THREE-POINT BENDING OF SANDWICH BEAMS WITH FRP FACING AND PP HONEYCOMB CORE

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Abstract: In this study, two sets of sandwich beams were tested in three-point bending. The sandwich panels were fabricated in a wet layup process. The facing component was made of either polyethylene terephthalate (PET) fiber-reinforced polymer (FRP), or glass fiber reinforced polymer (GFRP). The facing thickness was 3 mm for both PET FRP and GFRP. Polypropylene (PP) in honeycomb structure form, with a density of 80 kg/m3, was used as the core component among all tested beams. The sandwich beam dimensions were consistent at 1,200 mm length, 78 mm width, and 82 mm height. While testing each sandwich beam, the applied load, overall beam deflection, and facing strain were captured at mid-span. The resulting data were processed to produce load-deflection, moment-curvature, and load-strain diagrams. At peak load, bond failure between the walls of the cylindrical tubes within the honeycomb structure occurred; therefore, the failure mode for all tested sandwich beams was attributed to shear failure. The load-deflection relation was nonlinear in both sets, which was derived from the thermoplastic component (PET FRP facing and/or PP core). A nonlinear analytical model was developed and compared to the experimental testing data. The method used for experimental testing and analytical modelling was outlined in this study. The experimental matrix, testing results, and analytical model indicated that the nonlinearity of the sandwich beam's load-deflection relation stems from the facing and core components. In contrast, the nonlinearity of moment-curvature and load-strain relation stems solely from the facing component.

1 INTRODUCTION

Honeycomb sandwich panels are used in a wide range of structural applications (Wen-chao and Chung-fai 2000). Their high flexural rigidity and strength-to-weight ratio contribute to its widespread use in the following industries: automobile (He and Hu 2008), aerospace (Wang and Yang 2000), and marine (Meo et al. 2005; Zhang et al. 2021). An increase in environmental consciousness has promoted the development and analysis of new forms of honeycomb sandwich panels incorporating sustainable materials—namely, wood waste (Dutra et al. 2019), natural fibres (Petrone et al. 2013), and paper (Fu and Sadeghian 2020), in recent literature. Sandwich panels developed in this study consist of thermoplastic components. Besides having a relatively low cost, thermoplastics are recyclable and can be derived from mechanically recycled plastic waste. Thermoplastics' numerous superior features—including low density, corrosion resistance, and malleability—has led its usage to surpass that of various metals, including aluminium (Grigore 2017). Polypropylene (PP) and polyethylene terephthalate (PET) are among the most currently produced thermoplastic resins, significantly affecting the world's economy (Danso et al. 2019). Thus, PP honeycomb was selected as the sandwich panels' core component, whereas the facing components were comprised of PET fibre reinforced polymer (FRP) or GFRP composites.

The material nonlinearity associated with the PP core and PET FRP facing was observed from the flexural test results and further explored through a developed analytical model. The parabola equation was utilized to account for the material nonlinearity of the PP core. This method was previously used in literature for modelling nonlinear core and facing components of sandwich panels. Fu and Sadeghian used the parabola equation to simulate the shear stress-strain of the paper honeycomb structure used as a sandwich core component (Fu and Sadeghian 2020). Another study utilized the parabola equation to account for the nonlinearity of flax FRP facing while developing a model that described the overall sandwich beam's behaviour in flexure (Betts et al. 2020). Similarly, in this study, the stress-strain of PP honeycomb was assumed to follow a parabolic trend. The experimental testing results were used to verify this assumption.

2 EXPERIMENTAL PROGRAM

The experimental program was conducted to evaluate the mechanical performance of the sandwich beams in bending. The test matrix incorporated two sandwich beam sets, each consisting of three identical specimens. The primary difference between sets was the type of FRP composite used for the facing component. The two types of facing composites were fabricated with the same polymer matrix, and PP honeycomb was used as the sandwich beams' core component. The beam specimens were all tested under identical conditions in a three-point bending configuration. Consequently, the testing results were analyzed, and the midspan load-deflection, moment-curvature, and load-strain behaviours of each beam set were derived.

2.1 Fabrication of Sandwich Beams

Two sandwich panels were fabricated following a wet layup process. A layer of mixed epoxy and hardener was evenly spread on a lined parchment sheet illustrated in Figure 1 (a). The unidirectional fabric was cut to the required length and placed on the first epoxy layer, as shown in Figure 1 (b) and (c).

Figure 1: Fabrication of sandwich panel: (a) parchment paper taped on table surface; (b) fabric cut to the required length; (c) layer of fabric placed on epoxy layer; (d) core component placed on second layer of spread-evenly epoxy; (e) second FRP facing component set on PP core.

The fibres were oriented longitudinally through the length of the panel, and another layer of epoxy was spread onto the surface of the dry fabric. Subsequently, the PP core component was carefully set on the spread epoxy layer, as shown in Figure 1 (d). The FRP composite was left to cure with the core component for four days at room temperature. After the curing period, the second facing component was created and bonded to the other side of the core component using an identical fabrication procedure. After the sandwich panel fabrication, the panel was cut through its length into four equal sandwich beams. Each beam was 1200 mm in length and 76 mm wide. The facing component was approximately 3 mm thick, and the honeycomb core was 79 mm thick.

2.2 Instrumentation and Testing Procedure

The sandwich beams were tested in a three-point bending configuration. Each beam specimen was supported on a steel roller from each end, as shown in Figure 2, and the concentric load was applied at the unsupported mid-length through a 350 mm wide hollow structural section (HSS). To avoid premature failure due to the concentration of stresses at the corners of HSS and specimen interface, the HSS used for loading had round edges.

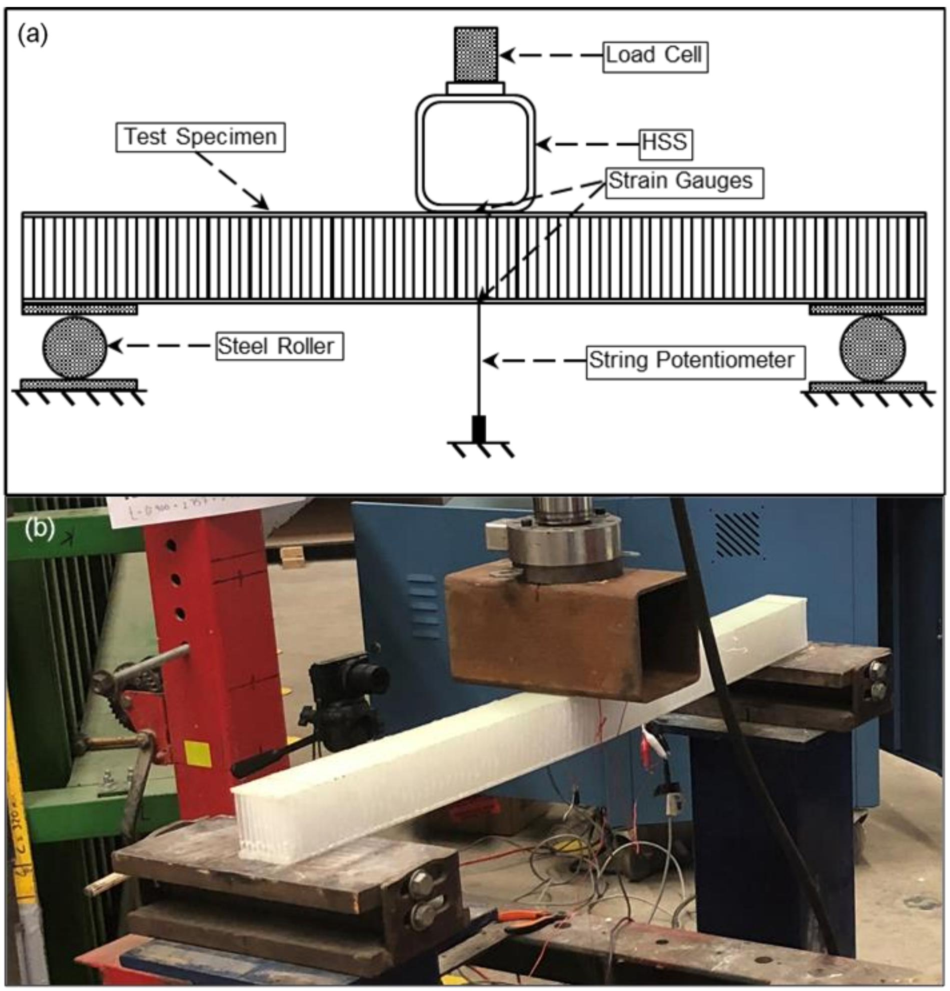

Figure 2: Three-point bending setup: (a) sketched test fixture; (b) photo of test specimen.

The weight of the HSS was accounted for during the analysis stage. The loading was set to a displacement-controlled rate of 6 mm per minute. Two strain gauges were mounted at the top and bottom facing components to capture the change in tension and compression strains through bending. The change in midspan displacement was captured using a string potentiometer. The strain gauges, potentiometer, and load cell were connected to a data acquisition (DAQ) unit throughout the bending test. The DAQ unit was set to record displacement, strain, and load-resistance data at a 0.1-second interval throughout the testing period and until each specimen reached peak load.

3 DATA ANALYSIS AND TEST RESULTS

Data obtained from the DAQ unit for the sandwich beam sets were derived, analyzed, and compared. All tested specimens failed in core shear mode. As shown in Figure 3 (b), delamination at peak load occurred at one point within the vertical honeycomb section. Table 1 provides a summary of the fundamental properties associated with each specimen at peak load. Sandwich beams made with GFRP had higher ultimate load and moment capacities than sandwich beams with PET FRP facings. In contrast, beams with PET FRP facing had significantly higher strain capacity.

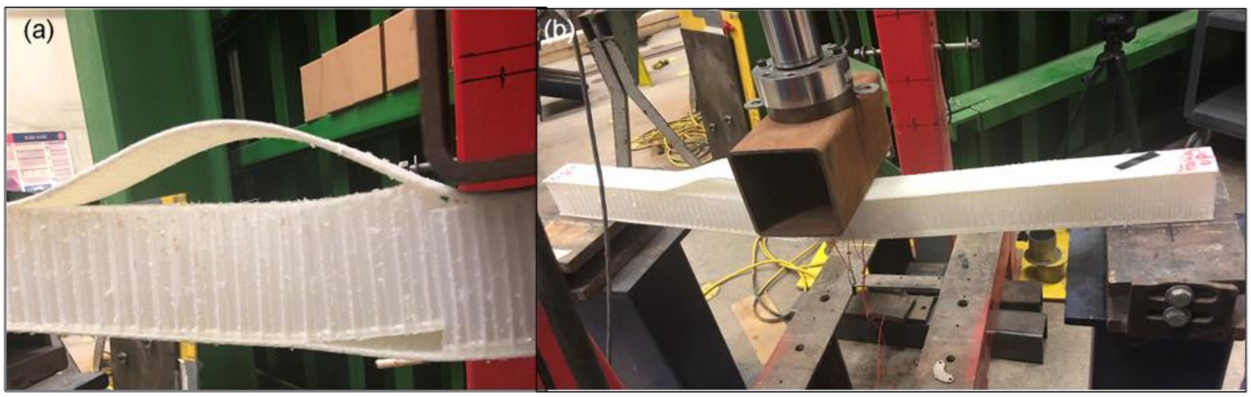

Figure 3: Specimen after reaching ultimate load capacity: (a) delamination of honeycomb structure; (b) overall specimen following core shear failure.

Table 1: Mechanical properties of sandwich beams at peak-load

Specimen	Load (kN)	Deflection (mm)	Tensile Strain (με)	Compressive Strain (με)	Moment (kNm)	Curvature (1/m)
1-PET FRP-PP80	4.2	38	9561	-12398	1.2	0.28
2-PET FRP-PP80	4.3	36	8223	-9196	1.2	0.20
3-PETFRP-PP80	4.5	32	9557	-14657	1.2	0.33
1-GFRP-PP80	5.5	33	3878	-4127	1.5	0.09
2-GFRP-PP80	6.1	41	3458	-5529	1.4	0.10
3-GFRP-PP80	5.2	27	3532	-4184	1.4	0.09

Figure 4 presents the load-deflection relation of sandwich beams throughout the bending test. As illustrated, the facing component stiffness significantly impacts the overall beam stiffness. Hence, beams with GFRP facing had higher stiffness compared to beams made from PET FRP facing. Nevertheless, both sandwich sets failed in core shear; the choice of material used for the facing component could increase the beam's overall load-resistance capacity. The load-deflection relation of all sandwich specimen followed a linear trend during the initial loading stage. As the applied load increased, the load-deflection relation became nonlinear, which stems from thermoplastic components—namely, PP core and PET FRP facing of the sandwich beams.

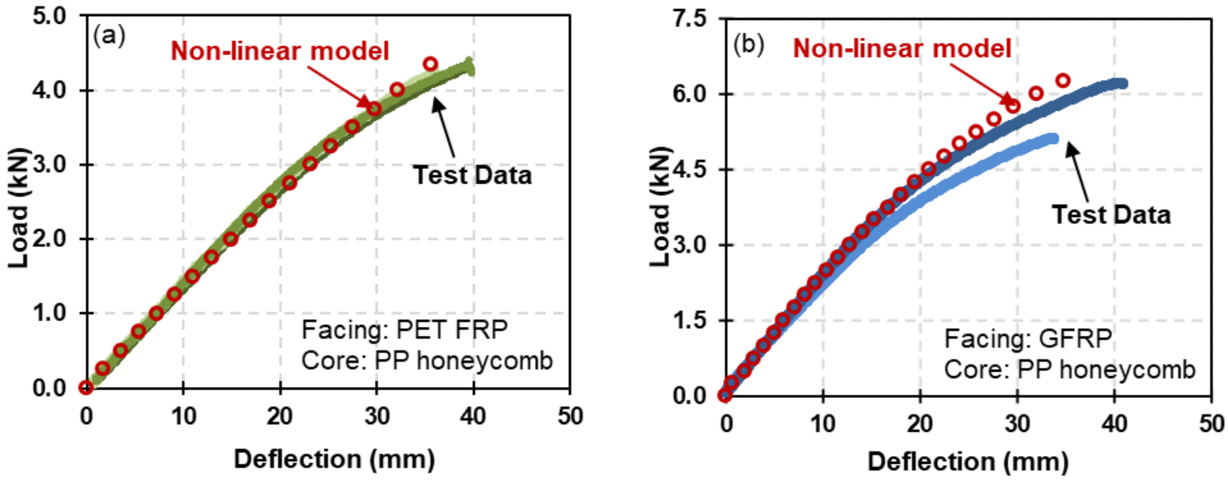

Figure 4: Load-deflection of tested sandwich specimens made from: (a) PET FRP facing; (b) GFRP facing.

The strain was captured from the top, and bottom sandwich facings. The large strain capacity of PET FRP–compared to GFRP–could be noticed by comparing the load-strain and corresponding moment-curvature relationships of the two sandwich beam sets. The stress-strain relation of GFRP is linear. Therefore, load-strain and moment-curvature–illustrated in Figure 5 (a) and (b)–relationships of beams comprised of GFRP facing followed a linear trend.

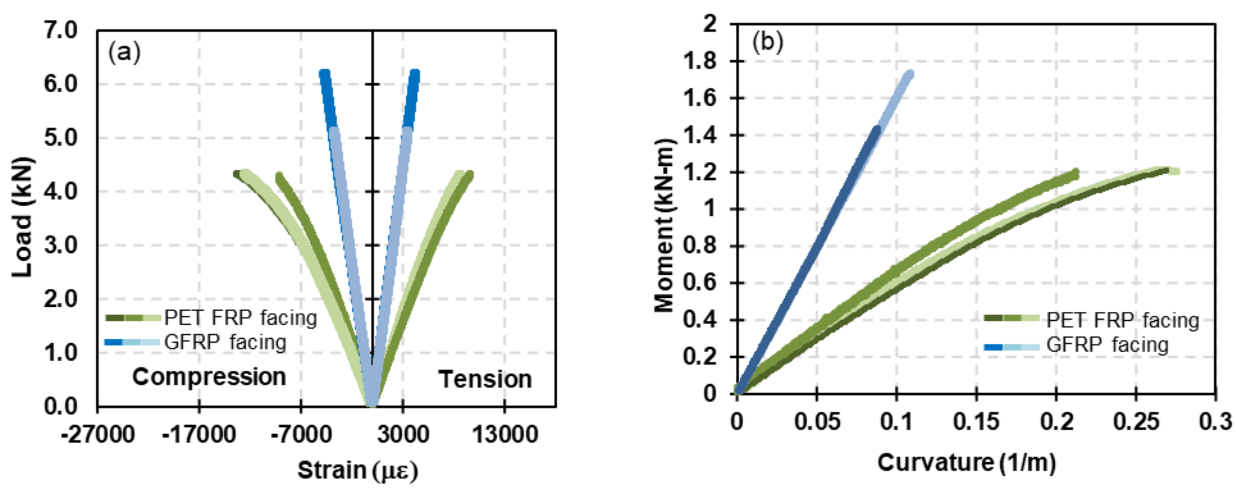

Figure 5: (a) Load-strain and (b) moment-curvature relation derived from testing data.

4. NONLINEAR MODEL

The nonlinear load-deflection relation was modelled assuming the shear stress-strain relation of PP honeycomb core holds a parabolic relation. Following this assumption, the secant shear modulus was used at each loading stage. The shear modulus was obtained from the technical data sheet provided by the manufacturer (Plascore 2021). Furthermore, a bilinear model accounted for the nonlinearity of PET FRP's stress-strain relation (Kassab 2020). Secant elastic modulus was used for each load step of the load-deflection model for the sandwich set comprised of PET FRP facing. Figure 4 illustrates the nonlinear load-deflection model and test data of the two sandwich sets. As Figure 4 illustrates, model prediction is in good agreement with the experimental testing results. Therefore, this justifies the use of the parabola equation within the model.

5. FUTURE STUDIES

Future studies will explore ways to trigger various modes of failure, including face wrinkling and face rupture. Subsequently, a failure mode map will be developed and verified using the collected data. Future research will also seek to achieve a sandwich panel with a lower environmental impact by substituting epoxy with bio-based resin. In addition, the sandwich facing and core will be obtained from a mechanically recycled plastic source.

6. CONCLUSIONS

This study presents the three-point bending test result of two sets of sandwich beams comprised of PET FRP and GFRP composite facing and PP honeycomb core. The testing results were analyzed, and key mechanical properties deduced. The stiffness of the facing component had a direct effect on the stiffness of the overall sandwich beams. Sandwich beams made with GFRP facing reached a higher ultimate peak load at failure compared to beams comprised of PET FRP facing. The thermoplastic components have caused the load-deflection relation of all tested beams to be nonlinear. An analytical model—considering PP and PET FRP's material nonlinearity—was developed and verified against the test data.

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