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ASSESSING THE IN-PLANE CORE SHEAR CONTRIBUTION OF COMPOSITE SANDWICH PLATES USING THE PICTURE FRAME TEST METHOD

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1. INTRODUCTION

Numerous structural members such as shear webs for wind turbine blades, shear walls, and plate girders etc. are mainly subjected to in-plane shear loading. Assessing the real contribution of the core to the in-plane shear capacity of the sandwich structure, can lead to a better realistic design and eventually to a reliable optimized structure. Few researchers have used experimental approach to study the in-plane shear behavior. [1] used biaxial method to evaluate two aluminum plate specimens, while [2] looked at in-plane shear tests of sandwich plates using two different experimental procedures. Recently, [3] investigated two different picture frame fixture configurations for in-plane shear strength of composites sandwich constructions. Shear frame test fixtures recently became adopted as a standard testing method in Europe and North America ([4] [5]). There exist a number of barriers to overcome before the wide adoptions of composite sandwich construction beyond the scope of research, particularly in civil infrastructure. Consequently, there are need for an established design methodology and data for composite-foam based materials for sandwich construction. Additionally, few of the available simplified design approaches need validations [6].

This paper discusses the in-plane shear characterization of shear load resistant structures. A systematic experimental approach coupled with both 2D and 3D digital image correlation (DIC) techniques were used to test and characterize 20 samples using the newly released ASTM picture frame test method. This research produced a new in-plane shear data along with a simplified analytical model that will assist designers and engineers to confidently size, design, and predict the in-plane shear capacity of sandwich structural members.

2. MATERIALS SELECTIONS AND MANUFACTURING

All composites sandwich plates and laminates tested in this experimental work were molded using E-glass double bias skin (E-BXM 1708 [±45/Mat]) and infused with Derakane 610C-200 vinyl ester resin. The Vacuum Assisted Resin Transfer Molding (VARTM) process was used to mold all samples. Experimental setup utilized the recently released ASTM D8067 standard test method (picture frame device) for in-plane shear properties of several sandwich panel configurations with varying core densities (C70.55, H80, and H100 foam core) and face-sheet layup (2 plies vs. 4 plies).

3. EXPERIMENTAL RESULTS

In this work, two predominant failure modes were identified for composite sandwich plates: global buckling (Fig. 1) and face sheet fracture. Core fracture was also observed in the plain H-series and C70.55 foam (Fig. 2). Global buckling was detected for the composite laminates only (Fig. 3).

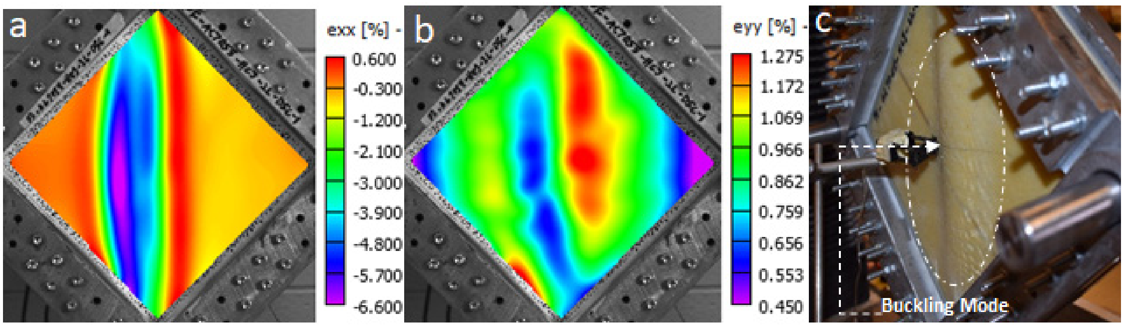

***Fig. 1:** Buckling mode of sandwich plate, Core: C70.55 with core joint, 12.7mm thick, Facings: [±45/mat]$_2$ (a) diagonal compression strain, (b) diagonal tension strain, (c) buckling mode.*

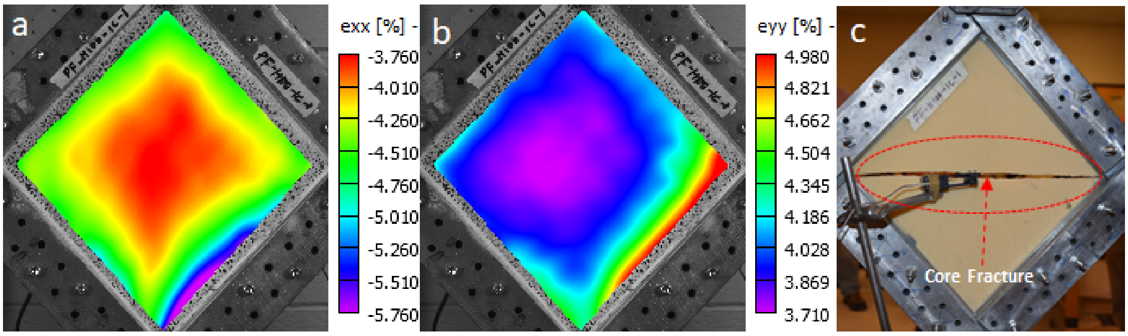

Fig. 2: Core fracture of foam panel, Core: H100, 25.4mm thick, (a) diagonal uniform compression strain, (b) diagonal uniform tension strain, (c) core fracture mode.

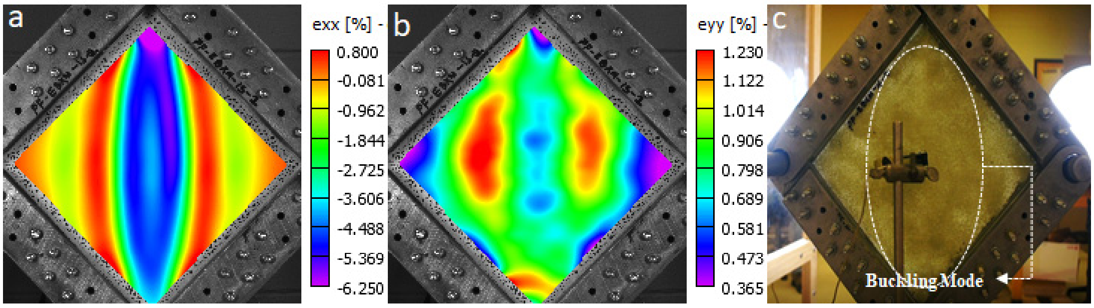

Fig. 3: Global buckling of 2 x EBXM ([±45/mat]₂) laminate (a) diagonal compression(DC) strain, (b) diagonal tension strain(DT), (c) buckling mode.

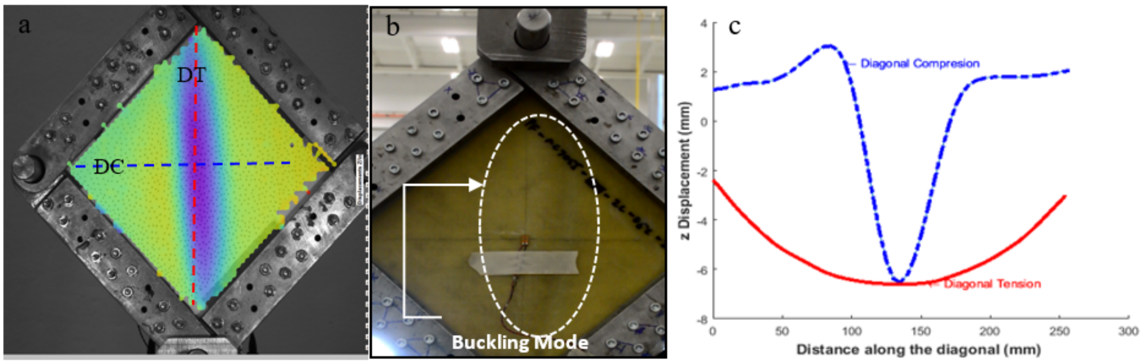

Fig. 4: (a) 3D DIC fringe pattern of buckling mode shape for C70.55 (12.7 mm thick core) and Facings: 2 x EBXM [±45/mat]₂, (b) onset buckling of the actual specimen, (c) Out-of-plane buckling mode shapes (z-direction) along the diagonals – one wavelength along the Tension vertical line, three wavelengths along the Compression horizontal line.
Note: DC (diagonal compression), DT (diagonal tension).

4. SIMPLIFIED MODEL

To obtain a realistic design, engineers need to assess the proportion of load carried by the core in the sandwich construction. The practical assumption that all of the in-plane applied load on sandwich construction is carried by the laminates is somewhat misleading. This section helps understand the influence of core to the mechanical performance of the panel.

A simplified predictive equation was developed to quantify the influence of core to the mechanical performance of the panel. This simplified analytical equation could be used to select, size, and predict the load capacity and failure mode of composite sandwich structures under in-plane shear loading. With this approach, the maximum failure load for each of the constituent components of sandwich can be predicted using the following Eq. 1.

$$P_s = P_c\left(1 + 2G_\phi\right) = P_f\left(2 + \frac{1}{G_\phi}\right) \quad (1)$$

Where $G_\phi = \frac{G_f t_f}{G_c t_c}$: Shear stiffness dimensionless parameter. G and t are shear modulus and thickness respectively.

P = Maximum load. The subscripts s, f, and c are sandwich, face skin and core respectively.

Using this Eq. 1, the effect of core shear modulus and thickness as well as the composites face-sheet shear modulus and thickness on in-plane sandwich performance is presented in Table 1 and Fig. 5. The dotted points represent the experimental data where face-sheet fracture occurred at ultimate load. The sandwich specimen with the C 70.55 foam core (12.7 mm thick) samples (red cross-points) failed by buckling and then face-sheet fracture

Table 1. In-plane Shear Test Results and Failure modes (Foam and sandwich panels).

Plate Type	Foam Type	Thickness (mm)	No of plies	Max. Diagonal Compression Strain (%)	Max. Diagonal Tension Strain (%)	Max Load (kN)	Failure Mode
Foam	H100	12.7	Plain Foam	4.35%	4.37%	7	Core Fracture
		12.7		3.84%	3.51%	6	Core Fracture
		25.4		4.27%	4.02%	13	Core Fracture
		25.4		4.21%	4.05%	12	Core Fracture
	H80	12.7		3.82%	3.59%	7	Core Fracture
		25.4		4.19%	3.93%	10	Core Fracture
		25.4		3.60%	3.27%	10	Core Fracture
	C70.55	12.7		2.66%	3.16%	3.6	Core Fracture
		25.4		3.31%	3.63%	7.3	Core Fracture
		25.4		3.35%	3.55%	7.3	Core Fracture
Sandwich	H100	12.7	1 X EBXM	Not available		96	Face-sheet Fracture
		25.4	1 X EBXM	Not available		114	Face-sheet Fracture
		12.7	1 X EBXM	1.03%	1.15%	118	Face-sheet Fracture
		25.4	1 X EBXM	1.13%	1.31%	117	Face-sheet Fracture
		25.4	1 X EBXM	0.91%	1.03%	103	Face-sheet Fracture
	H80	25.4	2 X EBXM	0.86%	0.85%	168	Face-sheet Fracture
		25.4	2 X EBXM	0.87%	0.92%	184	Face-sheet Fracture
	C70.55	12.7	2 X EBXM	1.17%	0.95%	(152)	Global Buckling
		25.4	2 X EBXM	0.93%	0.92%	177	Face-sheet Fracture (Mixed Mode)
		25.4	2 X EBXM	0.86%	1.07%	183	Face-sheet Fracture

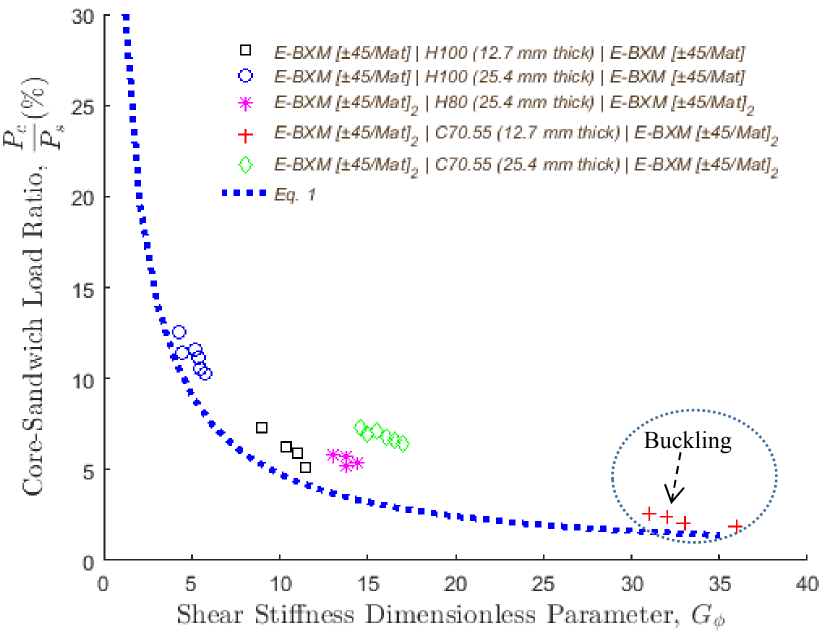

Fig. 5: Ratio of core load to sandwich load against shear dimensionless parameter.

5. CONCLUSION

This work reports a progressive systematic experimental approach for the in-plane shear contribution of sandwich core materials. A total number of 20 samples were tested using the picture frame device. Constituent materials, such as plain foam cores, laminates, and sandwich constructions featuring several foam core densities and face-sheets were tested using the in-plane picture frame. The major highlight from this experimental work is that that designers should not neglect the in-plane load carrying capacity of the core material. It was found that for stiff foam the load contribution of the core could be as high as 10 to 15 % of the total in-plane load. In addition, this test method is a reliable experimental tool to understand the true capacity of the core shear contribution to the overall structure. This test method is valid to detect the buckling load and could be extrapolated to predict the performance of large-scale non-load bearing shear walls for potential use in infrastructure applications.

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