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IMPACT BEHAVIOR OF SUSTAINABLE SANDWICH PANELS WITH FLAX FRP FACES AND CARDBOARD CORES

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ABSTRACT

Structural sandwich panels have been shown to be effective for use as building cladding materials due to their low weight and high relative strength and stiffness. To increase the sustainability of these panels natural and recyclable materials can be used in place of the traditional synthetic materials such as metals, synthetic fiber-reinforced polymers (FRPs) and foams. In this study, a total of six large-scale sandwich panels with flax fiber-reinforced polymer (FFRP) faces and cardboard cores were fabricated and tested under quasi-static and impact loads. The FFRP faces were made using two layers of a bidirectional woven flax fabric and a bio-based epoxy with a reported bio-content of 30%. The cores were made of sections of corrugated cardboard. The panels were tested under both quasi-static three-point bending and using a drop weight impact. The drop weight impact was designed such that the energy matched the failure energy observed during the static tests. The specimens were 150 mm wide, 75 mm thick and 1200 mm long and were impacted by a 150 mm impact surface at midspan. A string potentiometer was used to measure deflection at the midspan and strain gauges were applied to the top and bottom faces at midspan. The data was acquired at a rate of 10 Hz for the static tests and 25 kHz for the impact test. The aim of this project is to provide data to the growing field of study, present a deeper understanding of impact on FFRP sandwich panels and to show the viability of natural and recycled materials for use in sustainable sandwich panels as cladding in new infrastructure. Another aim of this research is to show that materials which are often not considered due to limiting factors, such as moisture resistance, can be used with minor modifications and should not be discounted. This is on-going research and results will be available for the submission of the full paper.

INTRODUCTION

The need for sustainable infrastructure alternatives is increasing. One viable option is the use of environmentally-friendly materials, such as bio-based polymers reinforced with natural fibres. There are a variety of natural fibers that can be used in fiber-reinforced polymers (FRPs) (Ramesh, Palanikumar and Reddy, 2017), but one notable fiber is the flax fiber. Flax fibers have relatively high strength and stiffness when compared to other natural fibers and are commercially available for use in composites. Flax FRPs (FFRPs) can be used to replace their synthetic counterparts in applications where the high strength of the glass or carbon FRPs is not required, such as in the case of sandwich panel faces. For this reason, sandwich panels with foam cores and FFRP faces have been studied under flexural loading (Mak *et al.*, 2015; Sadeghian, Hristozov and Wroblewski, 2016; D. Betts, Sadeghian and Fam, 2018) and axial loading (Codyre, Mak and Fam, 2016). More recently, to further increase the sustainability of these structures, they have been studied with cores constructed of corrugated cardboard (McCracken and Sadeghian, 2018). There are limitations on the use of sandwich panels with cardboard cores, such as their susceptibility to damage from moisture and fire. However, these panels can potentially be used when moisture is present if waxed cardboard is used as a core material. Waxed cardboard is protected from moisture by applying a wax coat after cardboard fabrication. Additionally, these panels would be suitable in applications where fire limitations are not present, such as in non-fire-rated wall partitions.

Another potential application of sandwich panels in building construction is for use a cladding system. As cladding systems can be subjected to impact loads from debris during high wind events, it is important to understand their behavior under dynamic loading. In a previous study, FFRP sandwich panels with foam cores were tested under impact loading (Betts, Sadeghian and Fam, 2018). In this study large-scale panels constructed with corrugated cardboard cores were constructed and will be tested under both quasi-static and impact loads.

EXPERIMENTAL PROGRAM

Test Matrix

As a part of this study, a total of six sandwich panel specimens will be tested under both static and impact loading. The main test parameter in this study is the core type: plain cardboard or waxed cardboard. The specimens were named according to the following naming convention: XFL-(P/W)C-(S/D)-Y, where X is the number of flax layers in the face, P/W stands for "plain" or "waxed", S/D stands for "static" or "dynamic" and Y is a sequential number to differentiate individual specimens. The test matrix is presented in Table 1.

Table 1. Test Matrix

No.	Specimen Group	Quantity	Test Type
1	2FL-PC-S	3	Static
2	2FL-PC-D	3	Dynamic (Impact)

Specimen Fabrication

The specimen fabrication procedure is presented in Figure 1. The cardboard was provided by a manufacturer in sections 1215 mm long and 76 mm wide and approximately 4 mm thick. To make a core width of 150 mm, 38 cardboard sections were required. They were arranged as shown in Figure 1a and glued together using the same glue used by the manufacturer to make the cardboard. Weights were pushed against the side as shown in Figure 1b and the glue was allowed to set for five minutes.

A bio-based epoxy with an approximate bio-content of 30% and a bidirectional flax fabric with a nominal areal mass of 400 g/m^2 (gsm) were used to make the FFRP faces. First, a layer of parchment paper was placed on a flat working surface. A layer of epoxy was applied to the parchment paper. The first layer of flax fabric was then placed on the epoxy and a scraper was used to push the flax into the epoxy layer below. Another layer of epoxy was applied to the surface of the flax fabric and then the second layer of flax fabric was placed. More epoxy was applied to the top of the second layer of flax fabric, such that it was saturated. Finally, the cardboard core was placed at the top of the saturated FFRP face as shown in Figure 1c. The epoxy was then allowed to cure for a minimum of 24 hours, at which point the procedure was completed for the opposite face. The specimens were then allowed to cure for a minimum of seven days, as prescribed by the epoxy manufacturer. A sample specimen is shown in Figure 1d.

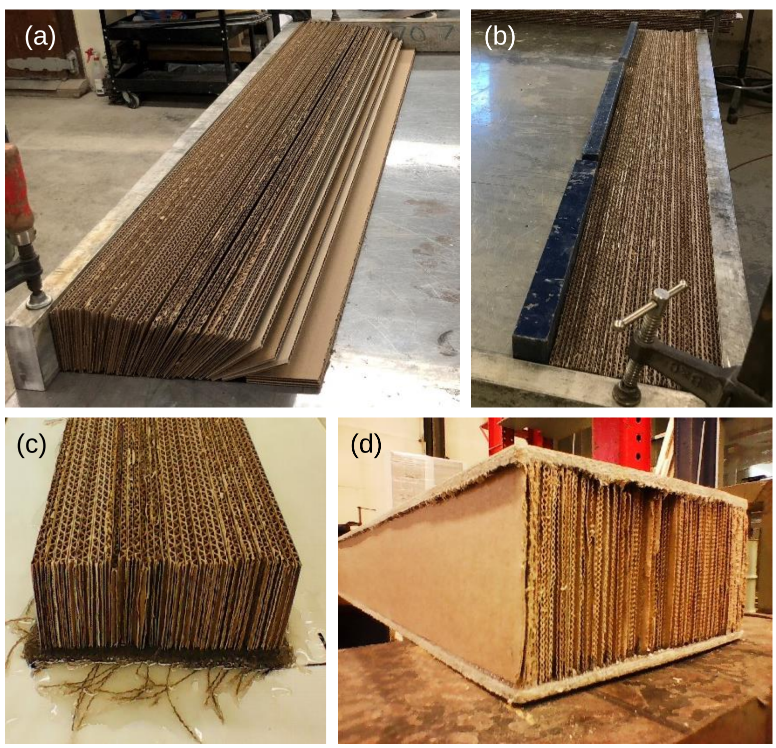

Figure 1. Specimen Fabrication (a) Preparation for Core Manufacturing; (b) Core Glue Curing; (c) Face FFRP Curing; and (d) Finished Sandwich Beam

Test Set-up

Thus far, the static tests have been completed and one impact test has been completed. The static tests were performed using the test set-up presented in Figure 2a and the impact tests were performed using the drop weight (10.4 kg) test set-up presented in Figure 2b. The height of the drop was calculated based on the energy to cause failure during the static tests. For both types of tests, strain gauges were applied at the center of the top and bottom face at midspan and string potentiometers were used to measure deflection at midspan. The quasi-static test data was recorded at 10 Hz, whereas the impact test data was recorded at 25 kHz. The impact tests were recorded using a camera with a frame rate of 500 fps.

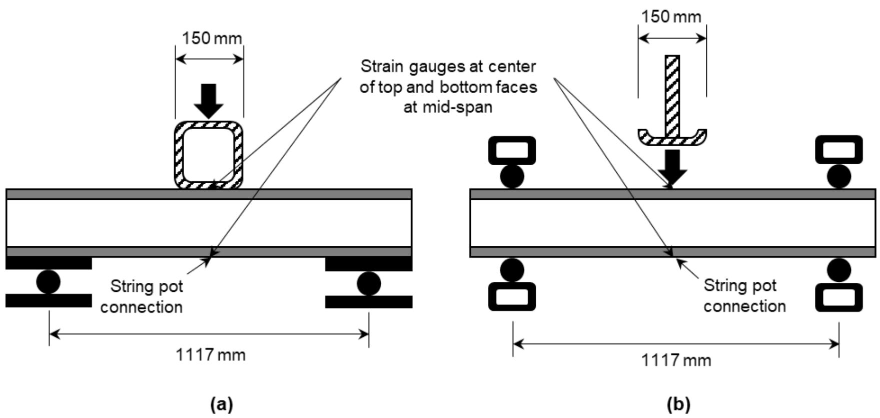

Figure 2. Test Set-ups (a) Quasi-Static Three-Point Bending Test (b) Impact Test

RESULTS AND DISCUSSIONS

The load-displacement results of the three static tests are presented in Figure 3a. Evidently, specimen 2FL-PC-S-1 failed prematurely. It was noted before the test that there was visible delamination between the top face and the core which caused an observable pre-mature failure. For this reason, this specimen was excluded from all calculations going forward. However, all specimens, including 2FL-PC-S-1 failed in the same mode: compression crushing / wrinkling. The maximum load, moment and deflection (Specimens 2 and 3) observed during testing were 4.21 kN, 1.2 kN-m and 24.6 mm, respectively. To calculate the drop height required for the impact test, the average static energy causing failure (i.e. the area under the load-displacement curve) was calculated. For a 10.4 kg weight, the required height was determined to be 614 mm.

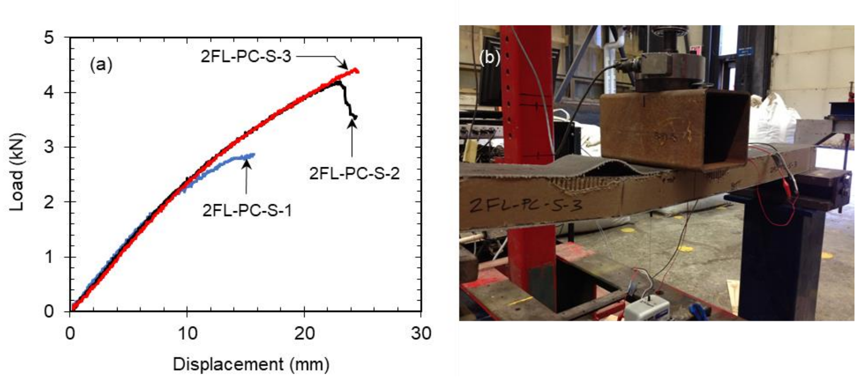

Figure 3. Test Results (a) Load-Displacement Plot (b) Photo of Failure Mode

Specimen 2FL-PC-D-1 was tested under impact using a drop weight test at the average maximum energy resisted by the static test specimens. A photo of the test is shown in Figure 4. The results of the test are presented in Figure 5. The specimen resisted the energy without any observable damage. Based on the deflection data presented in Figure 5a and 5b, the damping coefficient was calculated as 8.9% based on the free vibration after the first impact.

Figure 4. Impact Test (a) Set-up (b) Impact Event

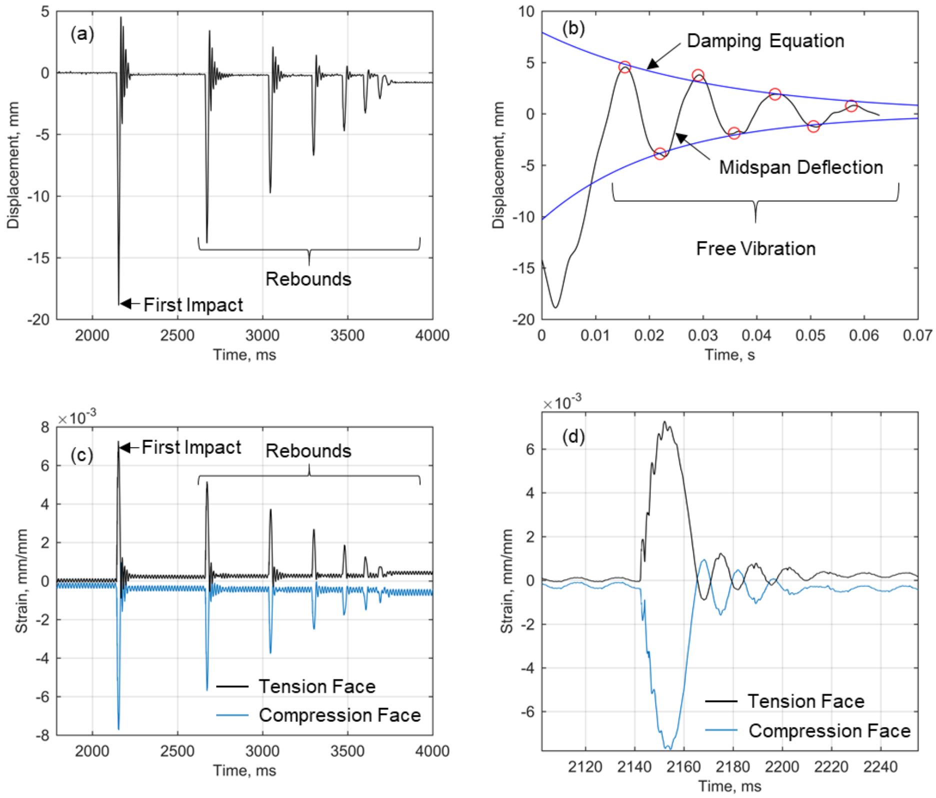

Figure 5. Impact Test Results (a) Displacement vs. Time (b) Damping Equation (c) Face Strains vs. Time and (d) Face Strain vs. Time During First Impact

The face strains during the test are presented in Figure 5c and 5d Figure 5d. The face strains are relatively symmetric, suggesting that the neutral axis of the section is close to the midplane. The maximum face strain observed in the top face was 0.0077 mm/mm whereas the maximum face strain observed in the bottom face was 0.0073 mm/mm.

CONCLUSIONS

As a part of this study, three quasi-static three-point bending tests and low velocity impact test were performed on sandwich panels made of flax fiber-reinforced polymer faces and corrugated cardboard cores. Based on the results of the tests, the following conclusions were made:

- the sandwich panels had a maximum moment capacity of 1.20 kN-m;
- the sandwich panels resisted a maximum energy of 62.72 J; and
- the sandwich panels all exhibited failure in the compression face due to wrinkling / compression crushing.

Based on these conclusions, these systems could be viable for use as building envelopes. One concern for these systems is the affect of moisture on structural behavior. To compensate for moisture, panels could be made with waxed cores which are more resistant to moisture than plain cardboard. Another concern with these structures is their fire-rating, however they could potentially be used in applications such as non-fire-rated wall partitions. Future research in this study will include testing panels fabricated with waxed corrugated cardboard cores.

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