hole tension/compression and filled hole tension/compression cases with a countersunk hole configuration are discussed. The effect of bolt pretension on the filled hole failure analysis case is also presented and the failure mechanisms are discussed.

Keywords:
Composite laminates, Progressive failure analysis, Virtual testing

1. Introduction

Progressive damage and failure analysis (PDA) of multi-bolt joints that connect fiber reinforced laminates is a computationally challenging task due to a number of competing material and geometric nonlinearities including effects of interaction between different mechanisms of failure, [1, 2, 3, 4, 5]. Because of this, the development of new methods require tackling simpler problems that include features found in a multi-bolt joint. Recent studies related to progressive failure modeling of composite laminates including open hole and impact damage analyses have been reported in [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. A virtual testing framework for composite laminates is presented in [17]. The I2CBM model presented here is also intended to be used as a virtual testing platform for composite laminates. Distinguishing features of the model are highlighted in the following sections. Importance of using ply-by-ply fiber aligned meshing strategy is also highlighted in [15, 17]. This work focuses on the application of the I2CBM model to address problems associated with bolted joints. The modeling approach is validated against open hole and filled hole loading cases.

Experimental results from open hole and filled hole laminates subjected to remote tensile and compressive loading are used to motivate the development of the I2CBM model. The following effects are identified and studied systematically; (a) Effect of stress concentration due to a hole: Open hole tension and compression cases are standard ways of verifying that the PDA method can account for this. A countersunk hole simulation has additional challenges due to the 3D stress state around the hole. This can also produce local out of plane displacements complicating the failure

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