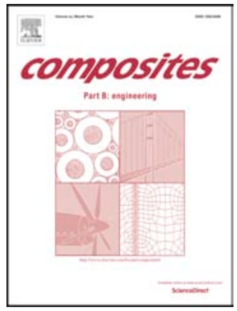

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Progressive Failure Analysis of Three-Dimensional Woven Carbon Composites in Single-Bolt, Double-Shear Bearing

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Abstract

A three-dimensional progressive damage model has been developed to capture the onset and initial propagation of damage within a three-dimensional woven composite in a single-bolt, double-shear joint. Reinforced with a three-dimensional woven ply to ply interlock IM7 carbon fiber preform impregnated with toughened epoxy resin and manufactured using a resin transfer molding process, the composite represents a unique material currently used in select aerospace structures. The modeled joint is commonly found in many aerospace structures and, when combined with the progressive damage response of this three-dimensional woven composite, the material response can be reliably predicted with a three-dimensional non-linear finite element model. This model is constructed using an orthotropic material assumption far from the bearing area and a voxelized mesoscale model with an as-molded geometry representing matrix and impregnated tow phases. The well-established Hashin failure criteria and the Matzenmiller-Lubliner-Taylor damage model were implemented with the unique morphology of three-dimensional woven composites. The onset of damage and trends seen in the model were found to be in agreement with previous experimental findings.

Keywords: A. 3-Dimensional reinforcement , A. Polymer-matrix composites (PMCs) , C. Damage mechanics , C. Finite element analysis (FEA) , Bolted joints

1. Introduction

Three-dimensional (3D) woven composites are used in a variety of aerospace structures. Some of the current applications include fan blades and casings from the CFM International Leading Edge Aviation Propulsion (LEAP) engine, the LiftFan from the Rolls-Royce F-35 Lightning II and landing gear braces from the Boeing 787-8 Dreamliner. Three-dimensional woven composites are attractive alternatives to composites with traditional two-dimensional fiber reinforcement. In addition to improved fracture toughness, notch sensitivity and impact resistance [1, 2], three-dimensional woven composites feature near net shape preforming. That is, dry fiber preforms are woven into shapes very similar to the final part geometry. This feature alone has been found to result in reduced material scrap and fabrication labor all at a lower cost [3]. Delamination is effectively eliminated as a potential failure mode because fiber reinforcement is included not only in-plane but also in the through-thickness direction. Three-dimensional woven fiber preforms and composites can be tailored to specific applications. The three-dimensional woven composite discussed in this paper is representative of a typical aerospace composite with three-dimensional fiber reinforcement.

To support expanded use of these unique composites beyond their current applications, an extensive laboratory investigation was conducted to capture the physical material response when subjected to tensile, compressive and shear loading [4]. Efficient bolted joint design requires an in-depth understanding of the bearing behavior of the joined materials. Three-dimensional woven composites have been experimentally evaluated in single-bolt joints in both single-shear and double-shear configurations [5, 6]. To enhance this understanding and to support joint design, a numerical prediction tool is needed. This paper describes the development and validation of a progressive damage model for predicting the behavior of composites reinforced with a three-dimensional woven ply to ply preform in single-bolt, double-shear joints. Experimental investigation of three-dimensional woven composites revealed a complex state of bearing damage and failure that included interaction between different tows and matrix material that challenges the classic understanding of bolted bearing