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A TRANSVERSELY ISOTROPIC MATERIAL MODEL FOR FOAM CORES IN MARINE COMPOSITE SANDWICH PANELS UNDER BLASTS

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1. INTRODUCTION

Structural polymeric foams are used as the core material in lightweight composite sandwich ship structures. Traditional sandwich theory suggests that the primary function of the foam core is to transmit shear to the fachesheets, thereby rendering high bending stiffness and strength from a panel with minimum weight penalty. Recent analysis on the underwater blast response of PVC foam-core composite sandwich panel, however, shows that in addition to the above, PVC foams have blast mitigation effects via energy absorption during plastic core crushing [1]. Sandwich panels with softer more ductile foam cores can offer better blast resistance than panels with stiffer and stronger foams because of the associated energy dissipation due to core crushing. This is especially true in water blast cases where yielding of the foam is under transverse shear and compression and in all three principal directions. Furthermore, a foam-core sandwich panel is able to resist blast loading even after the foam has plastically deformed, as long as fracture has not ensued. Plastic deformation of the foam parent material, which is semi-rigid PVC for Divinycell PVC H100 foam, leads to permanent changes in the geometry of the foam cells and hence, a corresponding change in the overall material behavior of the foam. Such behavior after permanent, plastic deformation has not been addressed until very recently [2-5].

Chen and Hoo Fatt [2] characterized the out-of-plane (transverse) and in-plane, elastic-plastic hysteresis behavior of PVC H100 foam under cyclic, uniaxial compression and simple shear. This foam exhibited transversely isotropic properties, with a ratio of out-of-plane to in-plane stiffness and yield strength for the PVC H100 foam to be approximately 3/2 in both the compression and shear modes. Once yielding occurred, the foam underwent permanent damage and exhibited hysteresis, mainly in the form of viscoelasticity. Similar behavior was reported for the form under combined transverse compression and shear in Refs. [4-5]. The objectives of this research are (1) to design pressure vessel experiments for obtaining multi-axial, elastic-plastic and hysteresis properties of PVC foams, and (2) to use the experimental results to develop 3D crushable foam core constitutive models that account for transverse isotropy, plasticity, damage and hysteresis.

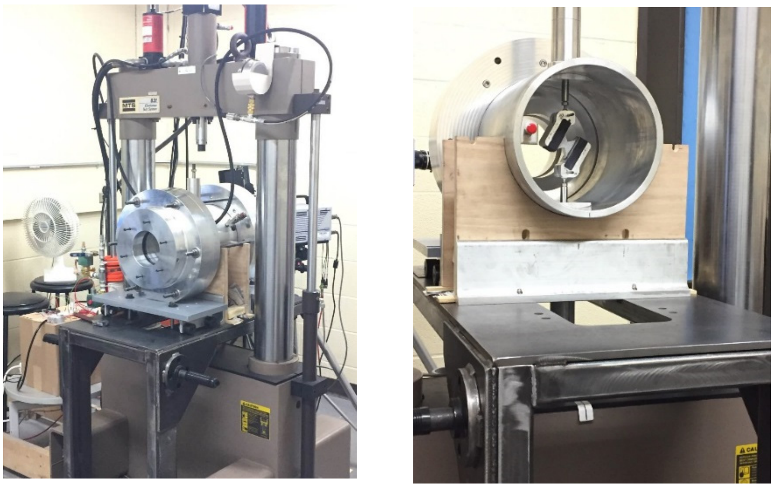
2. PRESSURE VESSEL EXPERIMENTS

In order to obtain tri-axial material properties of PVC H100 foam, a pressure vessel apparatus shown in Figs. 1(a) and (b), was built to encase specimens in a servo-hydraulic MTS machine. The air pressure in the vessel was controlled through a micro-controller circuit board and two solenoid valves. Output signals from the MTS controller were fed into the micro-controller circuit board and used to synchronize the pressure with the MTS actuator motion. The pressure inside the cylinder was measured by a pressure transducer. Signals from the pressure transducer were directly fed into the data acquisition of the MTS machine controller itself. As shown in Fig. 1(a), sight-windows in the end-caps of the pressure vessel were used to enable Digital Image Correlation (DIC) measurements of strains in a wide assortment of specimens, which are shown in Fig. 2. Figure 1(b) shows an Arcan specimen inside the cylinder. Nozzle-guided pistons pass straight through the body pressure chamber in order to achieve good alignment of these specimens. The pistons were sealed with a specially-designed, low friction lip seals.

Extensive testing of the PVC foam was done under uni-, bi- and tri-axial loading in both out-of-plane and in-plane material directions. As described in Fig. 2, Arcan butterfly specimens were used for shear loading (0 deg), as well as combined shear and compression (15-75 degs) and compression (90 deg). A dogbone specimen was used for tension. Pressurizing the air in the chamber allowed for tri-axial loading, and DIC allowed for strains to be measured in the neck regions of the Arcan and dogbone specimens.

3. CYCLIC STRESS-STRAIN CURVES

Tri-axial compression and shear stress-strain were obtained by enclosing the 0 deg Arcan specimen in the pressure chamber and pressurizing it. The strain distributions in the specimen are shown in Figs. 3(a)-(c), and the resulting stress-strain behaviors are given in Figs. 4(a)-(c). These strains were obtained using 2D DIC measurements. It was assumed that in-plane behavior of the foam would be similar, although 3D DIC will be used later to confirm this. Elastic-plastic response followed by viscoelastic hysteresis can be seen in Figs. 4(a)-(c).



(a) (b)

Fig. 1: Pressure vessel experiments to obtain multi-axial hysteresis of PVC foam: (a) pressure chamber and (b) Arcan specimen inside chamber.

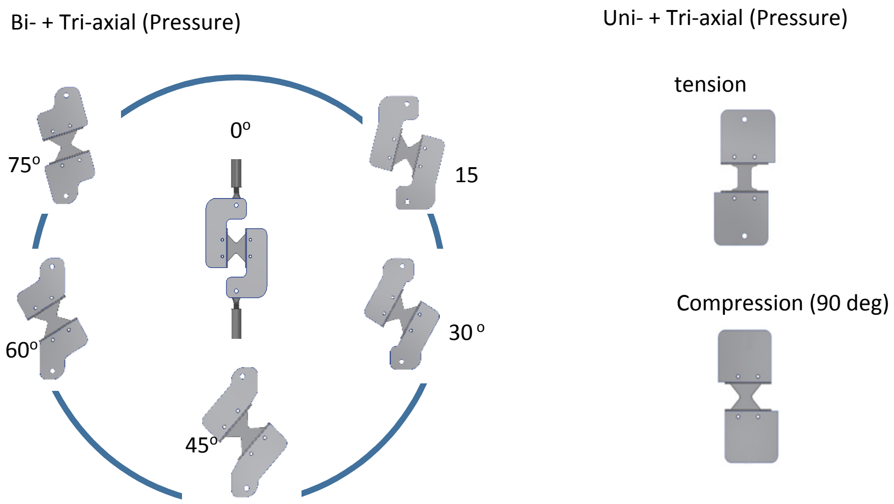
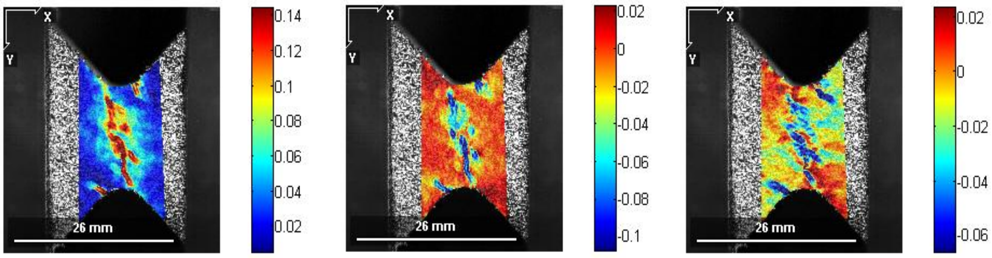
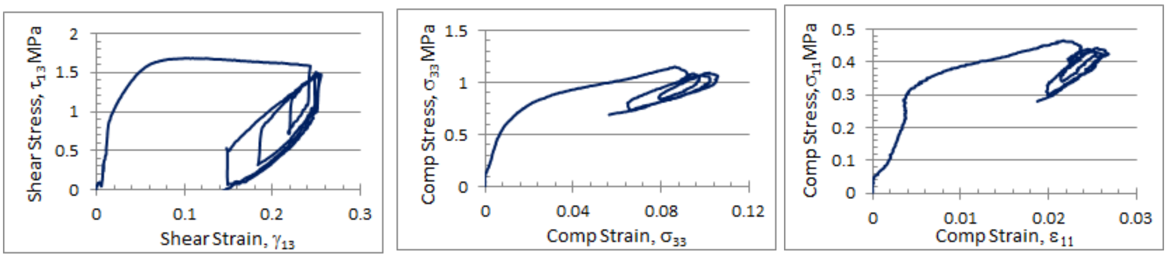


Fig. 2 Specimens used to determine uniaxial, biaxial and tri-axial material properties of PVC H100 foam.



(a) (b) (c)

Fig. 3: Strain distributions in pressurized Arcan specimen: (a) transverse shear, (b) transverse compression and (c) in-plane compression.

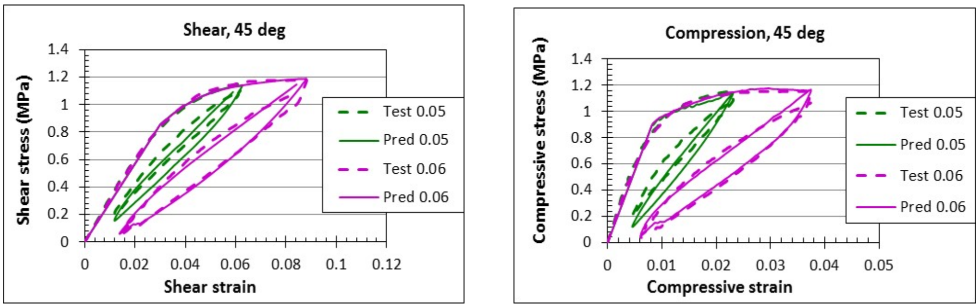


(a) (b) (c)

Fig. 4: Cyclic stress-strain curves: (a) transverse shear, (b) transverse compression and (c) in-plane compression (1- and 2-directions assumed same because of foam transverse isotropy).

4. CONSTITUTIVE MATERIAL MODEL

The foam exhibited elastic-plastic with viscoelastic hysteresis and damage after initial yielding. The onset of plasticity and damage occurred simultaneously, and before these occurred, the foam experienced linear elastic behavior. A material model based on coupled Tsai-Wu plasticity, with mixed kinematic and isotropic hardening, and linear viscoelasticity after yielding/damage was developed for the PVC H100 foam. Good agreement can be seen between the predicted response based on the above constitutive model and the combined shear-compression test data of the 45 deg Arcan specimen in Figs. 5(a) and (b). Similar good agreement was also found for other angles, and the model is currently being applied to the tri-axial test data.



(a) (b)

Fig. 5: Comparison between predicted and experimental results for 45 deg Arcan specimens: (a) transverse shear and (b) transverse compression.

5. CONCLUDING REMARKS

Experiments were done to determine the multi-axial, elastic-plastic and hysteresis behavior of Divinycell PVC H100 foam. The foam, which was transversely isotropic, exhibited elastic-plastic response followed by damage and viscoelastic hysteresis. A Tsai-Wu plasticity model, including combined kinematic and isotropic hardening, was coupled with viscoelasticity and damage to describe the foam behavior. This constitutive model will be used to simulate the response of composite sandwich panels subjected to underwater blasts.

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