Novel Hybrid Structural Core Sandwich Materials for Aircraft Applications

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INTRODUCTION

The European aircraft industry has strong interest in novel structural concepts for future aircraft fuselage and wing structures with lower fabrication costs and high performance. An important class of these next generation aerospace materials will employ advanced manufacturing techniques for sandwich structures with cellular core materials giving high strength/weight and improved impact resistance under critical aircraft load cases such as foreign object impact from birds, tyre rubber and runway debris. Sandwich fuselage designs are being used now for small aircraft, such as executive jets, and in helicopters or as secondary structures in wing high lift devices. However, these current aircraft sandwich structures are particularly vulnerable to impact damage, due to their thin composite skins and low strength honeycomb or polymer foam cores. The requirement now is new sandwich material concepts for primary aircraft structures, with higher performance low weight structural cores [1].

The paper will present an overview of a new EU project CELPACT [2] whose main objective is the development and design of new cellular materials and twin skinned sandwich structures made from hybrid composites and metals. CELPACT is developing fabrication technology for cellular metals based on selective laser melting of periodic cellular cores and new fabrication concepts for hybrid composite sandwich structures with folded structural composite cores. To support the materials developments, computational methods are being developed based on micromechanics cell models with multiscale modelling techniques for understanding progressive damage and collapse mechanisms for use in structural analysis. Impact performance is critical for sandwich aircraft structures and the simulation tools are being used to design efficient impact resistant aircraft structures. Structural integrity of these advanced cellular structures are being assessed by dynamic materials tests and gas gun impact tests on cellular beam and panel structures under high velocity impact conditions relevant to aircraft structures.

ADVANCED STRUCTURAL CORE MATERIALS

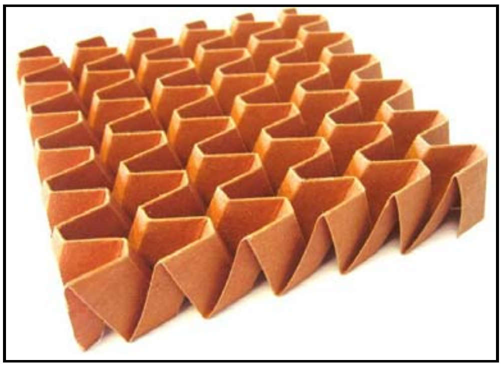

Fig. 1: Aramid/phenolic foldcore material [3]

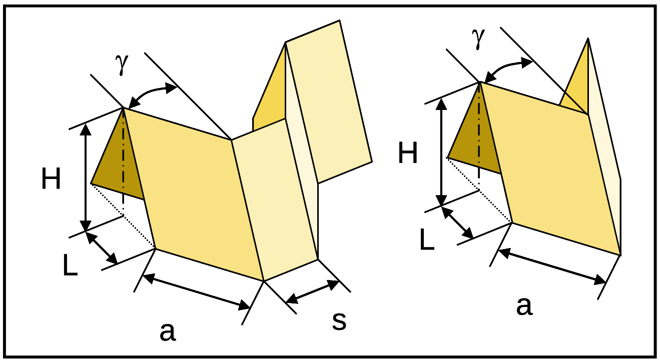

Fig. 2: Unit cell as basis of foldcore geometry and FE core model

Current aircraft sandwich structures are made from CFRP skins with Nomex paper honeycomb or polymer foam cores for low weight secondary structures such as radomes, wing flaps, internal bulkheads, luggage containers, etc. More critical structures with improved energy absorption may have aluminium skins with aluminium honeycomb cores. In all cases the main function of the core is to be low weight, low cost, and stiff enough in shear and compression to maintain the separation distance between the load bearing skins. The developments being considered in CELPACT are new low weight structural cellular cores with enhanced properties made of composites and metals. New folded composite core structures are fabricated in a continuous manufacturing process which is currently under development at the University of Stuttgart [3]. The core material for the initial state-of-the-art cell structures is aramid fibre paper preimpregnated with phenolic resin and thickness ca 0.3 mm. Initial folding patterns are a trapeze-form zig-zag geometry, which gives an open cellular structure with a repeating geometry element, Fig. 1. The core mechanical properties are controlled by changing the basic cell geometry parameters Fig. 2, together with the core material and its thickness. By varying the geometry parameters in Fig. 2 about 30 standard foldcore core materials have been defined using aramid/phenolic core material with core thickness ranging from 10 – 30 mm and core densities from 50 – 200 kg/m³, giving a wide potential range of core mechanical properties. Other composite core materials and cell geometries with glass and carbon fibre fibres are also being evaluated by partners in CELPACT. Hybrid composite sandwich panels have been developed and tested with CFRP skins bonded to aramid fibre foldcore with film adhesive. An important feature of foldcore is that it has open cells and sandwich panels can be ventilated, which is important for aircraft primary structures since there is a problem with moisture accretion in conventional Nomex honeycomb core structures.

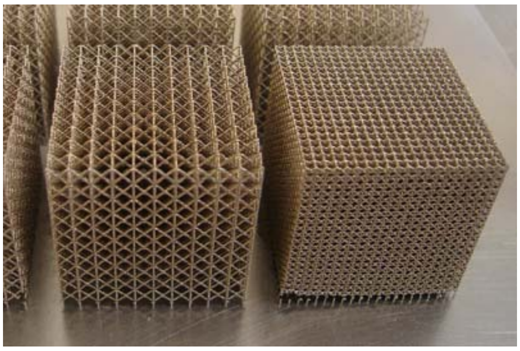

Fig. 3: SLM core material with BCC steel struts [5]

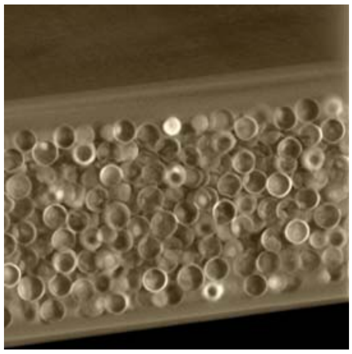

Fig. 4: Core with hollow nickel spheres from ATECA

A second group of advanced cellular materials being studied uses an open lattice geometry cellular metal (CM) core which is being developed at Liverpool University [4]. Fabrication is by selective laser melting (SLM) with stainless steel and titanium as basic core materials. With the rapid prototyping SLM technique, the realisation of metallic open cellular lattice structures at the micro meter scale is possible. In this process a bed of metal powder (particle diameter 15 -30 micrometers) is selectively melted layer by layer by a computer controlled laser. For example, micro lattice structures can be developed with strut diameters of 100 -150 microns, and with aspect ratios from 1 to 100. Fig. 4 shows a body centred cubic (bcc) block manufactured from stainless steel 316L. Sandwich structures with CM cores are being developed with CFRP skins by directly embedding the lattice core into the carbon/epoxy prepreg before curing, which has been demonstrated to provide a strong skin-core bond. Dynamic tests have studied collapse mechanisms in these novel sandwich structures [5] and ongoing studies in CELPACT are concerned with FE modelling of local core collapse and energy absorption. Since a range of different cell geometries can easily be fabricated, with different metals and strut thicknesses, validated FE models are urgently required to design and optimise CM sandwich cores with required properties.

Alternative high performance CM core materials are also under investigation, including closed cell cores consists of hollow nickel spheres typical diameter 2.5 mm, wall thickness 12 microns, close packed and adhesively bonded together with epoxy resin, Fig. 4. Here the aim is to replace metallic foam cores, which have variable geometry due to manufacture with a core of consistent density and spherical pore size. In this case the CM core material is formed into a metallic sandwich panel with bonded aluminium skins and has good impact resistance and could be suitable for aircraft applications such as bird impact protection panels in the front cockpit.

MODELLING CELLULAR CORES

To support the materials developments design analysis studies are being carried out using FE modelling, with parametric core models which permit numerical design and optimisation studies. The models are based on development of parametric unit cell FE models and are vital for identifying cores with suitable properties, since manufacture and test of all the possible foldcores or SLM CM geometries is not practical. Of particular interest for the design of sandwich structures is the computation of core compression and shear performance up to complete core crushing as described in [6] for foldcore materials, and FE models for prediction of impact damage under a range of impact conditions. Examples of the FE core models being developed in CELPACT are described here.

Foldcore compression test

A foldcore sandwich plate was loaded in compression through the thickness by compression between steel plates, which leads first to foldcore microbuckling, followed by element folding then crushing together at final compaction. The compression tests used a foldcore sample Type 31 composed of 5x13 unit cells and supplied by IFB, University Stuttgart. The foldcore geometry, referring to Fig. 2, is given here, where ρ is the core density:

H [mm]	a [mm]	γ [°]	S [mm]	ρ [kg/m^3]
20	12.5	30.5	5	113

A compression model of 3x6 unit cells was modeled to represent the test. Materials tests in tension and compression were performe d on the aramid/phenolic core material and used as a basis of a ply material model with failure in the commercial explicit FE code PAM-CRASH. The foldcore cell geometry was meshed with multilayer-shells consisting of 4 plies with an element side length of 1 mm, with constant loading rate applied of 0.2 mm/ms. Because damage initiation is caused by shell buckling, experience has shown that regular FE meshes are not appropriate so the node positions were randomly distorted in a range of -0.5 to 0.5 mm via node shaking to represent geometrical irregularities.

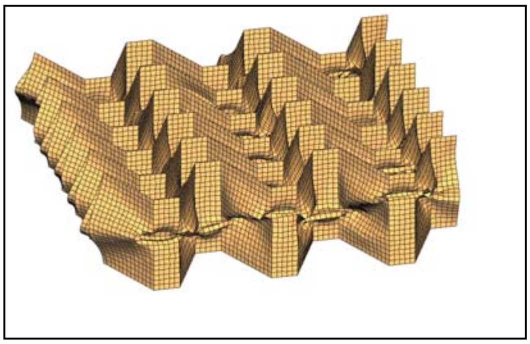

Fig. 5: Foldcore model in compression at 15% strain

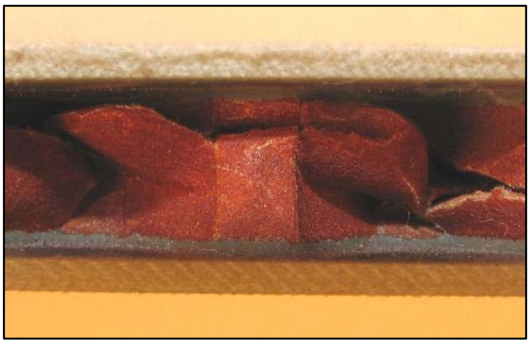

Fig. 6: Failure mode observed in compression tests

Fig. 5 shows the failure pattern simulated at 15% compression strain. The initial cell wall buckles form sharp kinks at the stiffer folded corners, leading to extensive contact, friction and then local fracture and tearing of the aramid plies. This type of failure pattern is also observed in test, Fig. 6. For a quantitative evaluation of the FE model, Fig. 7 compares measured and predicted compression stress-strain behaviour. Both experiment and simulation perform elastically until a sharp peak load, when shell buckling leads to a collapse of the foldcore. The stress magnitude at peak is lower for the experiment compared to the simulation. The stress-strain curve indicates a reasonable agreement within the collapse zone, which is for the most part dominated by buckling and kinking before final compaction begins at about 60% strain. However, at strains above about 30% the FE model underestimates the crushing stress. This difference was attributed to the use of element elimination at failure in the simulation and absence of suitable friction models, which leads to a lower compaction stress at large strains.

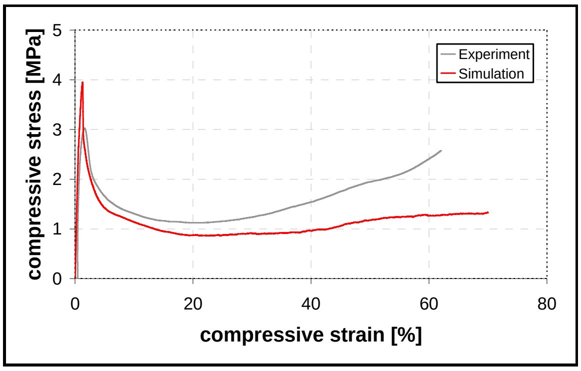

Fig. 5: Stress-strain behaviour of foldcore type 31 in compression

Impact damage in steel microlattice core

A series of indentation and low velocity impact tests with spherical indenters were carried out by Liverpool University on an SLM bcc microlattice structure and indentation depth measured for different impact energies [5]. This data has been used to validate detailed FE models of the microlattice core structures in the explicit FE code LS-DYNA. The cell size is 2mm with a strut diameter of 200 microns. The material is Stainless Steel 316L. Each micro strut has been modelled with three beam elements. A microtest fixture was used to measure the tensile properties of the SLM struts to provide data for an elastic-plastic model. Failure of beam elements is characterised by plastic strain to failure value obtained from stress-strain plot of lattice strand uni-axial tensile test data. The beam micromechanics of failure is highlighted by Fig. 6, with bending or buckling of the strands, followed by tensile loading of strands as they are pulled into the damage zone, then finally local compaction. Fig. 7 shows the predicted indentation in the test at 2.1 J impact energy. There is excellent agreement between the numerical model and experiment in terms of the localised indentation damage spreading to the surrounding lattice at increasing displacements. The trend of the load-displacement curve is also in good agreement with experimental results. These initial results show that the FE models are suitable for design of improved core structures with specific energy absorption capabilities.

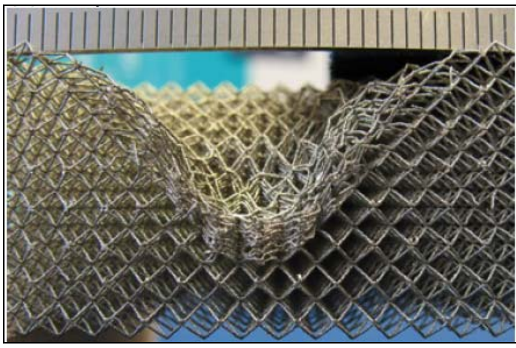

Fig. 6: Damage in SLM steel lattice core at 2.1 J impact

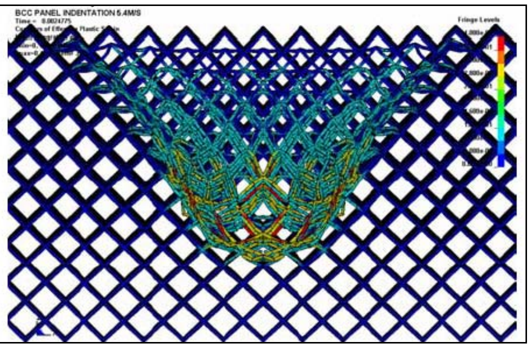

Fig. 7: FE simulation of core failure in impact

Acknowledgement

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References

[1] R. Kehrle, M. Kolax, “Sandwich structures for advanced next generation fuselage concepts”, *SAMPE Europe Conference*, Toulouse, September 13-14, 11-16, 2006.

[2] CELPACT, “Cellular structures for impact performance”, EU Research Project, FP6-031038, 2006-2009.

[3] K. Drechsler, R. Kehrle, “Manufacturing of folded core-structures for technical applications”, *25th International SAMPE Europe Conference*, Paris, 508-513, 2004.

[4] R.A.W. Mines, “On the characterisation of foams and micro lattice materials used in sandwich construction”, *Strain*, **44**/1, 71-84, 2008.

[5] R.A.W. Mines, S. McKown , W. Cantwell, S. Tsopanos, W. Brooks W., C.J. Sutcliffe, “On the progressive collapse of micro lattice structures”, In *ICEM13* (Ed. E.E. Gdoutos), Paper No.158, 2007.

[6] S. Heimbs, P. Middendorf, S. Kilchert, A. F. Johnson, M. Maier, “Experimental and numerical analysis of composite folded sandwich core structures under compression”, *Applied Composite Materials*, 14, 5-6, 2007.