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Numerical Modelling of Crushing Morphology in Composite Energy Absorbers

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Abstract

The increase usage of polymer composite materials in the aerospace and automotive industry has generated considerable interest in using composite materials for crashworthy structures. Crashworthy structures have the ability to absorb impact energy through a controlled failure in progressive crushing. By tailoring the fibre type, matrix type, fibre-matrix interface, fibre stacking sequence and fibre orientation, composite crashworthy structures have been shown to have excellent energy absorption performance characteristics. Recent studies [1] identified the key factors preventing the introduction of composites in primary crash-resistant structures in aircraft and automotive as the absence of available design guidelines, accurate and inexpensive numerical simulation tools, specialized test methods for the characterization of energy-absorption, accessible and adequate composite material property database. A coordinated cross-organizational effort has therefore been undertaken by the Crashworthiness Working Group of the CMH-17 (Composite Materials Handbook), which comprises representatives from the aerospace and automotive industries, academia, and government laboratories and operates in parallel with ASTM Committee D-30 on Composite Materials. This group is currently developing a standardized test method for measuring the specific energy absorption (SEA) capability of composite materials, and developing guidelines for analytical methods to effectively simulate composite structures under crash loading. The group is coordinating a numerical round robin to compare and benchmark composite constitutive models in the various commercially available explicit Finite Element (FE) codes. The target structures in the round robin FE modelling are a corrugated plate specimen, featuring three semicircular repetitive units, followed by a composite box beam under axial crush loads. The trigger mechanism is a 45º chamfer, which allows the crushing process to initiate in the highly stressed region at the tip of the chamfer and then develop into a stable crush zone.

In this paper numerical methods are being developed for simulating composite elements such as half tube segments under axial crush loads [2], which will then be applied to the test structures in the Crashworthiness Working Group. Composite materials models have been developed for a commercial explicit Lagrangian FE code PAM-CRASH [3] which was developed for automotive crash simulations with metallic materials. The method adopted here is a meso-scale composite model in which the composite laminate is modelled by layered shell elements. The shells are composed of composite plies assumed to be homogeneous orthotropic elastic or elastic-plastic damaging materials whose properties are degraded on loading by microcracking prior to ultimate failure [4]. In-plane shear ply properties are controlled by matrix behaviour which is irreversible or inelastic, due to matrix cracking and plasticity. Experiments on similar crushing responses at the DLR [5] have shown the critical influence of delamination failures in controlling failure mode and energy absorption in crush specimens. Thus mesoscale FE models were extended to include stacked shell elements for the composite laminate connected through cohesive interfaces as described in [6] for modelling impact failure. This can be described as a 2.5D FE model, where the stacked shell technique allows a composite laminate to split into plies or sublaminates when the cohesive interface fails and delamination occurs. The cohesive interface uses a fracture mechanics failure criterion where, for example, under tensile loads when the interface energy exceeds the critical fracture energy value G_{IC}, then the mode I fracture energy is absorbed and the delamination crack is advanced.

A key feature of the segment FE analysis is to model the chamfer trigger so as to initiate a numerically stable crush process. Studies of crush front morphology indicate that the chamfer trigger bends on contact with the loading plate and initiates a central delamination crack in the segment wall. This then causes splaying of the laminate with a fibre debris wedge, followed by formation of axial fronds resulting from splits in the hoop direction. Numerical triggers were developed to represent the chamfer failure mechanism observed in the experimental tests. The main feature was the addition of a rigid element called a separation wedge which mimics the behaviour of the debris seen in tests that separate the lamina bundles into two distinct portions. In addition to separating the lamina bundles, the wedge introduces hoop stress in the lamina bundles causing axial cracks that create the fronds in the quasi-static crush test by bending the lamina bundles about a radius of curvature. In order to control the extent of separation and hence the length of the central delamination crack length, the contact distances in the contact algorithm for the separation wedge may be varied. Results of an axial crush simulation of a 2 mm thick CFRP segment specimen composed of 7 plies of carbon fabric/epoxy are shown in Fig. 1. The model contains 4 stacked sublaminate shells with 3 cohesive interfaces with ply and delamination data measured at the DLR. The FE model captures the steady crush behaviour seen in tests, with frond formation. Crush force levels and energy absorption also agree well with measured data. Ongoing work is concerned with extensions of the crush model to more complex crash elements including those being studied in the CMH-17 Crashworthiness WG.

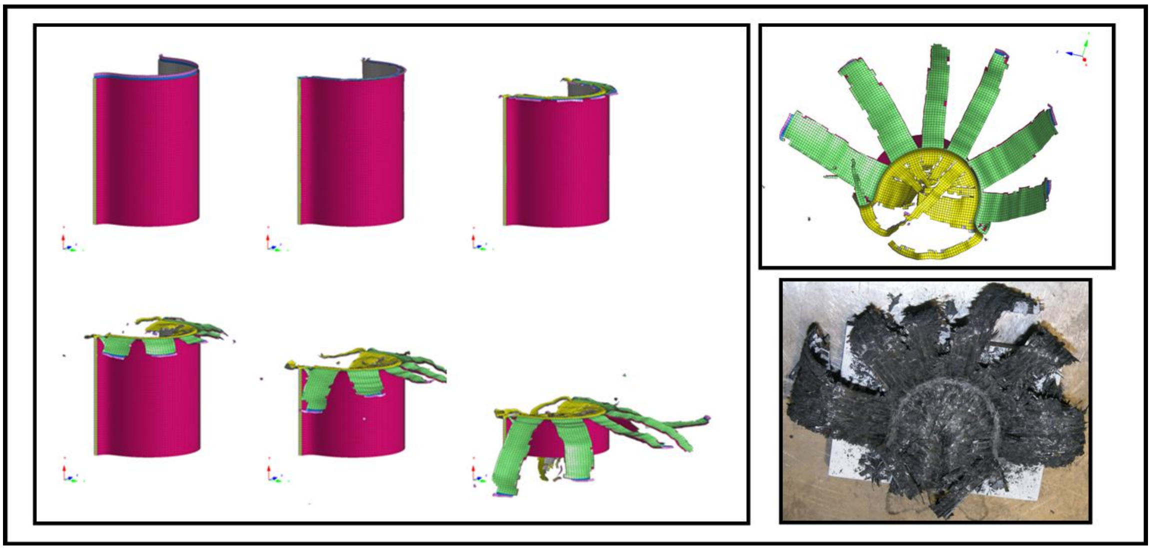

Fig. 1. Numerical representation of the axial crushing process in composite segment specimens

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