A Virtual Testing Framework for the Analysis of Damage in Composite Structures

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The present work involves the progressive damage analysis of composite structures using refined beam elements based on advanced structural theories, developed within the framework of the Carrera Unified Formulation (CUF) [1]. The main concept of CUF is the use of expansion functions across the cross-section (for 1D beam elements) and thickness (for 2D shell/plate elements) to enrich the kinematics of the element. Such an approach removes the restrictive assumptions associated with classical 1D and 2D finite elements, resulting in a 3D-like accuracy of the solution at a highly reduced computational cost with respect to standard 3D FEA. It is therefore an ideal framework for the virtual testing of failure mechanisms in composite structures, since such a non-linear analysis is extremely computationally expensive.

Various computational tools available in CUF are used to predict the progression of damage within the structure. A multi-scale analysis is performed by considering a representative volume element (RVE) at the micro-scale, where the fibre and matrix are independently modelled using Component-Wise (CW) analysis [2]. The CW approach is based on Lagrange-type polynomials leading to a physically based description of the RVE, which results in a high-fidelity model and correspondingly accurate stress fields. Matrix and fibre failure can thus be detected at the microscopic level, where matrix non-linearities are taken into account using an elasto-plastic constitutive model. Interface modelling capabilities are present, via which delamination and debonding effects can be considered. Delamination is modelled using cohesive elements governed by a traction-separation law. Interface modelling can be extended to the domain of contact mechanics by introducing contact elements, thus gaining the ability to solve a new class of structural 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.

References

[1] Carrera E, Cinefra M, Petrolo M, Zappino E. “Finite element analysis of structures through unified formulation”, John Wiley & Sons (2014).

[2] Kaleel I., Petrolo M., Waas A.M., Carrera E., "Micromechanical Progressive Failure Analysis of Fiber-Reinforced Composite Using Refined Beam Models", Journal of Applied Mechanics (2018), 85.