Residual Behavior of Sandwich Panels with Flax FRP Faces and Foam Cores After an Impact Event

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ABSTRACT

In this paper, the residual properties of sandwich panels with flax fibre-reinforced polymer (FFRP) faces which have been subjected to impact loading will be investigated. The sandwich panels tested in this study were fabricated using a closed cell polyisocyanurate foam with a density of 64 kg/m3 and faces made of a balanced bidirectional flax fabric (nominal areal mass of 400 g/m^2) and an epoxy resin with an approximate bio-content of 30% after mixing. Each specimen was 1220 mm long, 150 mm wide and approximately 80 mm thick. The sandwich panels will first be subjected to an impact of 100% of the impact energy resisted in previous tests using a drop weight impact test. The span length of the tests will be 1117 mm and a drop weight (10.413 kg) with an impact surface width of 150 mm will impact each specimen at midspan. For these tests, the top face strain, bottom face strain and deflection at midspan will be sampled at a rate of 25 kHz. After the impact, the panels will be tested under quasi-static three-point bending to failure. During this test the load, midspan deflection, and top and bottom face strains at midspan will be sampled at a rate of 10 Hz. The results of the post-impact quasi-static flexural test will be compared with similar flexural tests performed on intact specimens to determine the effect of the impact on the flexural behavior of the sandwich panels. It was determined that the properties of these sandwich panels are not adversely affected by an impact event. There is potential that the impact increases the static capacity of the sandwich panels, however more research is required. This research is part of a larger on-going study and more results will be available at the time of the conference.

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INTRODUCTION

As society becomes more environmentally conscious, it is important to have sustainable alternatives to traditional building materials. An opportunity to increase the sustainability of sandwich panels with fibre-reinforced polymer (FRP) faces is using natural fibres, such as flax, and bio-based polymers. Flax fibers are relatively strong and stiff when compared with other plant fibers and have a lower embodied energy than traditional fibers, such as glass and carbon (Cicala et al. 2010). Flax fabrics are already commercially available which makes them a viable option. Recently, sandwich panels made with flax FRP (FFRP) faces have been studied under flexural loading (Betts et al. 2017a; Fam et al. 2016; Mak et al. 2015; Sadeghian et al. 2018) and under axial loading (Codyre et al. 2016).

As one typical application of these sandwich panels is cladding systems, it is vital that their behaviour after an impact event is understood. There have been studies on the impact behavior of sandwich structures with synthetic FRP faces (Atas and Potoglu 2016; Schubel et al. 2005; Torre and Kenny 2000), but there is a gap in the research in terms of the effect of impact on sandwich panels with FFRP facings as well as the residual properties after an impact event. Therefore, the aim of the current study is to provide an understanding of the behavior of sandwich structures with FFRP faces during and after impact loading. This paper will focus specifically on the effect of core density on the residual properties of sandwich panels with FFRP faces and foam cores impacted at 100% of the known impact resistance.

EXPERIMENTAL PROGRAM

Test Matrix

As a part of this study, three specimens were tested under drop weight impact loading and then tested under static load to determine the residual properties. The 10.413 kg drop weight impacted the specimens at midspan. Each specimen was tested at 100% of the energy resisted during previous tests (Betts et al. 2018a). After the impact tests, the specimens were tested under three-point bending. The main test parameter was the effect of the facing thickness on the post-impact behaviour of these sandwich panels. The test matrix is shown in Table 1.

Table 1. Test Matrix

No.	Specimen I.D.	Number of Layers	Core Density (kg/m^3)	Drop Height (mm)
1	1FL-P400	1	64	300
2	2FL-P400	2	64	1200
3	3FL-P400	3	64	1700

Note: FL = Flax Layers, P400 = 64 kg/m^3 core density

Specimen Fabrication

As this study is a part of a larger research project, the specimen fabrication has been discussed in previous works by (Betts et al. 2017a; b, 2018a). The materials used for the project are listed in Table 2.

Table 2: List of Materials

Specimen Part	Material	Supply Size
Core	Polyisocyanurate Foam	2400 x 1200 x 75 mm
Face Resin	Bio-Based Epoxy Resin	1 L Epoxy, 0.5 L Hardener
Face Fibre	Bidirectional Flax Fabric	1200 mm roll (400 g/m^2)

Four of each type of specimen were fabricated. Each type of specimen was fabricated as a 600 mm wide panel. After curing, each of these panels was cut down to the final specimen size of 150 mm wide and 1200 mm long using a band saw. The specimens were fabricated using the following procedure, photos of which are shown in Figure 1:

1. cleaning the surface of the foam of dust and debris;
2. applying an even layer of bio-based epoxy to the surface of the foam;
3. placing a layer of the bidirectional flax fabric;
4. applying the bio-based epoxy on the flax fabric;
5. repeating steps 3 and 4 for a second layer of flax fabric;
6. applying a layer of parchment paper using an aluminum roller to remove excess resin and air and to provide a flat finish to the face;
7. placing a weighted flat board on the top surface and allowing to cure for seven days;
8. repeating steps 1-7 for the other FFRP face;
9. cutting the panels into four separate specimens using a band saw.

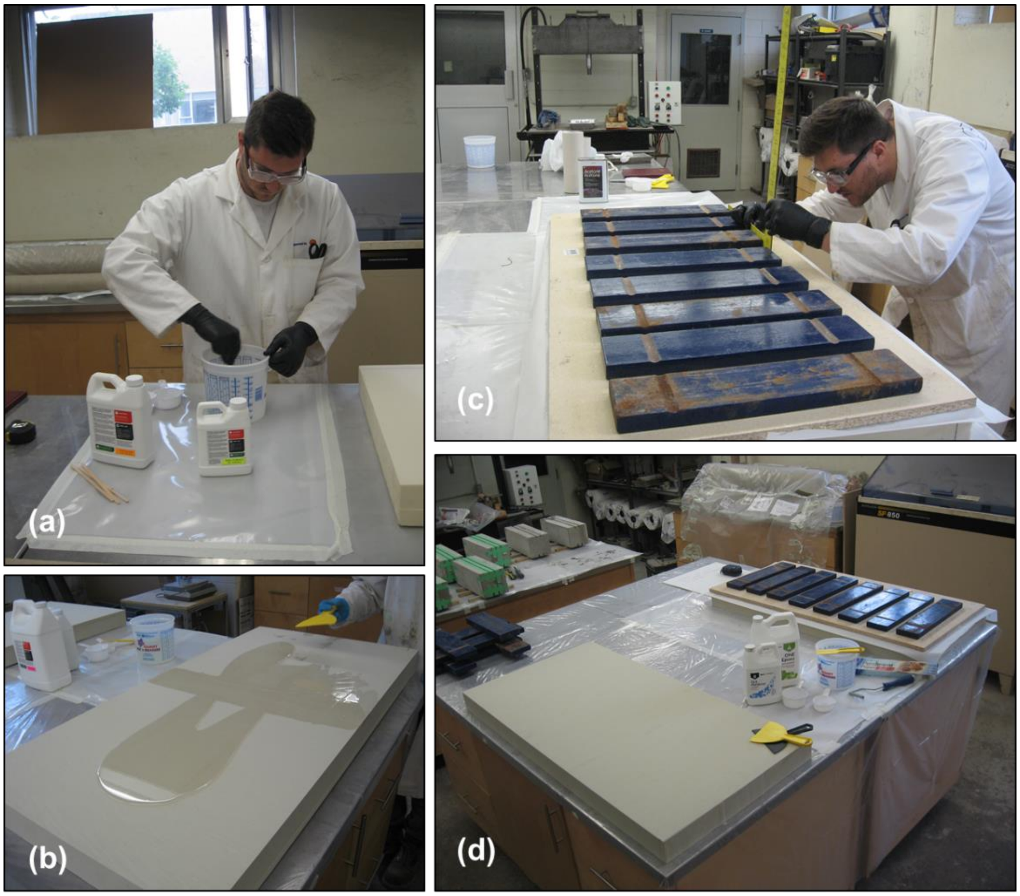

Figure 1: Specimen fabrication (a) mixing epoxy resin (b) application of epoxy resin to foam core (c) placement of weights for curing (d) one specimen cures while another is prepared for application of FFRP face – Courtesy of Dillon Betts and Pedram Sadeghian

Test Set-up

The impact test set-up is shown in Figure 2. A strain gauge was applied at the centreline of the top and bottom faces at the midspan and a string potentiometer was used to measure displacement at the midspan. An accelerometer was placed on the drop weight to measure the acceleration of the impact. Additionally, a camera with a high frame rate was used to record each impact at a frame rate of 500 fps.

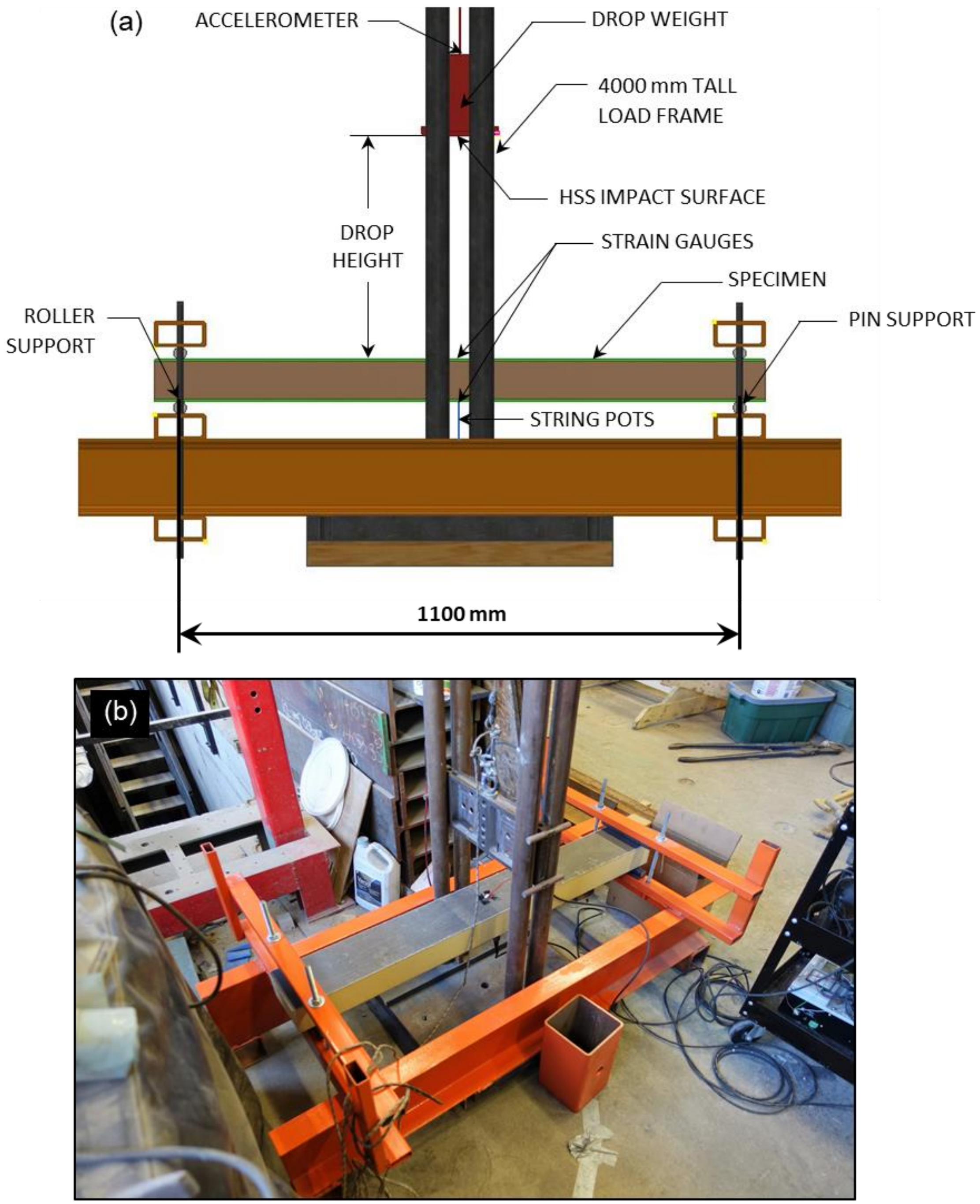

Figure 2: Impact Test set-up (a) schematic (b) lab photo – Courtesy of Dillon Betts

The three-point bending static test set-up is shown in Figure 3. The specimen was supported on two roller-pin supports and loaded through a steel hollow structural section (HSS) with dimensions matching the HSS loading surface used during the impact tests. The additional weight of the HSS was added to the recorded load during the data processing stage. A string potentiometer was placed under the specimen at midspan.

Figure 3: Static Three-point Bending Test Set-up – Courtesy of Dillon Betts

RESULTS AND DISCUSSIONS

Each specimen was impacted one time at 100% of the energy resisted during a previous study (Betts et al. 2018a) and then tested under static three-point bending to determine the residual properties. All tests were completed within a 24-hour period.

Figure 4 shows the data from the impact test of specimen 2FL-C64. The drop weight was allowed to rebound during the tests. Figure 4a shows the displacement data throughout the entire test, Figure 4b shows the free vibration of the sandwich beam after the main impact event and Figure 4c shows the strains during and after the first impact.

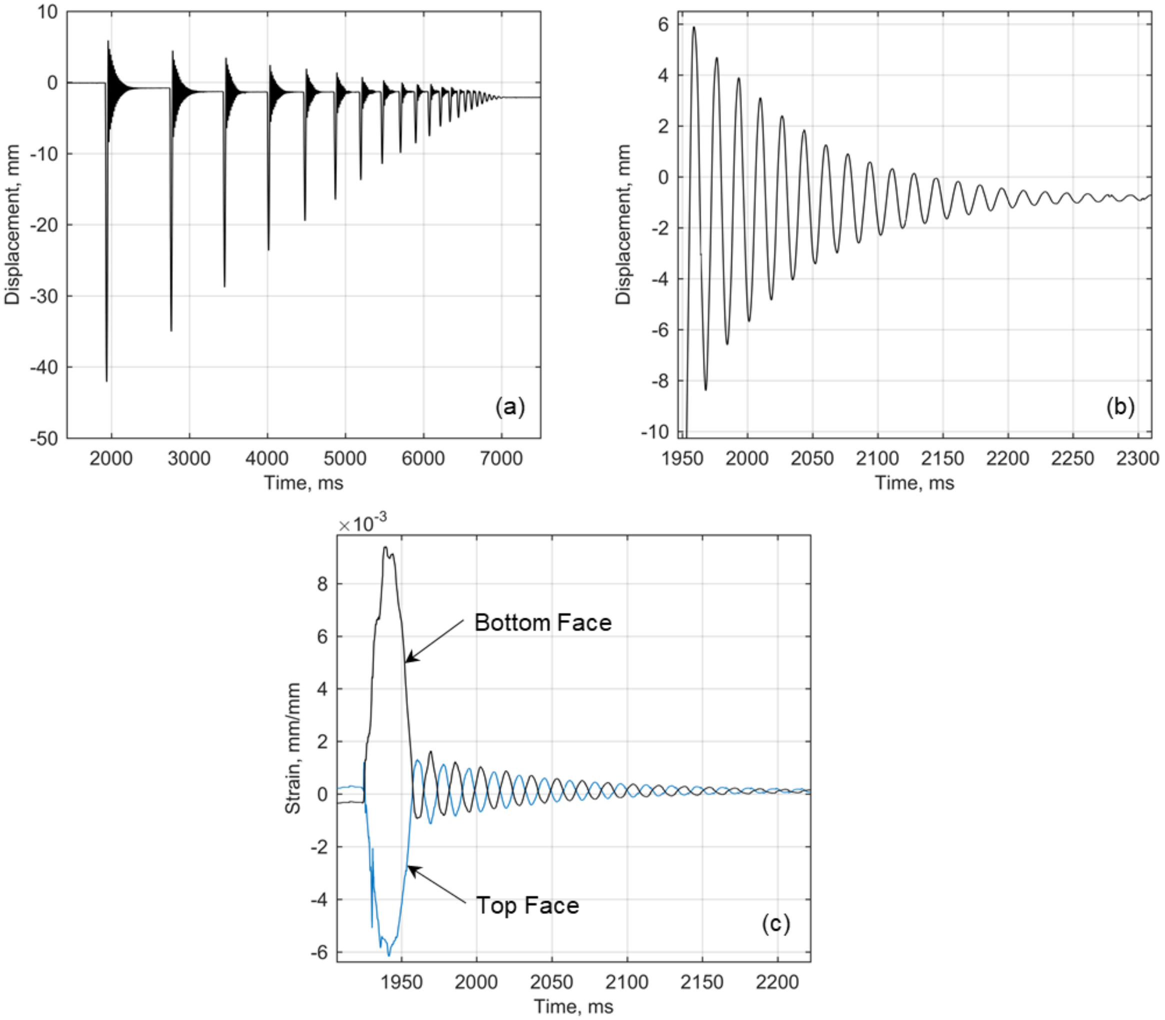

Figure 4: Impact Test Data: (a) Displacement Data; (b) Free Vibration After Impact and; (c) Face Strains During First Impact

Table 3 and Figure 5 shows the results of the residual static tests compared with the results of intact static tests performed by Betts et al. (2018b). Table 3 shows that, in both cases, strength increased with facing thickness. It also shows that the residual tests exhibited higher flexural rigidity for each specimen type. Additionally, Figure 5 shows that the initial stiffness of each residual specimen was higher than that of the intact static tests.

Table 3: Test Results and Comparison to Intact Static Tests

I.D.	Residual Peak Load, kN	Intact Peak Load, kN *	Residual/ Intact Ratio	Residual Peak Moment, kN-m	Intact Peak Moment, kN *	Residual/ Intact Ratio
1FL-C64	2.48	2.37	1.04	0.69	0.66	1.05
2FL-C64	4.17	3.26	1.28	1.16	0.91	1.28
3FL-C64	5.53	4.62	1.20	1.55	1.29	1.20

* *Data from Betts et al. (2018b)*

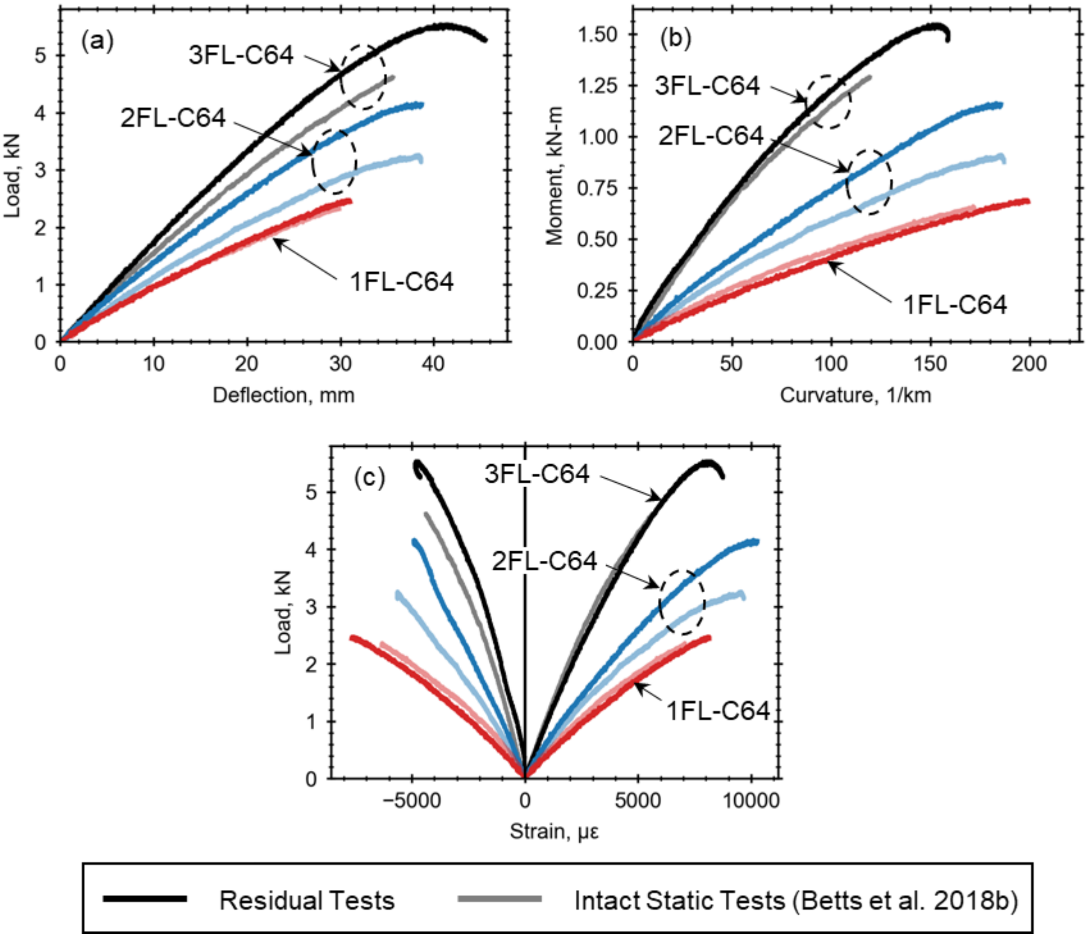

Figure 5: Comparison of After-Impact Residual Static Tests and Intact Static Tests: (a) Load-Deflection; (b) Moment-Curvature and; (c) Load-Strain

Based on the observations of the test results, there is potentially a strengthening in the sandwich panels due to an impact event. This strengthening effect is more apparent in the specimens with thicker faces (2FL-C64 and 3FL-C64). More research is required into the cause of the increase in strength after an impact event.

Failure Modes

The failure modes observed during intact static tests by Betts et al. (2018b) and failure modes observed during the current study matched closely and are presented in Figure 6. In both cases, specimens 1FL-C64 and 2FL-C64 failed at the compression face and compression face core interface, whereas the specimens with the stronger faces, 3FL-C64 specimens, failed due to core shear in both cases.

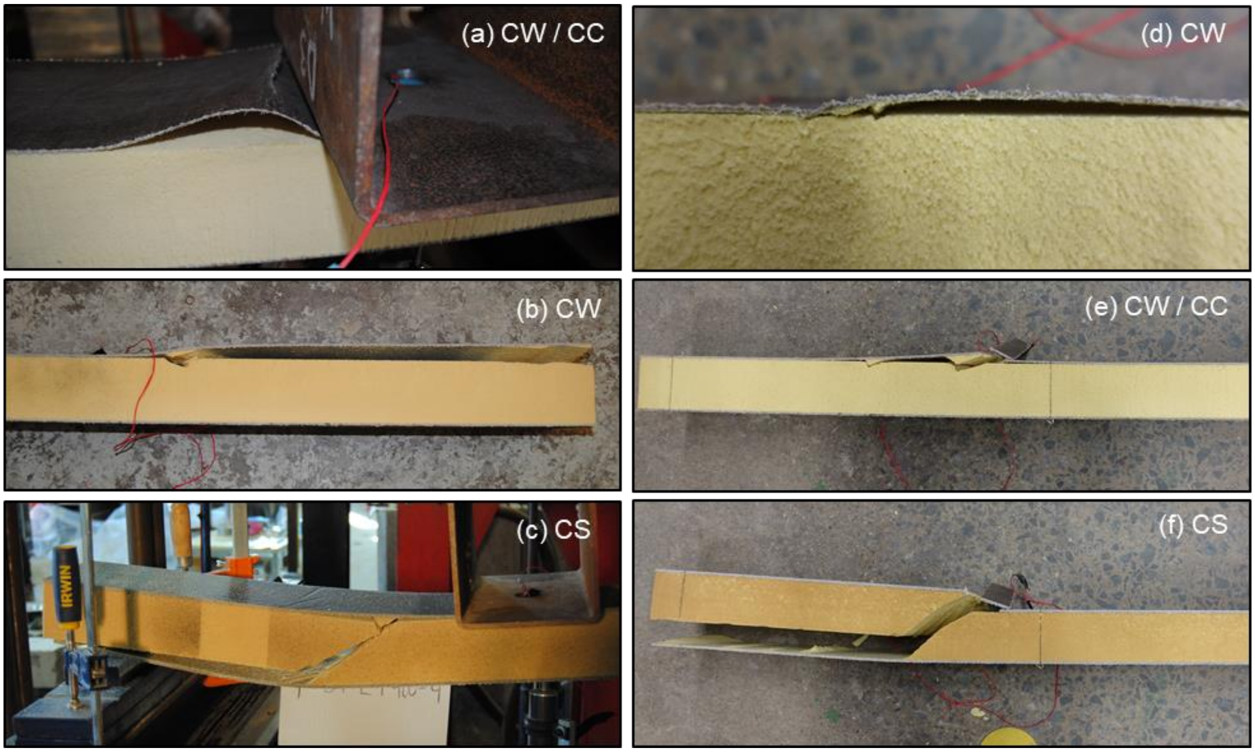

Figure 6: Failure Modes (a) Intact 1FL-C64; (b) Intact 2FL-C64; (c) Intact 3FL-C64; (d) Residual 1FL-C64; (e) Residual 2FL-C64 and; (f) Residual 3FL-C64 – Courtesy of Dillon Betts

CONCLUSIONS

As a part of this study three sandwich beams were tested under impact at 100% of the previously determined impact resistance and then tested under three point-bending to determine the post-impact residual strength. It was determined that the specimens generally performed better in flexure after an impact event. This indicates that there is potentially some strengthening effect from the impact event. Though, more testing and research is required to prove this hypothesis and determine the cause. From the tests presented in this study, the following conclusions were drawn:

- Sandwich beam moment capacity increased with face thickness.
- All post-impact specimens performed better than the intact specimens. The Peak Moment Residual/Intact Ratio for 3FL-C64 was 1.20.
- Failure modes of residual tests and intact tests were closely matched.

Future research will include post-impact residual testing of more sandwich beams at varying levels of impact energy. Additionally, future studies will include testing flax fiber-reinforced polymer (FFRP) tension coupons under impact forces and testing the residual tensile properties to determine the material level behavior the sandwich specimens.

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