Computationally-efficient multiscale models for progressive failure and damage analysis of composites

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A class of computationally-efficient tools to undertake progressive failure and damage analysis of composites across scales is presented. The framework is based on a class of refined one-dimensional (1D) theories referred to as the Carrera Unified Formulation (CUF), a generalized hierarchical formulation that generates a class of refined structural theories through variable kinematic description. 1D CUF models can provide accurate 3D-like stress fields at a reduced computational cost, e.g., approximately one to two orders of magnitude of degrees of freedom less as compared to standard 3D brick elements. The effectiveness of 1D CUF models to undertake physically nonlinear simulation is demonstrated through a class of problems with varying constitutive models. The virtual testing platform consists of a variety of computational tools such as failure index evaluations using component-wise modeling approaches (CUF-CW), CUF-CW micromechanics, concurrent multiscale framework, interface, and impact modeling. Failure index evaluation of a class of composite structures underlines the paramount importance of the accurate stress resolutions.

Within the micromechanical framework, the Component-Wise approach (CW) is utilized to represent various components of the RVE. The crack band theory is implemented to capture the damage propagation within the constituents of composite materials and the pre-peak nonlinearity within the matrix constituents is modeled using the J_2 von-Mises theory. A novel concurrent multiscale framework is developed for nonlinear analysis of fiber-reinforced composites. The two-scale framework consists of a macro-scale model to describe the structural level components, e.g, open-hole specimens, coupons, using CUF-LW models and a sub-scale micro-structural model encompassed with a representative volume element (RVE). The two scales are interfaced through the exchange of strain, stress and stiffness tensors at every integration point in the macro-scale model. Explicit finite element computations at the lower scale are efficiently handled by the CUF-CW micromechanics tool. The macro tangent computation based on perturbation method which leads to meliorated performances. A novel numerical framework to simulate progressive delamination in laminated structures based on component-wise models is presented. A class of higher-order cohesive elements along with a mixed-mode cohesive constitutive law are integrated within the CUF-CW framework to simulate interfacial cohesive mechanics between various components of the structure. A global dissipation energy-based arc -length method to trace the complex equilibrium path exhibited by delamination problem. The capabitlies of the framework are further extended through the introduction of contact kinematics to handle impact problems.

A combination of the above tools is used to obtain an accurate material response of the structure in the non-linear regime, from the structural level i.e. macro-scale to the material constituent level i.e. the micro-scale, in a computationally efficient manner, providing a suitable virtual testing environment for the progressive damage analysis of composite structures. The accuracy and efficiency of the proposed computational platform are assessed via comparison against the traditional approaches as well as experimental results found in the literature.