Composites: Part A 57 (2014) 16–26

Contents lists available at ScienceDirect

Composites: Part A

journal homepage: www.elsevier.com/locate/compositesa

Modelling the impact behaviour of sandwich structures with folded composite cores

S. Kilchert *, A.F. Johnson [1], H. Voggenreiter

Institute of Structures and Design, German Aerospace Center, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

ARTICLE INFO

Article history:
Received 27 March 2013
Received in revised form 23 October 2013
Accepted 29 October 2013
Available online 8 November 2013

Keywords:
B. Impact behaviour
C. Finite element analysis
D. Mechanical testing

ABSTRACT

The European aircraft industry has strong interest in novel structural concepts for future aircraft fuselage with lower fabrication costs and high performance. A critical safety issue for the design of aircraft structure is vulnerability and damage tolerance due to foreign object impact. This paper focuses on the improvement of modelling techniques for foldcore sandwich structures with composite skins under low velocity impact. A new modelling approach for the foldcore cell wall material – aramid paper – is presented, which considers the aramid papers inhomogeneous nature in the thickness direction. In combination with in-ply continuum damage mechanics and a cohesive delamination interface for the modelling of the composite surface skin the proposed modelling approach is used to reproduce drop tower impact tests performed at various impact velocities. Results and interpretation of the numerical and experimental work are presented. The strengths and weaknesses of the presented modelling approach are discussed and evaluated.

1. Introduction

The application of composite materials in modern aircraft structures has grown steadily with each generation of aircraft. Existing composite aircraft structures adopt conventional design principles of skin/frame/stringer developed for aluminium lightweight construction. Current research is focusing on integrated design concepts which factor the different properties of composites. A promising approach for a next generation aircraft fuselage are twin-walled sandwich structures which provide improved shell bending stiffness and far higher strength/weight ratios than single skin designs [1].

However, sandwich structures are vulnerable to impact loads due to their reduced skin thickness and low core strength. As a result they are mainly limited to secondary structures as impact safety is a critical aspect of the design of primary aircraft structures. Therefore the improvement of their impact resistance is considered critical.

The importance of the impact properties of sandwich core materials was shown in the EU Project CELPACT [2], which investigated a range of advanced core materials with improved impact characteristics. Honeycomb cores are the most well-known cellular core type and they provide an excellent ratio of strength to weight and remarkable kinetic energy absorbing properties [3]. In CELPACT it was found that a particularly promising sandwich core material was foldcore (Fig. 1), which is an open cell core type. Foldcores have recently drawn considerable research [4–8], as compared to honeycomb cores they demonstrate similar mechanical properties but offer advantages such as lower moisture accumulation [9] through the ventable open core, and a more cost-efficient production process [10].

In order to investigate the impact behaviour of foldcores and in particular to allow insight into the different mechanisms of energy absorption in the complex interaction of core and skin a detailed modelling approach is necessary. There are two prevalent approaches to represent foldcore/honeycomb sandwich cores in finite element methods.

One is homogenisation, which replaces the cellular core with an equivalent continuum model of three-dimensional solid elements. Through homogenisation the constitutive behaviour of the solid element is adapted to the effective properties measured for the respective cellular core. This approach has been investigated in various publications. Homogenised solid elements to predict the impact behaviour of foldcore and honeycomb sandwich panels were used in [7,11–13]. The honeycomb core was modelled as an orthotropic material uncoupled in the three orthogonal directions with a linear elastic-perfectly plastic material behaviour. It was shown, that a homogenised model is a convenient way to represent the real core geometrically, but it is limited if it is used to model

* Corresponding author. Present address: Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, Eckerstr. 4, 79104 Freiburg, Germany. Tel.: +49 761 2714 303.

E-mail addresses: sebastian.kilchert@emi.fraunhofer.de (S. Kilchert), alastair.johnson@web.de (A.F. Johnson), heinz.voggenreiter@dlr.de (H. Voggenreiter).

[1] Present address: Hildebrandstr. 57, 70191, Stuttgart, Germany.

1359-835X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compositesa.2013.10.023

core damage and failure. The main reason is that in each homogenised element the constitutive behaviour of a foldcore/honeycomb block is implemented, whereas in the finite element (FE) a core element represents only a small part of the block with different locale failure behaviour.

In recent years the increase in computational power has promoted the meso-model approach, which models the core explicitly with shell elements to obtain more realistic distributions of stresses and strains so that local failure by micro-buckling and core material fracture are considered. Impact of rigid spheres on aluminium honeycomb and foldcore sandwich structures was modelled in [14] using an isotropic non-linear elastic–plastic cell wall model. First results showed potential but were abandoned due to excessive computational time consumption. Heimbs et al. [7,15,16] compared explicit simulation and experiment of aramid and carbon composite foldcore crushing and impact behaviour. The folding and kinking cell walls of the aramid paper structure were satisfactorily modelled on basis of an isotropic elastic-perfect plastic cell wall model.

Klaus et al. [17] investigated the residual strength of foldcore sandwich plates. In the numerical approach the material behaviour of the foldcore cell walls was assumed to be elastic–plastic, with a failure criterion based on the maximum plastic strain. Comparison with experimental results showed good agreement in case of low energy-low velocity impact and 4-point bending.

In order to derive geometrical defects Baranger et al. [18] used a foldcore meso-model to simulate the folding process. They reported good agreement with defects observed in actual cores. A comparison between numerical results of a foldcore with thus generated defects and experimental results of foldcore compression showed good coincidence.

A multi-scale method was employed in Buitrago et al. [19] to model an aluminium honeycomb sandwich structure. Here the face sheets were modelled using a fine mesh of solid elements and the honeycomb core was modelled with the shell-based meso-model. Away from the impact location the honeycomb core was represented by homogenised solid elements. Good agreement of experiment and simulation was reported for impact with high velocities.

Lebée and Sab [20] applied the Bending-Gradient theory for thick plates to model foldcore unit cells. They proposed a homogenisation scheme for periodic plates in order to represent sandwich panels. The approach was validated by comparing the homogenised solution to a full 3D simulation of a sandwich panel under bending.

An important advantage of the meso-model approach is, that due to the detailed representation of the cellular core damage initiation and propagation can be modelled accurately up to total failure based on the implemented material degradation and failure mechanisms of the cell wall. A further advantage is that the cellular structure can be directly represented by fold geometry and cell wall material behaviour. Therefore there is no need to determine experimentally the complex constitutive behaviour of cores with different fold geometry.

The above meso-model approaches generally assume homogeneous material properties in the through-thickness direction of the cell wall material. However, in [21,22] an inhomogeneous distribution of fibre reinforcement in the thickness direction was observed for resin impregnated aramid paper, which is a common base material for foldcores, and has an influence on the cell wall tension, compression and bending properties. A new cell wall material model is proposed here in order to capture this inhomogenity which is applied and validated by numerical models for foldcore sandwich structures presented in [4].

The new predictive approach was then used to model high energy blunt impact on sandwich panels with foldcore. To that purpose the carbon composite skins of the sandwich panel were represented by a stacked shell model as presented in [23]. Simultaneously, the impact behaviour of foldcore sandwich panels was investigated on the basis of a drop tower test programme. The setup of the impacted sandwich structures was oriented towards primary aircraft fuselage panel structures investigated in [1]. Results of the numerical and experimental work were used to show the validity of virtual testing by simulation as well as to gain insight into the different mechanisms of failure and energy absorption in core and skin during impact.

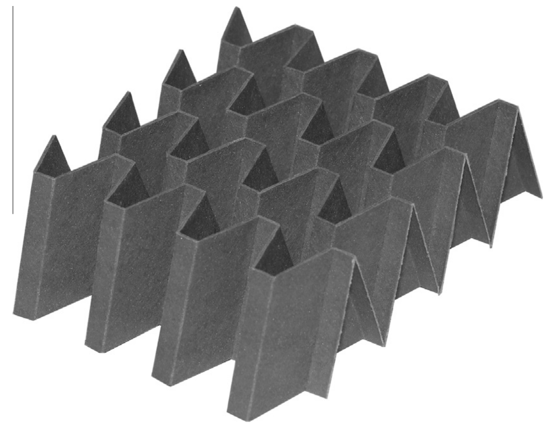

Fig. 1. Foldcore sandwich core.

2. Experimental

2.1. Approach

In the scope of this work the damage tolerance of foldcore sandwich structures for low velocity impact is experimentally investigated. A drop tower test programme was carried out on foldcore sandwich panels with a 23.6 kg spherical impactor at impact velocities in the range of 2.2–5.8 m/s. The foldcore sandwich plates had dimensions 300 × 300 × 24 mm with ~1.8 mm carbon fibre reinforced polymer (CFRP) skins (Cytec HTS/977-2, 16 UD plies quasi-isotropic lay-up). For the tests they were supported on a steel box-section frame giving test plate dimensions of 250 × 250 mm.

It is noted that the performed drop tower tests with ~23.6 kg drop weight and spherical impactor tip usually represent ground impact for example by contact with a vehicle or during baggage handling. This type of low-velocity, high energy blunt impact may also occur during maintenance when a tool or structure drops onto the sandwich panel. It provides a wide range of failure modes depending on impact energy, and thus provides experimental data suitable for detailed validation of the damage models and the FE simulation methods developed in this publication.

The presence and nature of the impact damage was evaluated on the basis of high speed film sequences taken during the impact and computed tomography (CT). Using CT the internal structure and damage in the sandwich cores were quantified.

The aim of the test programme was to determine the critical kinetic energies and impact velocities in foldcore sandwich panels with the 50 mm steel ball impactor to cause various damage states:

- Damage on the outer skin.
- Perforation of outer skin.
- Core damage and penetration.
- Damage on the inner skin.
- Perforation of sandwich panel.