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Modelling Impact Damage in Sandwich Structures with Folded Composite Cores

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Abstract

The paper describes FE simulation methods for novel folded structural composite cores being developed for sandwich structures with enhanced performance for use in aircraft fuselage and wing primary structures. Current sandwich materials used in light aircraft, helicopter fuselages and wing secondary structures are particularly vulnerable to impact damage, due to their thin composite skins and low strength honeycomb or polymer foam cores. There is a requirement for sandwich materials for aircraft and vehicle structures with high performance cores for improved impact resistance and crash energy absorption. Folded composite core structures 'foldcore' are fabricated in a new continuous manufacturing process from aramid fibre paper preimpregnated with phenolic resin [1]. Initial folding patterns are a trapeze-form zig-zag geometry, which gives an open cellular structure with a repeating unit cell. The core mechanical properties are controlled by changing the basic cell geometry, the core materials and cell wall thickness. Hybrid composite sandwich panels have been developed and tested in the EU CELPACT project [2] with CFRP skins bonded to foldcore. A feature of foldcore is that it has open cells and sandwich panels can be ventilated, important for aircraft primary structures to prevent moisture accretion in honeycomb cores. To support these materials and structural developments, computational methods were developed in CELPACT based on micromechanics cell models of the core with multiscale FE modelling techniques for understanding progressive damage and collapse mechanisms. The paper discusses the computational models and applies them to analyse the structural integrity of the advanced cellular core sandwich structures under impact load conditions relevant to aircraft structures.

FE models of a foldcore sandwich plate under transverse impact loads were developed and validated by detailed comparison with failure modes and damage observed in low and high velocity impact tests. A foldcore micromodel is used with shell elements attached to sandwich skins modeled as layered composite shell elements, or stacked shells with cohesive interfaces. The foldcore has a repeating unit cell geometry of Belytschko-Tsai shell elements with a 4 ply composite model representing central plies of aramid paper with surface resin plies. Details of the aramid paper model with its folding behaviour and validation by simulation of compression crush tests of the core are discussed in [3]. Under impact loads the skin laminate failure is critical for the prediction of core and sandwich panel failure. The UD composite plies are modeled here by a global ply damage model which includes ply degradation and failure. This mesoscale ply model represents a homogeneous elastic or elastic-plastic damaging material whose properties are degraded on loading by ply microcracking prior to ultimate failure. The formulation follows Ladevèze [4] with a continuum damage mechanics (CDM) formulation where the ply stiffness degradation parameters are internal state variables governed by damage evolution equations. In-plane shear ply properties are controlled by matrix behaviour which is irreversible or inelastic, due to matrix cracking and plasticity. Additionally a fibre fracture criterion based on maximum strains in the ply is superposed for ply ultimate failure and failed element elimination. Impact tests on composite structures at the DLR have shown the critical influence of delamination in controlling local energy absorption and impact penetration for both hard and soft body impactors. Delamination is a through-thickness failure mode and FE panel models suitable for application to impact failure in composite laminates have been

developed based on stacked shell elements for the composite laminate connected through cohesive interfaces, as discussed in [5]. 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 similar model for sandwich skin-core debonding through a tied or cohesive interface may also be included in the model.

In the scope of this work the damage tolerance of different foldcore sandwich structures for low velocity impact was experimentally investigated. A drop tower test programme with a 23.6 kg mass and 50 mm diameter spherical indenter was carried out on supported sandwich panels at impact velocities in the range of 2.2 – 5.8 m/s. A wide range of failure modes was observed, ranging from impactor rebounding from the outer skin, outer skin damage, core penetration, inner skin damage and inner skin penetration. The presence and nature of the impact damage was evaluated on basis of high speed film sequences taken during the impact and computer tomography (CT). Using CT the internal structure and damage in the sandwich cores were quantified. The foldcore tested contained 13 x 52 unit cells giving core diemensions 294.5 mm x 292.8 mm and thickness of 20 mm. The CFRP sandwich skins were composed of 16 UD plies in a quasi-isotropic layup $[45°/90°/-45°/0°/+45°/90°/-45°/0°]_{sym}$ with a laminate thickness of ca. 2 mm. Parameter studies to verify the FE model showed that shell element sizes of 1.5 mm in the foldcore micromodel and the skin laminate gave good results with stable computations. The CFRP skins were modelled by 4 stacked shells of sublaminates with 3 cohesive interfaces to represent delamination failures. DLR delamination test data were available composite prepreg material used here and the delamination model was validated by simulation of mode I and mode II delamination tests, as discussed in [5]. Figure 1 shows typical computations of impact damage for the case of a 3.4 m/s normal impact with impact energy of 138 J, which is compared with CT images of the damaged sandwich panel after the test. In this test the impactor penetrated the top skin laminate crushed into the foldcore, which absorbed impact energy then the impactor rebounded without damaging the inner CFRP skin. The simulation predicts failure mode very well and also gave good agreement to measured peak forces and energy absorption. Both test and simulation show how localised the impact damage is in sandwich structures with foldcore away from the contact point relatively undeformed, in contrast to typical stringer stiffened composite panels where skin/stringer debonding damage is found away from the impact position due to wave effects.

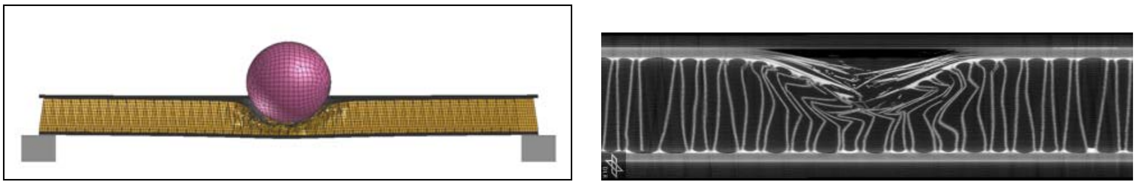

Figure 1: FE model of impact damage compared with CT scans of impacted sandwich panel

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