Investigation of the structural integrity and stability of steel foam sandwich panels

Dr Stylianos (Stelios) Yiatros
Marie Curie Intra-European Fellow at the Centre of Offshore Renewable Energy Engineering, Cranfield University, UK (s.yiatros@cranfied.ac.uk)

Prof. Feargal Brennan
Director of Energy, Head of Offshore Renewable Energy Engineering, Cranfield University, UK (f.brennan@cranfield.ac.uk)

INSIST
INVESTIGATION OF THE STRUCTURAL INTEGRITY AND STABILITY OF STEEL FOAM SANDWICH PANELS
A MARIE CURIE IEF (FP7) PROJECT

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Introduction

INSIST is an EU-funded Intra-European Marie Curie Fellowship within the 7th Framework programme undertaken at the Structural Integrity Lab of the Centre of Offshore Renewable Energy Engineering at Cranfield University in the UK. The aim of the project it to train the researcher in experimental structural integrity and stability and allow him to pursue research in the area of metal foam sandwich structure, including the development of novel and/or smart integrated structural solutions for the (offshore) energy industry. The project commenced in January 2015 and will run for 24 months.

Motivation

Sandwich construction has been very popular in structural design in numerous sectors, ranging from aerospace and automotive to civil and marine structures [1]. Its success has been attributed to the balance of lightweight design and high stiffness, but at the price of potential instabilities in the form of interactive buckling that can greatly reduce the load carrying capacity of sandwich structures in bending or compression.

Metallic foams, manufactured with powder metallurgy methods, can be used as cores in sandwich construction can bring added benefits to lightweight metal structures by mitigating buckling [2,3], damp vibrations, dissipate energy under impact and blast loading and exhibit the usual elasto-plastic behaviour akin to metal but at a much lower weight. Manufacturing of SAS (Steel-Aluminium foam-Steel Sandwich) has been developed at Fraunhofer IWU in Chemnitz and production has been scaled up by Havel Metal Foam GmbH (Fig. 1). Industrial take-up of this material has been slow and this can be attributed to the absence of design guidelines backed by structural integrity and stability testing. This project aims to perform initial integrity and stability testing on SAS panels of different dimensions under monotonic and cyclic conditions. The aim is to generate data for failure maps and S-N curves to calibrate and validate numerical simulations, which will lead to the development of design guidelines.

Furthermore the research project will investigate the stability and integrity of SFSPs with graded cores, made from steel hollow spheres (Fig. 2) produced by Hollomet GmbH, a spin-off of Fraunhofer IFAM in Dresden. The project will build on the experience of the STEELFOAM NSF (USA) project [2-4] which has tested metal foams made from steel hollow spheres. The investigation will see the production of graded density metal foam cores by means of using hollow spheres of different diameters (Fig. 3). These will also undergo monotonic and cyclic testing in bending and compression and will be compared against single-diameter metal foam sandwich configurations. Gradation of properties, is not new and is actually a biomimetic design methodology aiming smooth transition of properties and in this case use density as a design parameter. Analytical work by Yiatros et al [5] highlighted the effect of stiffness gradation by means of density variation in the core of sandwich structures in interactive buckling, while Conde et al [6] reported the benefit of functional grading for lightweight design of sandwich structures using open-cell aluminium foam.

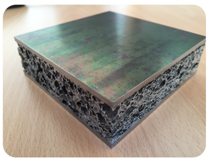

Fig. 1: A sample of SAS, Steel-Aluminium foam Sandwich, produced by Havel GmbH.

Fig. 2: A sample of sintered steel hollow spheres (globomet) produced by Hollomet GmbH.

Fig. 3: A sample with steel hollow spheres of different diameters produced by Hollomet GmbH and bonded together using a resin adhesive.

Planned Experimental Investigation

INSIST is an experimental investigation on the structural integrity and stability of novel steel foam sandwich panels (SFSPs) under monotonic and cyclic loading. The response of single density and graded properties cores will be studied and the differences in the observed failure modes will be quantified. Furthermore the project will explore the response of welded end-plates in steel foam sandwich panels and testing the strength and tolerance of the connection under static load and fatigue. Also a pilot corrosion test will take place in order to observe the failure propagation in fatigue within a corrosive environment (Tab. 1). The experimental set-up will include end compression tests (Fig. 4) and 4-point bending tests (Fig. 5). These tests are essential for the development of design guidelines and will pave the way for the use of SFSPs in structural engineering applications.

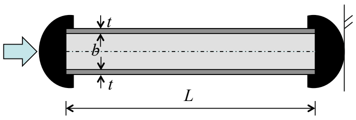

Fig. 4: Schematic of end compression test for sandwich struts.

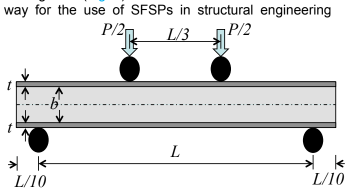

Fig. 5: Schematic of 4-point bending test for sandwich beams, subject to ASTM C273.

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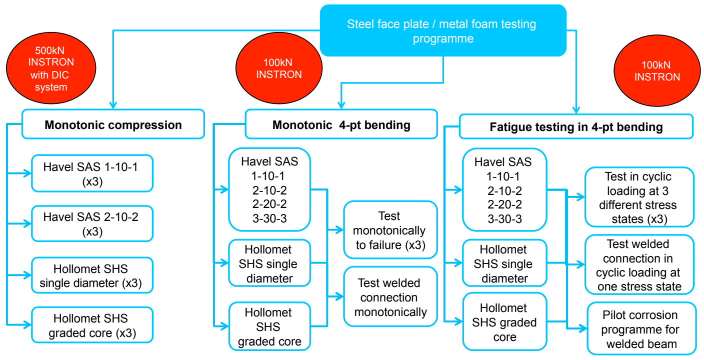

Tab. 1: A flow chart of the testing programme. The tests will comply with relevant testing standards such as ASTM C393, ASTM C394, ASTM G31, ISO 11845:1995, ISO 12107:2003.

Failure Maps

Initial failure maps (Fig. 6) for end compression and 4-point bending of Havel SAS based on published material data [7] and failure criteria reported in Ashby et al [8]. Material parameters will be reviewed and validated upon testing. Data for graded foam from steel spheres will be evaluated upon testing. In both cases, adapted failure maps for fatigue loading will be created.

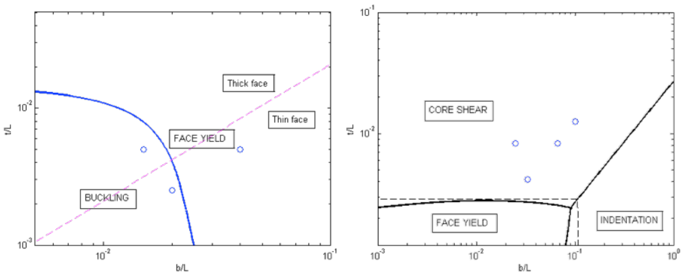

Fig. 6: Left: Failure map for SAS sandwich columns and Right: Failure map for SAS sandwich beams under 4 point bending. Specimen configurations are denoted by 'o'. On the left the dashed line indicates the area of validity of the "thin face plate" assumption, while on the right the dashed lines denote the thin plate approximate interaction equations.

Conclusions & Further Work

The test programme to investigate the stability and integrity of steel face plate/metal foam cores has been presented. The undertaken work will provide testing data for SAS sandwich panels manufactured by Havel GmbH, that will be used for the development of design guidelines. Furthermore a similar testing programme will be followed for bespoke steel foam sandwich panels made of steel hollow spheres manufactured by Hollomet GmbH. Here the investigation will focus on the comparison of SFSPs made of cores with identical steel hollow spheres and SFSPs with graded diameter of SHS in their core, in order to quantify the merits of core gradation in different loading conditions for the different failure modes, including fatigue and adverse environmental conditions.

Moreover, the project seeks to explore biomimetic optimized applications [9] for steel/metal foam sandwich panels in the offshore and marine sector that can perform more than one function, such as weight, vibration damping and even provide data for structural health monitoring purposes. Tapping on the inherent merits of metal foams and their manufacturing processes, which allows the integration of smart services within the panels, the viability of different applications will be quantified such as offshore wind turbine towers or other offshore structural components.

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Cranfield Campus
Centre for Offshore Renewable Energy Engineering / School of Energy, Environment & Agrifood
Whittle Building (52), Cranfield, Bedfordshire, MK43 0AL, UK