PARAMETRIC STUDY OF THE FLEXURAL BEHAVIOUR OF SANDWICH PANELS WITH FLAX FRP FACES AND FOAM CORES USING FINITE ELEMENT ANALYSIS

D. Betts[1], P. Sadeghian[1*] and A. Fam[2]
[1] Department of Civil and Resource Engineering, Dalhousie University
Halifax, NS, Canada
[2] Department of Civil Engineering, Queen's University
Kingston, ON, Canada
Email: dillonbetts@dal.ca, pedram.sadeghian@dal.ca, amir.fam@queensu.ca
* Corresponding Author

ABSTRACT
To meet the growing demands for increased sustainability in infrastructure, it is important to consider the use of more environmentally-friendly materials, such as plant-based fibre-reinforced polymers (FRPs). Plant-based FRPs, such as flax FRPs (FFRPs), can be used to replace their synthetic counterparts in applications where the high strength of synthetic FRPs is underutilized, such as sandwich structures. In this study, the performance of one-way sandwich beams with FFRP faces and foam cores is investigated numerically using the commercially available finite element analysis (FEA) software, LS-DYNA. The main parameter of the study was the effect of the foam core density on the structural performance of sandwich beams loaded under both quasi-static flexural loading. The main modelling challenge for this project was the selection of appropriate material models to accurately predict the behaviour of FFRPs, which are known to exhibit a nonlinear mechanical behaviour. The results of the FEA models were compared to a previous experimental study on panels with core densities of 32 kg/m3, 64 kg/m3 and 96 kg/m3. This is on-going research and more results will be available at the time of the conference.

KEYWORDS
Flax, Natural, FRP, Sandwich Panel, Numerical, FEA

INTRODUCTION
Sandwich panels are efficient structures made of two relatively strong and stiff faces separated by a lightweight core. The separation of the two faces provided by the core increases the moment of inertia which gives these panels a high stiffness and flexural rigidity. The faces resist the majority of the bending force, while the core resists shear force. As lightweight foams with high insulative properties can be used as the core material, these structures are ideal for applications where light weight and high insulation are required, such as building cladding materials.

As the core material is typically significantly weaker than the face materials, the capacity of these structures is often limited by the core strength. Traditional sandwich panel faces include: aluminum, glass fibre-reinforced polymers (GFRPs) and carbon fibre-reinforced polymers (CFRPs). As these traditional face materials are underutilized, there is an opportunity to replace these materials with weaker, but more sustainable materials, such as flax fibre-reinforced polymers (FFRPs). The material properties of FFRPs and other natural fibre-reinforced polymers have been investigated and the results show that they exhibit a nonlinear stress-strain response (Betts et al. 2018; Christian and Billington 2011; Sadeghian et al. 2018)

Recently, FFRP-foam sandwich panels have been investigated under flexural loads (Betts et al. 2018; Mak et al. 2015; Mak and Fam 2019; Sadeghian et al. 2018) and axial loads (Codyre et al. 2016). Some studies have been completed on experimental and finite element (FE) modelling of FFRP-cork sandwich panels under impact loads (Boria et al. 2018). However, in the study by Boria et al. (2018), the nonlinear behaviour of the FFRP faces is not considered. There are currently no studies providing an in-depth look at the behaviour of FFRP-foam sandwich structures under flexural loads using the finite element method (FEM). Therefore, this study will work to fill this gap research by presenting a finite element model of FFRP-foam sandwich panels with different foam densities and including the nonlinear behaviour of the faces.

NUMERICAL PROCEDURE

The commercially available finite element analysis (FEA) program LS DYNA was used to simulate the flexural behaviour of FFRP-foam sandwich beams. The models in this study were designed to match the two-layer FFRP-foam specimens tested by Betts et al. (2018). The faces were considered as two-ply bidirectional FFRPs and the cores were considered as polyisocyanurate (PIR) foams with densities of 32 kg/m^3, 64 kg/m^3 or 96 kg/m^3. The test matrix examined in this paper is presented in Table 1.

Table 1. Test matrix

Model I.D.	Face Layers	Core Density, kg/m^3
2FL-C32	2	32
2FL-C64	2	64
2FL-C96	2	96

Geometry and Loading

The model layout is presented in Figure 1. To match the tests from the study by Betts et al. (2018), the models were designed as a three-point bending configuration with a 150 mm wide constant displacement at midspan. One support was modelled as a pin and the other was modelled as a roller. The FFRP faces were modelled as 2.75 mm thick, the cores were modelled as 75 mm thick. The span length of the model was 1110 mm.

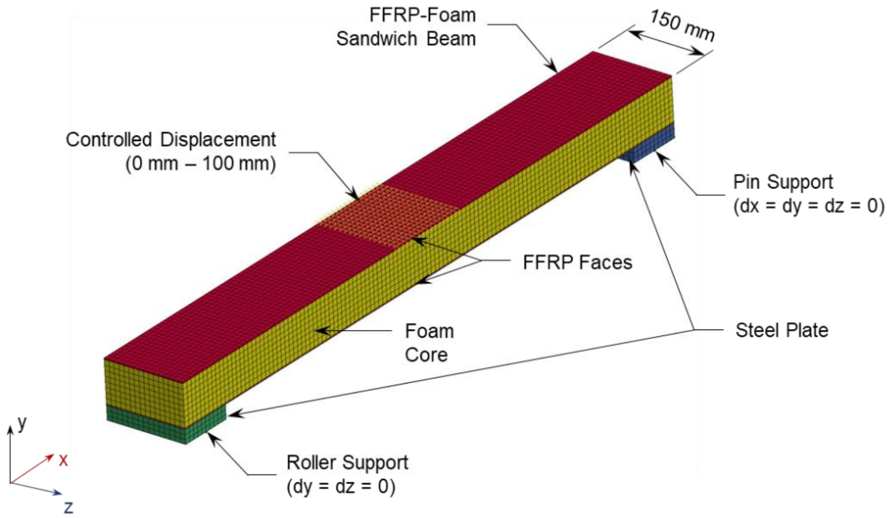

Figure 1. FEA model geometry

Material Models

The FE models were designed to incorporate the nonlinear behaviour of the FFRP faces and foam cores. For the FFRPs, this was accomplished by using the material model *MAT_NONLINEAR_ ORTHTROPIC and the face failure was considered using *MAT_ADD_EROSION. Separate instances of these material types were used for the top and bottom face to capture the difference in the behaviour of FFRPs in tension and compression. The stress-strain curves presented by Betts et al. (2018) and shown in Figure 2a were used to model the FFRPs in the longitudinal and transverse direction on the tension and compression face. Note that the FFRP exhibited nonlinear behaviour in both tension and compression and showed a higher strength in compression than in tension. The nonlinear behaviour in tension is attributed solely to the behaviour of the flax fibres; whereas in compression, the nonlinear behaviour is attributed to the fibres and the epoxy matrix. The difference in strength is thought to be attributed to the strength of the epoxy in compression. However, further investigation and tests are required into the compressive behaviour of these composites.

For the PIR foam cores, *MAT_LOW_DENSITY_FOAM was used. This material type can only be used for solid type element, which is why the beams were modelled in 3D. The compression behaviour of the foams presented by Codyre et al. (2016) and shown in Figure 2b were used in the material modelling. Future work includes testing of the foams in tension, compression and shear and the FFRPs in shear and using the test data to improve the model.

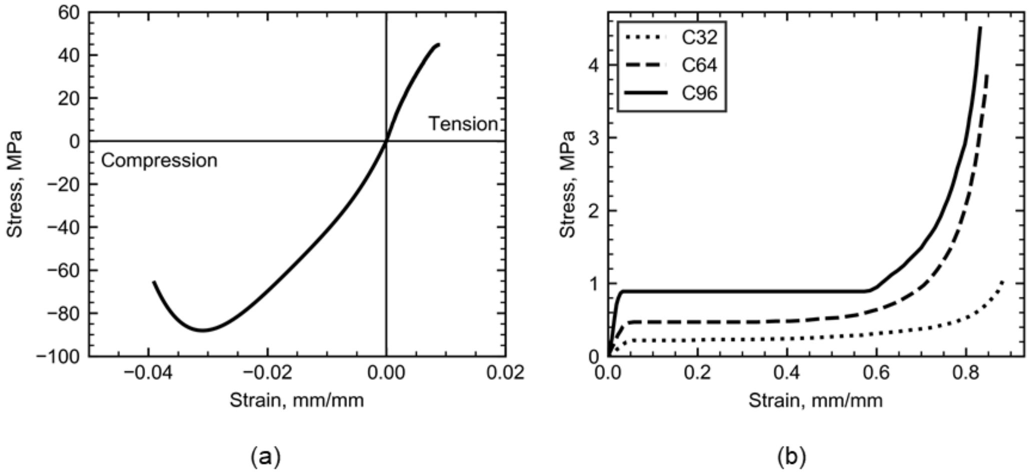

Figure 2. Stress-strain curves of (a) FFRPs (Betts et al. 2018) and (b) PIR foams in compression (Codyre et al. 2016)

RESULTS AND DISCUSSION

The load-deflection behaviour predicted by the FEA model is compared to the test data from the study by Betts et al. (2018) in Figure 3. To develop the load-deflection curves, the load was obtained by taking the total resultant forces on the boundary conditions in the model and the deflection was taken as the deflection of a node at the bottom face at midspan. In both the physical tests and the FEA models, the failure was evidenced by a sudden drop in the load to less than 50% of the ultimate load. The results of the tests and the FEA models show that both strength and stiffness increase with an increase in core density. Additionally, as presented in Figure 3, the tests and FEA models showed that the failure mode was affected by the core density. The stresses in the FEA model at failure are presented in Table 2.

Table 2. Stresses in FEA models at failure

Model I.D.	Compressive Stress in Top Face, MPa	Tensile Stress in Bottom Face, MPa	Shear Stress in Core, MPa
2FL-C32	-18.3	19.4	0.270
2FL-C64	-38.9	42.0	0.886
2FL-C96	-44.3	45.1	0.629

The 2FL-C32 and 2FL C96 models predict the behaviour of the corresponding test specimens well. However, the 2FL-C64 model is overpredicted both the stiffness and strength. As the only difference in the three FEA models was the input foam properties, it is suspected that this overprediction is due to the use of foam data from another study. However, these are the preliminary results and the model can still be improved through testing of the materials to more accurately model their behaviour and through improved modelling of the contacts. Currently, the FFRP faces and foam cores are connected using the contact type *CONTACT_ TIED_SURFACE_TO_SURFACE. Future work involves improving the model by using a tiebreak contact to capture the potential failure due to delamination or wrinkling.

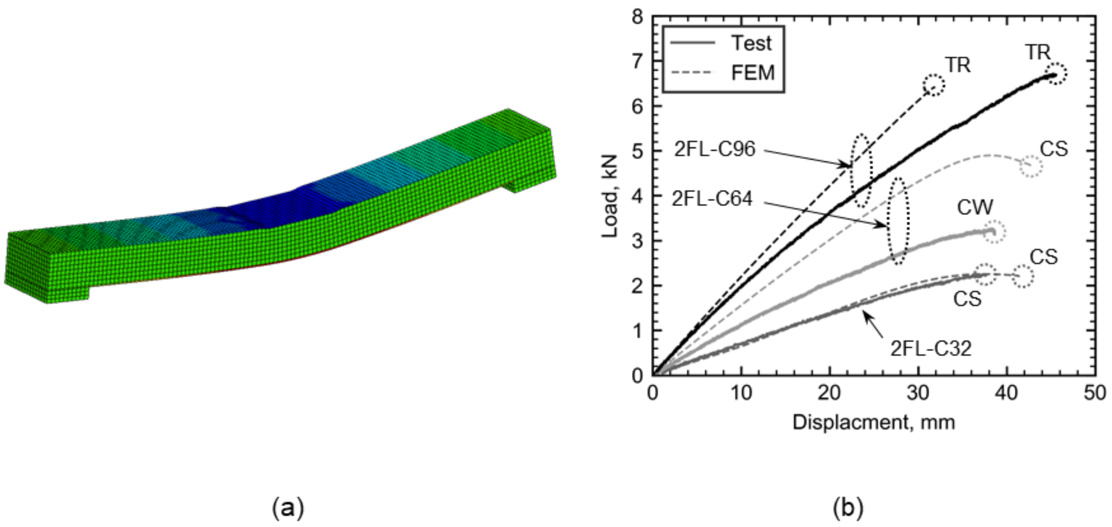

Figure 3. FEA model results (a) bending of model and (b) load-deflection behaviour compared to test data from Betts et al. (2018) (TR = tensile rupture; CW = compression wrinkling; CS = core shear)

CONCLUSIONS

A finite element method model was developed using a commercially available software to predict the behaviour of FFRP-foam sandwich beams under flexural loads. The main parameter of the modelling was the foam density. The model incorporated the nonlinear behaviour of both the faces and the foam core using material models available as part of the FE software. The model was found to accurately predict the behaviour of the 2FL-C32 and 2FL-C96 specimens, but overpredicted the strength and stiffness. This will be improved in future studies through the testing of the foams under different loading conditions.

ACKNOWLEDGEMENTS

The authors would like to thank Davide De Cicco for his assistance in finite element modelling. The authors would also like to acknowledge and thank the Natural Science and Engineering Research Council of Canada (NSERC), Queen's University and Dalhousie University for their financial and in-kind support.

REFERENCES

Betts, D., Sadeghian, P., and Fam, A. (2018). "Experimental Behavior and Design-Oriented Analysis of Sandwich Beams with Bio-Based Composite Facings and Foam Cores." *Journal of Composites for Construction*, 22(4), 1–12.

Boria, S., Raponi, E., Sarasini, F., Tirillò, J., and Lampani, L. (2018). "Green sandwich structures under impact: experimental vs numerical analysis." *Procedia Structural Integrity*, Elsevier B.V., 12, 317–329.

Christian, S. J., and Billington, S. L. (2011). "Mechanical response of PHB- and cellulose acetate natural fiber-reinforced composites for construction applications." *Composites Part B*, Elsevier Ltd, 42(7), 1920–1928.

Codyre, L., Mak, K., and Fam, A. (2016). "Flexural and axial behaviour of sandwich panels with bio-based flax fibre-reinforced polymer skins and various foam core densities." *Journal of Sandwich Structures and Materials*, 1–22.

Mak, K., and Fam, A. (2019). "Performance of flax-FRP sandwich panels exposed to different ambient temperatures." *Construction and Building Materials*, Elsevier Ltd, 219, 121–130.

Mak, K., Fam, A., and Macdougall, C. (2015). "Flexural Behavior of Sandwich Panels with Bio-FRP Skins Made of Flax Fibers and Epoxidized Pine-Oil Resin." *Journal of Composites for Construction*, 19(2003), 1–13.

Sadeghian, P., Hristozov, D., and Wroblewski, L. (2018). "Experimental and analytical behavior of sandwich composite beams: Comparison of natural and synthetic materials." *Journal of Sandwich Structures and Materials*, 20(3), 287–307.