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FLEXURAL BEHAVIOUR OF A SUSTAINABLE HYBRID COMPOSITE PANEL USING NATURAL FIBRES

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ABSTRACT

Although many efforts have been made to utilize natural fibers for building components, most were found to be either structurally or economically unviable. A bio-based building component with higher structural performance is normally achieved at the expense of significantly higher cost as a larger size is typically required. Similarly, reducing the size to maintain the cost will only produce a building component with lower structural perforce that may not competitive with conventional building materials. In order to overcome these shortcomings, a hybrid sandwich panel was developed where a natural fiber composite (NFC) laminate is placed as an intermediate layer in between an aluminum skin and an EPS core.

This paper presents the research outcomes of the flexural behavior of this hybrid composite sandwich panel which can be manufactured as modular panelized system. Two different types of natural fiber reinforced plastics (NFRP) laminate were incorporated into the new sandwich panel as an intermediate layer and their performance were compared. The flexural behavior was investigated through experimental testing.

1 INTRODUCTION

In order to meet the challenges of providing appropriate accommodation in a large scale at relatively affordable price, a research project has been carried out aimed at developing a new type of hybrid composite sandwich wall panel which can be manufactured as modular panelized system. The typical sandwich panel used in building application commonly consists of metal skins and soft core. Although oriented strand board (OSB) is commonly employed for the skin of sandwich structure in structural insulated panels (SIPs), the observed shortcomings of this typical skin such as mould build-up and disintegration in the presence of flood water [1] has reduced their usage. Metal skins are preeminent choice for their many advantages, but the price is always a concern. Consequently, reducing the thickness of the skin as much as possible is the only way to keep a competitive and reasonable overall cost. However, using thinner skins may result in the early failure of sandwich structure, such as face wrinkling or inundation. The sustainable hybrid concept developed in this paper has been considered as a practical solution where an intermediate layer made from natural fibers composite (NFC) laminate was introduced. Natural fibers are a major renewable resource material throughout the world specifically in the tropics. The use of NFC in a range of industrial applications has increased significantly over the last decades. Suddell and Rosemaund [2] claimed that the construction industry constitutes the second largest sector to employ NFC which includes light structural wall, insulation materials, floor and wall coverings, geotextiles and thatch roofing. Although many efforts have been made to utilize natural fibers for building components, most were found to be either structurally or economically unviable. A bio-based building component with higher structural performance is normally achieved at the expense of significantly higher cost as a larger size is typically required. Similarly, reducing the size to maintain the cost will only produce a building component with lower structural perforce that may not competitive with conventional building materials. In order to overcome these shortcomings, it is proposed that a NFC laminate is placed as an intermediate layer in between an aluminum skin and an EPS core.

The flexural behavior of sandwich structure and its mode of failure have been studied extensively by a number of researchers [3-5]. An early paper in this area was reported by [3], which highlighted some of the basic theories of flexure behavior, particularly as it applied to sandwich constructions. Manalo et al [4] studied the flexural behavior of structural fiber composite sandwich beams. The beams were made up of glass fiber reinforced polymer skins and modified phenolic core. The panels were subjected to 4-point static bending test to determine their strength and failure mechanism in flatwise and edge positions. The result of this study showed the potential of this innovative composite sandwich panel for structural laminated beam. Uddin and Kalyankar [5] reported their study on the manufacturing and structural feasibility of natural fiber reinforced polymer structural insulated panels (NSIPs) for panelized construction. The sandwich panel consists of jute fiber composite skins and expanded polystyrene (EPS) core. Flexural and impact testing were conducted for the structural characterization. It was found that the average failure load of NSIPs was lower than that of OSB SIPs, but almost doubled the average value of sandwich panel with glass polypropylene (G/PP). In term of bending stress, however, NSIPs was 90% higher than the traditional OSB SIPS and was only 20% less than G/PP SIPs. Clearly, there is a promising improvement when incorporating natural fiber composites in a sandwich panel structure. In this paper, 4-point bending test has been conducted to evaluate the flexural bending capacity of the hybrid sandwich panel.

2 SAMPLE PREPARATION

2.1 Natural fiber preparation

Although three types of natural fibers were used in our research project, only Jute and Hemp fibers were adopted for flexural strength testing. For details of natural fiber treatment, refer [6].

A vacuum bagging process was used for preparing natural fiber laminates. Vacuum bagging (or vacuum bag laminating) is defined as a clamping method that uses atmospheric pressure to hold the adhesive or resin-coated components of a lamination in place until the adhesive cures. A simple description of vacuum bag moulding is the process that combines a manual method using hand-layup or spray-up on the open mould to produce a laminated component with a vacuum process after covering the laminated using polymeric sheet [7]. A modified low viscosity epoxy resin (R180) was used with a hardener (H180) and a resin and hardener ratio of 100:20 by weight. Low viscosity combined with a fast cure makes this system ideal for marine and civil engineering application. Once the laminates were cured, they were cut into the required size. The equipment for the vacuum bagging process used in this research is shown in Figure 1.

The experimental characterizations of NFCs were performed using tensile, compressive, flexural and shear tests. The tests were carried out as per the relevant ISO and ASTM standards for composite laminates. The comparison of tensile strength among different NFCs and medium density fiber (MDF) tested is presented in Figure 2.

2.2 Flexural testing panel preparation

Jute and hemp laminates for the intermediate layer were fabricated as per described in Section 2.1. Aluminum skins were purchased from local warehouse in Toowoomba which is aluminum 5005 H34 sheet. Aluminum 5005 is a lean aluminum magnesium alloy, contains nominally 0.8% magnesium, which can be hardened by cold work. It has medium strength, good weld ability, and good corrosion resistance. It also has excellent thermal conductivity and low density. An expanded polystyrene (EPS) is used for the core of this hybrid sandwich panel. It is a closed cell, resilient, lightweight rigid cellular plastic material which contains no hydro-fluorocarbon (HFC) or hydro-chlorofluocarbon (HCFC) blowing agents that might cause depletion of ozone in the upper atmosphere. When used as insulation and cladding EPS provides a reduction in energy use and cost for cooling in summer or heating in winter. The characteristic of Aluminum skin and EPS core used in this research are presented in Table 1.

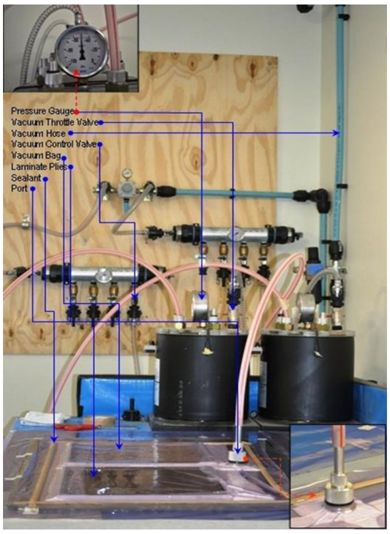


Figure 1 Vacuum bagging process

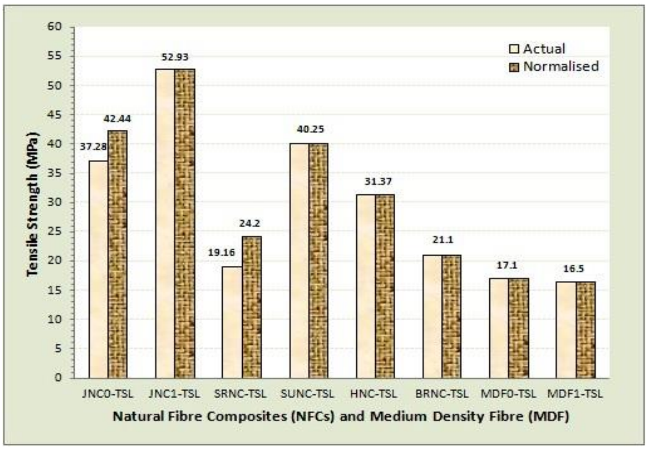


Figure 2 Tensile strength of NFCs and MDF

Table 1 Properties of aluminum skin and EPS core.

	Aluminum 5005 H34	**Isolite® EPS**
Density (ρ)	2700 kg/m^3	28 kg/m^3
Modulus Elasticity (E)	68.2 GPa	7.25 MPa
Poisson ratio	0.33	0.35
Shear modulus	25.9 GPa	–
Shear strength	96.5 MPa	0.24MPa
Ultimate tensile strength	159 MPa	–
Yield tensile strength	138 MPa	0.337MPa

Sandwich panel specimens were manually prepared using a pressing system. All constituent parts were cut into the same length and width and glued together using structural grade adhesive. The NFCs intermediate layers were sanded-up using sanding machine to obtain uniform thickness while aluminum sheet were roughed manually using sandpaper. The EPS core was sliced using hot knife foam cutter to obtain the required thickness. When all constituents ready, they were glued and placed in the pressure system. The system was prepared using wood and the pressure was given by the attached bolts at the end of each lumber. The fresh glued sandwich panel specimens were placed in between two 12 mm hardboards panels and clamped with pieces of wood at the top and bottom side. A torque wrench tool was used when tightens-up all the bolts to ensure uniform pressure were given to the samples. Furthermore, a structural grade adhesive with the commercial name of Kwik Grip Advanced was used for gluing all the sandwich layers together. As it contains no organic solvent, it is suitable for bonding materials sensitive to solvent attack, e.g. polystyrene foams. The process of sample preparation is shown in Figure 3.

The samples were prepared in two scales, medium and large scale. The medium size specimens were cut and shaped into a span length of 450 mm and the size of 550 x 50 x 22 mm for length, width and thickness, respectively. The large scale specimens were prepared in the size of 1150 x 100 x 52 mm with the span length of 900 mm. Aluminum sheet with the thickness of 0.5 mm was used as the skins for medium size specimens and 1 mm for the large specimens. For the intermediate layer, jute and hemp composite laminates were used with the thickness of 3 mm and 5 mm for the medium and large size specimens, respectively. For the medium size specimens, the thickness of EPS core for control level was 21 mm and 15 mm for the other two levels to maintain a constant overall thickness of 22 mm for the specimen. The large scale specimens were used EPS with the thickness of 50 mm for the control level and 40 mm for both variables to keep the overall thickness of 52 mm. Each level was replicated 5 times; hence the total of samples tested was 15 samples for the medium scale and also 15 samples for the large scale specimens. The arrangements of the flexural test specimens are shown in Tables 2 and 3.

Figure 3 Sandwich panel fabrication process

3 EXPERIMENTAL PROGRAM

The flexural test of hybrid composite sandwich panel was conducted in accordance with the ASTM C393-00 standard (ASTM, 2000) which is a standard test method for flexural properties of sandwich constructions. This test method covers determination of the properties of flat sandwich constructions subjected to flatwise flexure in such manner that the applied moments produce curvature of the sandwich facing planes. The load was applied at 1/3 and 2/3 of the span length. The testing was performed using a 100 kN servo-hydraulic machine with a loading rate of 5 mm/min. The loading pins and the supports had a diameter of 20 mm. In order to prevent the existence of early failure, a steel plate was placed in between specimen and loading point and also between specimen and support. Strain gauges were attached at the middle top and bottom surface of specimens to record the longitudinal strain during the progress of testing. The applied load, displacement and strains were obtained using System 5000 data logger system. Prior to each run of the testing, the loading pins were setup to nearly touch the top surface of the specimen and the machine then was re-set to the default position. The test was terminated after a visible collapse mechanism encountered or the specimen was undergoing large displacement but could not carry any increased load.

Table 2 Experimental arrangements for flexural testing (medium scale).

Samples Code	Skin		Intermediate layer		Core		Number of sample
	Material	Thickness	Material	Thickness	Material	Thickness	
CTR	Aluminum	0.5 mm	None	-	EPS	21 mm	5
JFC	Aluminum	0.5 mm	Jute	3 mm	EPS	15 mm	5
HFC	Aluminum	0.5 mm	Hemp	3 mm	EPS	15 mm	5

Table 3 Experimental arrangements for flexural testing (large scale).

Samples Code	Skin		Intermediate layer		Core		Number of sample
	Material	Thickness	Material	Thickness	Material	Thickness	
CTR	Aluminum	1.0 mm	None	-	EPS	50 mm	5
JFC	Aluminum	1.0 mm	Jute	5 mm	EPS	40 mm	5
MDF	Aluminum	1.0 mm	MDF	5 mm	EPS	40 mm	5

4 RESULTS AND DISCUSSIONS

4.1 Comparison of ultimate load and load-deflection behavior

The typical load-deflection curves of sandwich panels with medium and large size tested are presented in Figures 4 and 5 respectively. It is clearly shown in Figure 4 that the introduction of intermediate layer has substantially enhanced the load carrying capacity of sandwich panels. It is also demonstrated that the introduction of intermediate layer has increased the ductility of the panel. However, a sudden drop at ultimate load for panel with HFC intermediate layer is undesirable for earthquake resistant structure. Overall, hybrid sandwich panel with JFC intermediate layer performed best compared to other panels.

For large sized panel as shown in Figure 5, it is clearly demonstrated that hybrid sandwich panels with MDF intermediate layer were much stiffer than those with JFC intermediate layer. Sandwich panels with no intermediate layer (CTR) also stiffer than those with JFC intermediate layer. In general, although hybrid sandwich panels with JFC intermediate layer were less stiff than those with MDF intermediate layer, the very ductile behavior of this type of panel has an additional advantage of being much safer when utilized in the building. There has obvious advantage when intermediate layer is incorporated which is related to the toughness of the material and load carrying capacity.

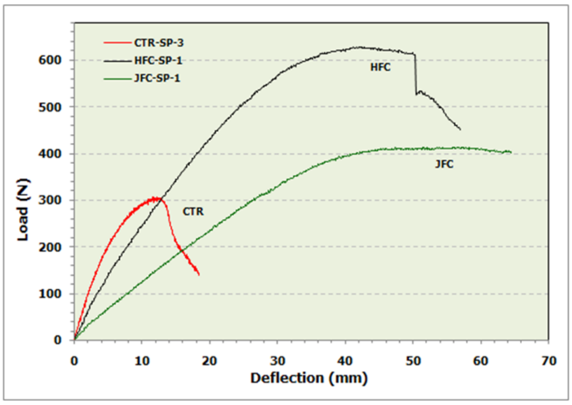


Figure 4 Load-deflection of medium-scale beams

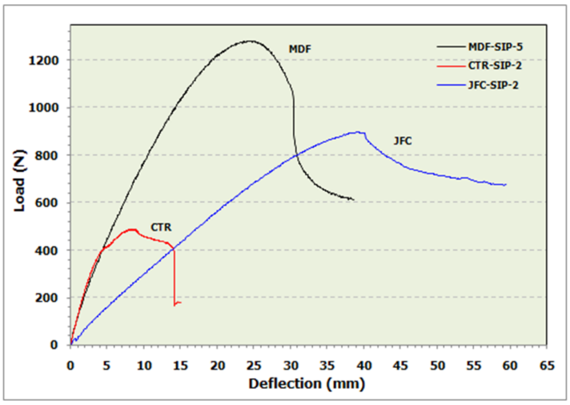
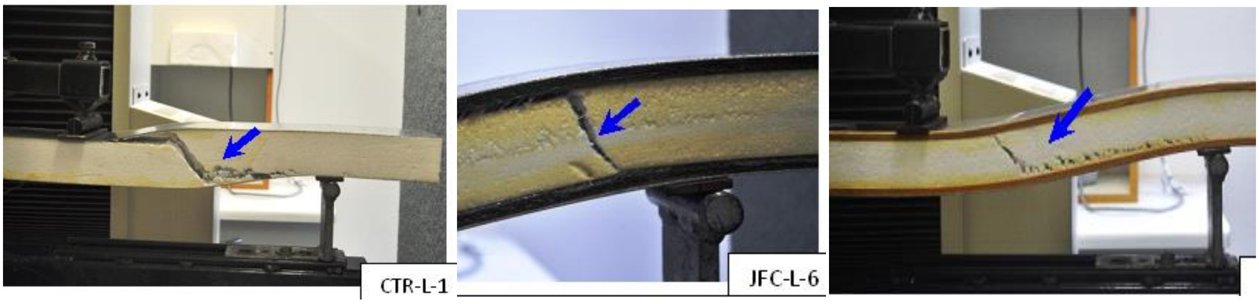


Figure 5 Load-deflection of large-scale beams

4.2 Comparison of failure modes

Only the failure modes for large sized samples are discussed here. Figure 6(a) shows the typical failure mode for CTR specimen which was the diagonal shear crack of the core. Another type of failure mode for CTR observed was the deboning at the interface of the core and skin at the upper part of the beam. Figure 6(b) shows the failure model of JFR specimen, delamination of the core-intermediate layer (weak bond) followed by the shear failure of the core. Figure 6(c) shows the typical failure mode of MDF specimen, which was a shear failure of the core without deboning at the interface of core and intermediate layer. It suggests that the bond strength at the interface of the core-intermediate layer exceeded the compression strength of the core and resulted in higher load bearing capacity of the specimens.



(a) CTR specimen (b) JFR specimen (c) MDF specimen

Figure 6 Failure modes of large-scale beams

5 CONCLUSIONS

The flexural behavior of hybrid sandwich panels with an intermediate layer made from natural fiber has been examined under the four-point bending test. The testing results indicated that incorporating intermediate layer significantly enhanced the flexural behavior of the hybrid sandwich panels. The load carrying capacity of medium sized hybrid panel was 29.6% and 93.46% higher than conventional sandwich panel for JFC and HFC specimens respectively. For large sized panels, the load carrying capacity of hybrid sandwich panel was approximately 62.59% and 168.58% higher than those of conventional sandwich panel for JFC and MDF specimens respectively. The hybrid sandwich panels also increased the ductility and toughness of the panel. The introduction of intermediate layer has prevented the occurrence of premature failure such as indentation or delamination of skin and core due to buckling and resulted in higher flexural ultimate load carrying capacity.

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