Virtual Testing of Composites: Opportunities and Challenges

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1 Abstract

The design of lightweight composite vehicle structures, for example airframe structures, relies on extensive testing, coupled to a bottom-up, pyramidal building block approach, to ensure structural integrity and damage tolerance. Reducing the number of tests can lead to a substantial decrease in total design cost of many vehicles. Cost reduction is enabled by developing high fidelity computational models which can provide valuable information regarding the performance of a structure up to and including failure, provided the modeling is based on material parameters that can be measured, and is validated using laboratory tests that are designed to be discriminatory. This activity, which is now a major area of research falls under the broad umbrella of “virtual” testing, and also includes parallel activities such as ICME (integrated computational materials science and engineering), and “digital twin” (the process of creating a high fidelity computational model of individual aircraft, to integrate computation of structural deflections and temperatures in response to flight conditions, with a depository of local damage evolution so that the “state” of the vehicle is updated and current at any given time). In this talk, the author will propose a ply level, mesh objective, finite element model for laminated composites that can be used in ICME and “digital twin” activities of aero-composite structures. The material parameters that are needed to execute the model and how these can be measured using coupon level samples will be discussed. Validation of the model through open hole tension and open hole compression tests of large structural panels will be presented. Finally, the many opportunities available to extend the model using multi-scaling strategies will be discussed and the many challenges that one encounters will also be presented. The finite element model development relies on modeling each lamina as a damaging layer, where the damage is primarily due to matrix degradation occurring because of microcracking and transverse cracking, Talreja (1985). This leads to a softening response under transverse tension-compression combined with shear. This degradation is captured through a thermodynamically based damage mechanics theory introduced by Schapery (1990), referred to as ST. The ST formulation, has been used before to model progressive damage in postbuckled panels, Basu et al. (2007), and is extended here to include ply failure due to fiber fracture, matrix splitting and matrix shearing leading to shear cracking (EST), in Pineda and Waas (2013). Under multi-axial stress states, the stress response at the local level leads to a downturn, resulting in a locally negative tangent stiffness. The onset of this loss of positive definiteness in the tangent stiffness is captured through a transition from a continuum to a non-continuum (NC) response of the ply. The NC response is modeled utilizing Bazant’s crack band model, Bazant and Oh (1983), with characteristic fracture length scales that in turn are related to characteristic finite element lengths, thus leading to mesh objective renditions of the local NC response. During this progressive devel-
opment of damage, there are regions within a lamina that are in the NC regime and also in the continuum regime depending on the local tangent stiffness. Just as an appropriate stress-strain relation is used to characterize continuum response, a traction-separation relation is used to characterize the NC response. The NC response thus requires appropriately defined toughness and strength measures that capture the failure mechanisms of fiber tensile fracture, fiber compressive fracture, matrix tensile and compressive fracture and matrix shear fracture. In some of these cases, mixed mode laws are needed to effectively simulate the response. In some instances, micromechanics is used to define the onset of NC response and to calculate the toughness values using the constituent material properties, see Pineda and Waas (2013), for details.

A disadvantage of EST is that it is unable to capture details of the failure mechanics within a ply. To address this, multiscaling strategies are developed. Two such approaches use a representative volume element (RVE) of the lamina at the sub-scale. In one case, both the sub-scale problem and the macro-scale problem are solved using the finite element method, while in another case, the sub-scale equations are solved using Aboudi’s generalized method of cells, Aboudi et al. 2001, while the macro-scale is solved using the finite element method. In each of these instances, there is a need to maintain mesh objectivity at each scale and to tie in the characteristic physical length scales at each scale to the geometric length scales that are appropriate to the discretization that is specific to a particular method. In this presentation, results from open hole tension and open hole compression tests of laminates will be used as the basis to discuss the advantages and disadvantages of the EST and multiscaling strategies for progressive damage and failure of laminates within the broader framework of virtual testing.

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3 References


