MECHANICAL CHARACTERIZATION OF PVC FOAM USING DIGITAL IMAGE CORRELATION AND NONLINEAR FE ANALYSIS

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1 Introduction

Polymer foam cored sandwich structures are often subjected to aggressive service conditions, which may include elevated temperatures. The mechanical properties of polymer foam materials degrade significantly with elevated temperatures, and significant changes in the properties may occur well within the operating range of temperatures. The material properties of foam cored sandwich structures depend on the temperature field imposed, and this is usually ignored in engineering analysis and design. As an example, the thermal degradation problem for wind turbine blades is especially associated with the use of polymer foam cores in the wing shells when these are exposed to high temperatures. This may occur most severely under hot climate conditions, but can also occur in temperate climates. An example would be very high gusting winds increasing on a warm/hot summer day, for instance due to the development of a thunder storm.

Furthermore sandwich core materials may experience multidirectional mechanical stress states. In a conventional sandwich panel the in-plane and bending loads are carried by the face sheets, while the core resists the transverse shear loads. A well known failure mode of such sandwich panels is 'core shear failure' in which the core fails due shear stress overloading. However, although the shear stress is often the main core stress, there are conditions in which the transverse normal stresses in the core are of comparable size or even higher than the shear stresses. Such conditions may occur in the vicinity of concentrated loads or supports and also in the vicinity of geometrical and material discontinuities. Under such condition a material element in the core is subjected to a multidirectional state of stress. Therefore, proper design of sandwich structures requires the characterization of the core material response under multi-directional stress states.

The conventional Arcan test rig has been used to measure the bidirectional properties of polymer foams used for sandwich core materials, especially in the bidirectional tensile-shear stress region [1]. A modified Arcan fixture (MAF) has been developed to characterize polymer foam materials tensile, compressive, shear and bidirectional mechanical properties at room and at elevated temperatures,. The measurements include the elastic constants as well as the complete stress-strain response to failure. Furthermore the MAF enables the realization of pure compression or high compression to shear bidirectional loading conditions that are not possible with the conventional Arcan fixture. The MAF is attached to a standard universal test machine equiped with an environmental chamber using specially designed grips that do not constrain the specimen rotation, and hence reduces paristic effects due to misalignment.

2 Characterisation of PVC Divinycell H100

In this paper the focus is on the characterization of the orthotropic material response of a H100 Divinycell cross linked PVC foam at room temperature, The design of the test setup to be used for testing of polymer foam core materials at elevated temperatures is described. The outcome is a set of validated mechanical properties that will form the basis input for detailed finite element analysis (FEA) studies of the nonlinear thermo-mechanical response of foam cored sandwich structures.

3 Modified Arcan Fixture (MAF)

The standard Arcan testing apparatus can be used to apply bidirectional loading to a butterfly shaped (BS) specimen. Fig.1a shows a standard Arcan test fixture with a circular distribution of the griping holes, which is limited to application of only combinations of tensile and shear loadings. A novel modified Arcan Fixture (MAF) has been designed, which enables the application of any combination of axial (tension or compression) and shear loadings (Fig.1b) by employing a quasi-spiral distribution of griping holes. The MAF provides an S-shaped fixture that consists of two boomerang shaped arms and two specimen tabs bonded to the test specimen in the centre of the fixture. The new apparatus appears as a simple fixture that may be attached to a test machine capable of imposing a tensile load to provide biaxial deformation at different shear to axial deformation ratios by selecting different attachment points on the boomerang shaped arms. Loading is applied through a double sided fork-lug connected to each boomerang shaped arm at one end, while at the other end each arm is connected to a universal joint to compensate for any misalignment in the test machine as shown in Fig. 1c.

4 Experimental technique

The objective of the proposed testing method is to enable determination of the full nonlinear stress-strain response up to failure for a range of temperatures from room temperature up to a possible foam working temperature. The experimental procedure herein is carried out for Divinycell H100 PVC foam at room temperature using Digital Image Correlation (DIC) in a configuration with one camera on either side of the specimen. Images of the strain field derived from the DIC are shown in Fig. 2.

5 Elevated Temperature Test Setup

Extensive experimental core characterisation is being planned at elevated temperatures. The elevated temperature tests will be carried out using an Instron environmental chamber. The specimens will be allowed to equilibrate inside the chamber before testing. The environmental chamber includes a window in the access door, and DIC measurements will be conducted through the window on the front side of specimen. It has been established recently that DIC through a window is feasible [4]. Images will be captured from the front and back of the specimen and 2D DIC setup will be used to establish the strain for on each face of the specimen prior to the elevated temperature testing and establish the symmetry.. After this initial mechanical test the back side camera will be removed and the environmental chamber will be inserted around the MAF rig, and the front camera will be used to acquire images through the environmental chamber window.

To acquire accurate load data from the load cell of the test machine, any heat transfer into the load cell should be restricted. To prevent heat transfer into the load cell, an intermediate isolating connection that can operate up to 200°C has been designed and manufactured (see Fig. 3); it includes an air cooled heat exchanger and a heat isolator made of Delrin polymer. The connecting rod, heat exchanger and polymer isolator have standard connection pins that are compatible with the Instron test machine connection.

Finite element analysis (FEA) has been conducted to analyse the heat transfer through the isolating connector using the commercial FEA package ANSYS 12.1. The FEA steady state simulation included conduction, radiation and convection over the constituent components. Fig. 5 shows that the FEA results predict a reduction of temperature from 200°C in the connection rod to 150°C in the Delrin isolator corresponding to the maximum operation temperature for the Delrin polymer material. The final temperature at end of the isolator is predicted to be about 26°C, which is sufficiently low for safe and accurate operation of the load cell.

6 Numerical strain field corrections

3D nonlinear finite FEA analyses, including both material and geometric nonlinearity, have been conducted using the FE code ANSYS 12.1 to estimate “correction factors” that are used to compensate for the difference between the measured surface field and the inhomogeneous strain field over the specimen cross section. A bilinear approximation of the experimentally obtained nonlinear shear stress-strain curve has been implemented in the nonlinear FEA model. An iterative solution procedure is used to “correct” the material model in the FE analyses until convergence of the derived “correction factor” is achieved (usually only requires 3-5 iterations). The “correction factor” is then used to “correct” the stress-strain response measured on the surface gauge line (see Fig. 2) to obtain the average shear strain on

the whole gauge section. Fig. 4 shows the shear stress field in a butterfly shaped shear test specimen predicted by the nonlinear FEA.
Fig. 6a displays the variation of the calculated strain “correction factor” as a function of the average strain on the gauge cross section. The strain “correction factor” displays it highest values in the linear (elastic) region of the PVC foam material, and as expected it decreases with increasing gauge section strains. The reason for this is that the specimen gauge section undergoes increasing plastic strains that will smooth the strain distribution leading to an almost uniform strain state when specimen fracture occurs. The “correction factor” appears to increase again just before fracture (see data point to the outermost right in Fig. 6a), but this behaviour is believed to be nonphysical and caused by numerical instability in the nonlinear FEA results. Original data obtained from shear testing of PVC H100 foam at room temperature and the corrected stress-strain curve are shown in Fig. 6b.

7 Results and discussion

A set of representative tensile and shear stress–strain curves measured for PVC H100 foam at room temperature is shown in Fig. 7. After an initially linear region, the curves reveal a substantial nonlinear softening response. The in-plane modulus is approximately 48% lower than the through-thickness modulus, and the in-plane strength is about 36% lower than the through-thickness strength. The Young´s moduli are 130 MPa and 67 MPa in the through-thickness and in-plane directions, respectively.

8 Ongoing And Future Work

Work is presently ongoing to characterize the stress vs. strain curves for PVC foam core materials loaded in compression and at elevated temperatures for tensile, shear and compressive loads. In a further continuation of the work the bidirectional properties of PVC foams at both room and elevated temperatures will be also be investigated.

Acknowledgements

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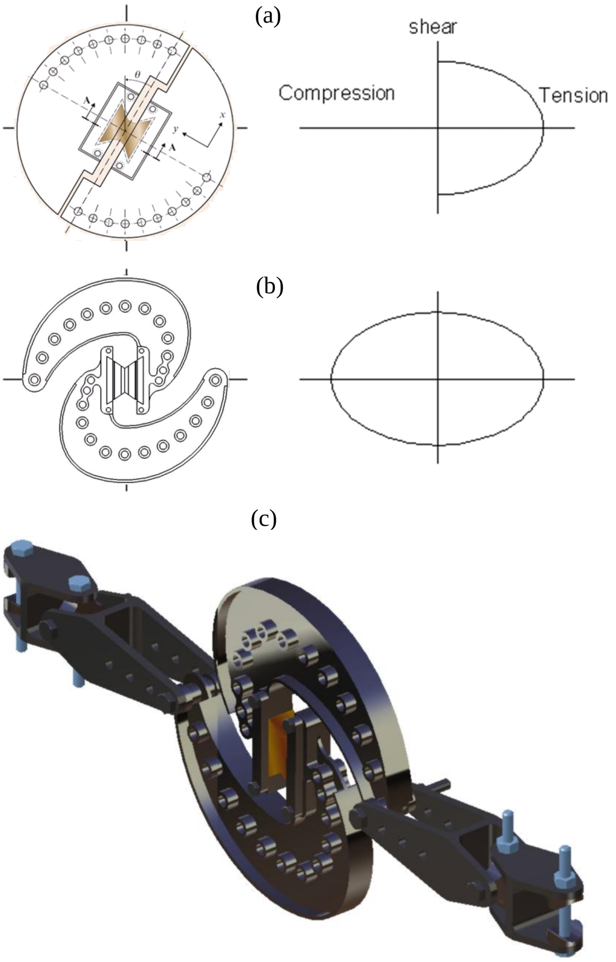

Fig. 1. Bidirectional test rigs: (a) classic Arcan fixture enabling only a tension-shear deformation envelope; (b) Modified Arcan fixture enabling the full range of tension-compression- shear deformation envelope; (c) Schematic of modified Arcan fixture

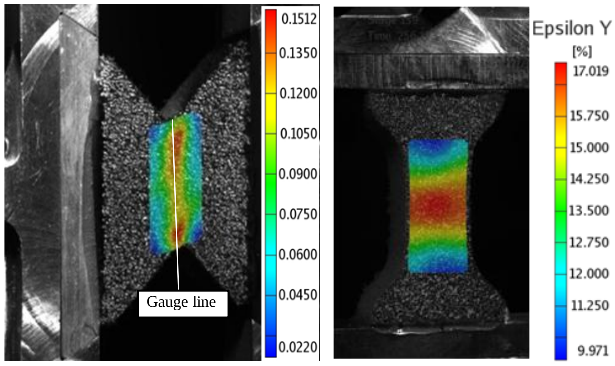

Fig. 2. Shear strains in shear butterfly shape specimen (left) and normal strains in tensile short dog bone specimens.

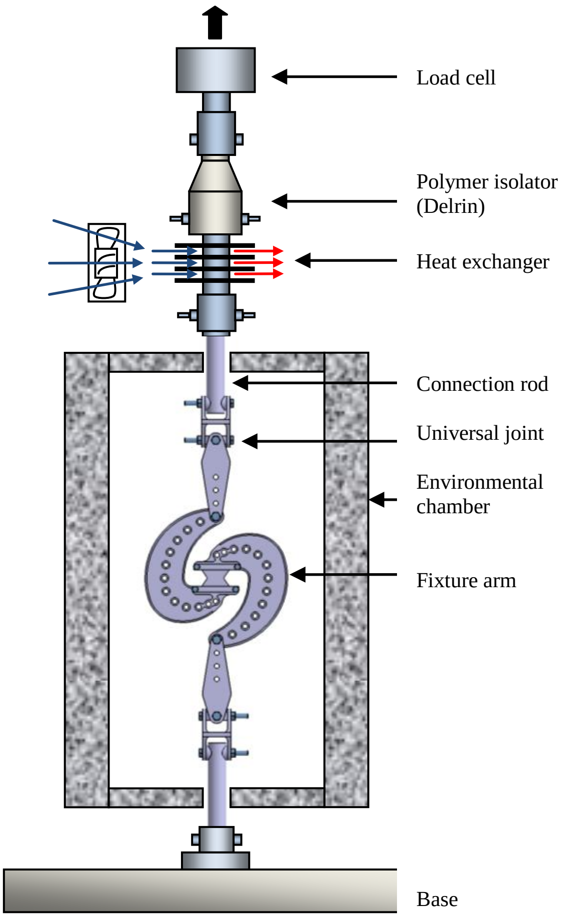

Fig. 3. Test setup for elevated temperatures

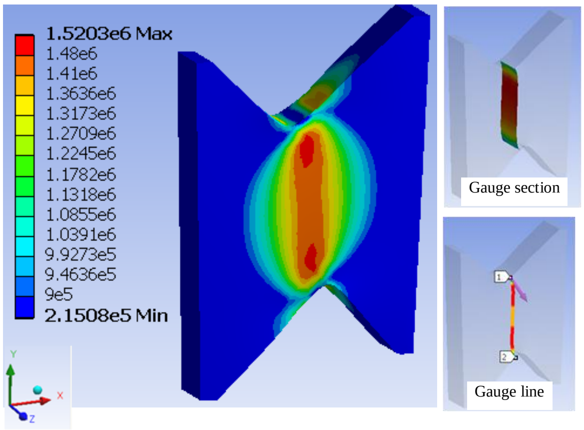

Fig. 4. Shear stress distribution in x-y plane (Pa) using nonlinear FEA modelling

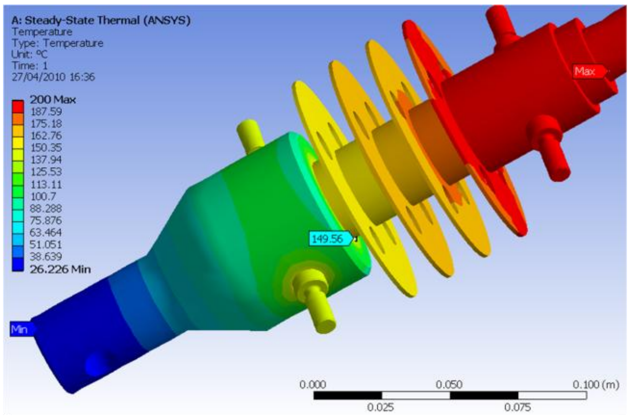

Fig. 5. Temperature contour map over thermal isolator predicted using FEA

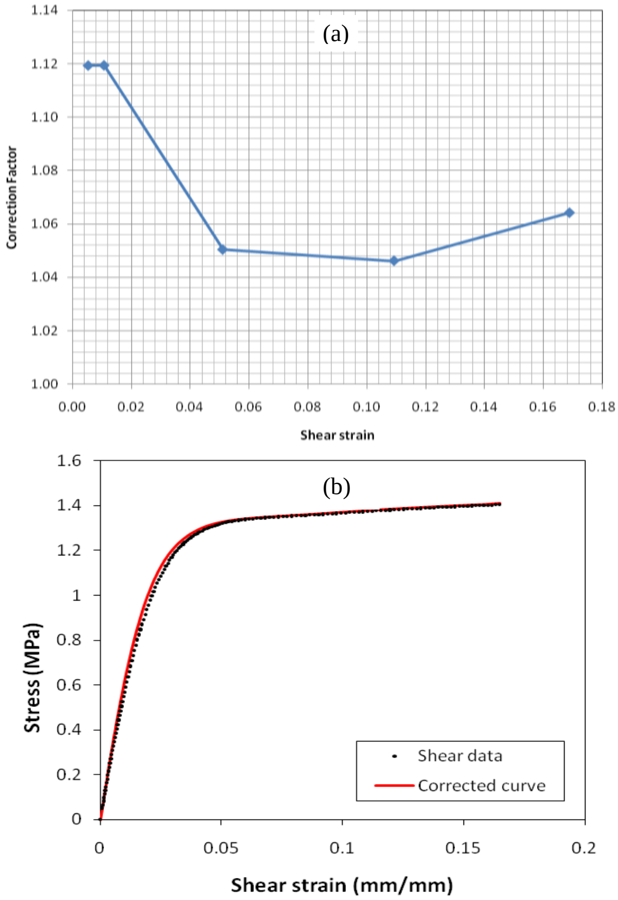

Fig. 6. Nonlinear FEA correction results for shear test: (a) shear strain "correction factor" computed as a function of total shear strain; (b) measured and corrected shear stress vs. shear strain curve for Divinycell H100 (through-thickness direction)

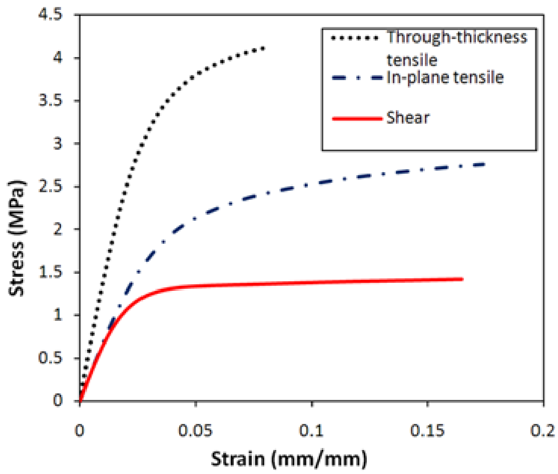

Fig. 7. Shear and tensile stress-strain behaviour of H100 PVC foam after "corrections"