Hybrid Composite Sandwich Panels for Lightweight Housing Components: Concept and Experimental Results

Jauhar Fajrin[1(✉)] and Yan Zhuge[2]

[1] Department of Civil Engineering, University of Mataram, Mataram, Indonesia
jauhar.fajrin@unram.ac.id
[2] Department of Civil Engineering, University of South Australia, Adelaide, Australia
Yan.Zhuge@unisa.edu.au

Abstract. Reducing the weight of structures is one of the key factors in maintaining affordable housing costs. The self-weight of a structure, which makes up a significant portion of the total load on a structure, may be decreased by using the appropriate material. Today, a lightweight composite sandwich panel that can be produced quickly, cheaply, and in huge quantities is an option for housing applications. This article describes the findings of experimental research into the development of hybrid composite sandwich panels with an intermediate layer made of natural fiber composites. A brief overview of two earlier experimental experiments is included in the article. This article is divided into two sections, the first of which covers the flexural behavior of a recently developed hybrid composite sandwich panel and the second of which is concerned with the in-plane shear behavior of a small-scale wall panel. The overall results showed that the hybrid composite sandwich panel performs better than conventional sandwich panels. In flexural testing, the use of an intermediary layer enables sandwich panels to withstand higher compression strain before reaching their maximum stresses, preventing panels from early failure such as buckling or indentation. The results of a diagonal shear test showed that adding an intermediate layer to a sandwich construction significantly enhanced the in-plane shear behavior of the newly developed hybrid composite sandwich panels.

Keywords: Sandwich Panel · Lightweight House · Hybrid Composite

1 Introduction

Humans have a basic need for housing. As the world's population has grown and cities have become more populated, housing demand has risen steadily. Providing enough suitable and cheap housing will be the greatest problem in the future. Considering how quickly the need is increasing, the housing supply is falling short of the demand. Because of this lopsided trend, especially in metropolitan areas, the cost of lodging has also been rising steadily. It has never been easy for the government or the housing industry to

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provide large-scale homes. It has been on the thoughts of the builders how to build new homes on a large scale at a fair price.

There are two key components to overcoming these challenges. First, reduce the weight of the buildings to keep prices down. The self-weight of a building makes up a sizeable portion of the total load when it is being built. The weight of a structure can be reduced by using the proper materials, which also reduces the size of the foundation and other supporting components and lowers the overall cost of construction. Second, adopting a panelized housing approach to encourage the production of homes in large quantities. All housing components in a panelized home system are manufactured in a factory and then delivered to the construction site for erection. A house can be built more quickly with this construction method than with stick-built dwellings. Most of the time, panelized homes may be put together in a couple of days, using less work and allowing for the construction of additional dwellings. Another advantage of panelized homes is their capacity to prevent cost overruns, limit weather damage during building, and utilize the greatest level of precise engineering [1].

In order to include those two crucial components in the building of homes, many construction industries now use composite sandwich panels, which can be made rapidly and inexpensively in significant quantities. Composite sandwich panels have historically been utilized extensively in manufacturing sectors like aerospace, marine, and automotive. It is now a feasible option, especially for lightweight applications, in other application fields like civil infrastructure. The most well-known benefit of composite sandwich panels, which put them first on the list of lightweight material options, is their high strength to weight ratio. In addition to being lightweight, composite sandwich panels also have the advantages of being simple to transport, requiring fewer resources to produce, and having excellent insulation properties. Due to this, composite sandwich panels are being employed more frequently as an alternative in modern lightweight constructions.

Composite sandwich panels have the extra advantage of being very resilient to earthquake risks because of their lightweight characteristics. According to Newton's law, the mass and rate of acceleration of the building are related to the earthquake force. This suggests that the force increases in direct proportion to the building's weight. Reducing the weight of structures or buildings is therefore the most important factor in minimizing the risk of an earthquake [2]. Some researchers claimed that using composite sandwich panels during construction makes a building is eligible for green certification. The fact that less waste was generated during construction is evidence for this claim. Hong et al. [3] stated that the typical wet construction process produces a significant amount of hazardous materials and industrial waste. The existence of hazardous waste material causes significant economic losses for society, increases energy use, and brings about environmental problems. Another researcher associates sustainability with earthquake-resistant construction. Natural disasters, according to Lewis [4], are the primary indicator of non-sustainable growth. Building earthquake resistance is thus essential for sustainable living.

2 Research Concept

The basic concept of this research is to develop a new type of sandwich panel capable of carrying more load and having better structural properties by adding a new layer between the skin and core of a conventional sandwich panel structure - which will be referred to as the intermediate layer. The intermediate layer made of natural fiber composites is placed between the skins and core of conventional sandwich panels to form hybrid sandwich panels, as shown in Fig. 1. Theoretically, when a loading scheme is applied to a monolithic panel made of homogenous material, the usual stress distribution is a straight diagonal line running from the top surface to the bottom. However, as illustrated in Fig. 1, the stress distribution will significantly change at the top and bottom contact between the skin and core layers for sandwich structures. Many authors have identified stress discontinuity as one of the primary causes of sandwich panel failure. In order to mitigate the problem, it is proposed to add a layer with intermediate properties between the skins and the core [5]. Hooke's laws, which relate induced stress to a material's elasticity modulus, provide the best foundation for explaining this concept. Because the elastic modulus of the intermediate layers has a value between that of the skin and core, therefore their incorporation can reduce the abrupt transition between the high and low stresses within the skins and core. Theoretically, the sandwich panel composed of two layers of skins and intermediate layers at the top and bottom, and a core in the middle has a higher flexural strength.

Davies [6], stated that the yield stress of the skin material is less of a concern in sandwich construction because the load-bearing capacity of a structure is often determined by the wrinkling of skins under compression or the shear failure of the core. Thus, it is essential to introduce another layer that has qualities halfway between those of the skins

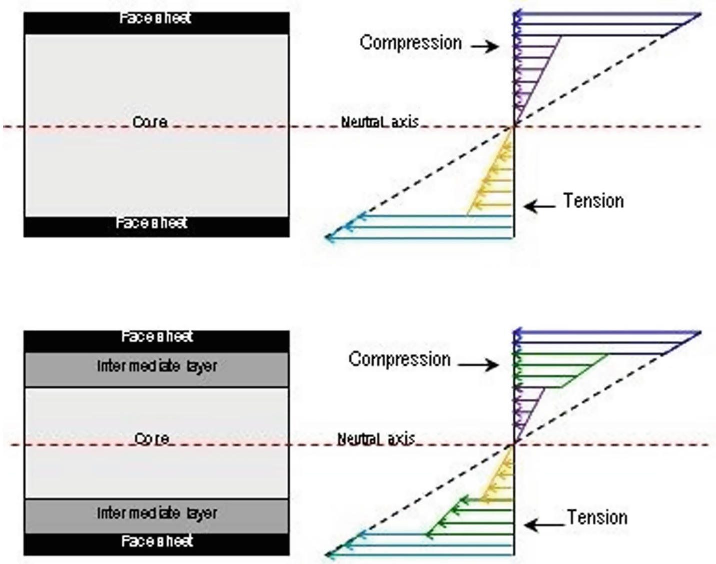

Fig. 1. Stress distribution in conventional and hybrid sandwich panel

and core in order to give the skins greater lateral support. Increasing the thickness of skins or improving the quality of core are currently the two most popular solutions to the problem. However, any strategy may have a significant impact on the overall cost. Due to the high cost of skin material, even a slight increase in face thickness will result in a significant cost increase. Even if the core is significantly less expensive than the skins, a thicker core may raise overall costs.

3 Results and Discussions

3.1 Experiment as Structural Insulated Panels

The most popular application of composite sandwich panels in the housing industry is thought to be structural insulated panels (SIPs). Oriented strand board (OSB) is commonly used as the skins, with a rigid insulating foam core sandwiched between them. SIPs construction is now used in favor of more traditional timber stud wall systems. Utilizing this cutting-edge building technology opens up a wide range of new possibilities for energy efficiency, design, and long-term cost savings. SIPs are a simple composite sandwich panel that can be used as the entire wall structure or as a wall component on top of timber framing. Using SIPs ensures high environmental sustainability as well as structural integrity. The finished product will use less material, energy, and materials than a traditionally constructed home. It will also produce less pollution and a better living environment. An energy-efficient curtain or cladding wall over timber framing can be built using SIPs at the component level. On its own, SIPs have the potential to create a strong, energy-efficient building envelope [8].

In this section, we highlight the work of Fajrin et al. as reported in reference [9], which is related to a flexural test experiment on a hybrid SIPs. The outer skins of panels were made of aluminum 5005 H34, and their inner cores were made of expanded polystyrene (EPS). Jute laminates and medium density fibre (MDF) board were employed for the intermediate layer. The specimens were prepared with dimensions of 1150 × 100 × 52 mm and a span length of 900 mm. The thickness of the samples corresponds the smallest size of commercially available structural insulated panels. In order to maintain a total thickness of 52 mm, the thickness of intermediate layer and the skins was 5 mm and 1 mm, respectively. A total of 12 beams were tested as per ASTM C 393-00 standard. A 100 kN hydraulic machine with a loading rate of 5 mm/min was used for the testing. The longitudinal strains were determined by mounting strain gauges to the top and bottom of the specimens. The applied load, displacement, and stresses were determined using the System 5000 data recorder. Sample settings and the actual testing setup are shown in Fig. 2.

The results of flexural testing are presented in Fig. 3. It is clearly shown that the average ultimate load capacity of traditional SIPs was 496.5 N, while the average ultimate load capacities of SIPs with intermediate layers made of JFC and MDF were 807.25 N and 1333.5 N, respectively. This means that the load carrying capacity of the hybrid SIP with JFC is 62.59 percent greater than the load carrying capacity of a traditional sandwich panel. SIPs with an MDF intermediate layer have a load carrying capacity that is approximately 168.58 percent greater. Furthermore, the load carried by the hybrid SIP with MDF intermediate layer was 65.19% greater than the load carried by the hybrid

Fig. 2. Sample preparation and the actual set-up of flexural test

SIP with JFC intermediate layer. It is also evidently demonstrated that conventional SIPs much stiffer than hybrid SIPs. Figure 3 also depicted the comparison of load-strain curves for the three sample categories. The figure shows that all of the tested beams have comparable top and bottom surface strains.

For instance, the curves for the conventional panels exhibit equal strain values at 210 microstrains for both the compression and tension sides. For the hybrid panels with MDF intermediate layer, slightly different strain values were discovered: 330 microstrains in tension and 360 microstrains in compression. Similar strains were also seen in hybrid panels with JFC intermediate layer, with 620 and 600 microstrains for the compression and tension sides, respectively. It is also worth noting that the conventional SIPs failed at 210 microstrains, which was only 58% of the strain in the MDF hybrid panels and 35% of the compression strain in the JFC hybrid panels. Overall, the addition of an intermediate layer allows hybrid SIPs to withstand more compression strain before reaching their ultimate loads, preventing them from buckling prematurely under compression.

3.2 Experiment as Wall Panels

The previous experiment results showed that the hybrid sandwich panel developed in this study performed exceptionally well under flexural pressure. However, flexural behavior is not really important aspect when using this type of sandwich panel as a structural building wall. Shear behavior, also known as in-plane shear behaviour, is crucial to understand when using sandwich panels for a wall, especially if the wall is intended to serve as a structural wall. The addition of an intermediate layer was expected to improve the in-plane shear behavior of sandwich panels. The following section describes the diagonal tension test used to evaluate the in-plane shear behavior of the newly developed hybrid sandwich panel. For this experiment, the specimens were prepared with the size of 380 $\times$ 380 mm, with a clear internal dimension of 300 $\times$ 300 mm within frame borders. For all specimens, the total thickness was kept constant at 26 mm. The hybrid panels was made by adding JFC laminate and MDF board, both of which had a 3 mm

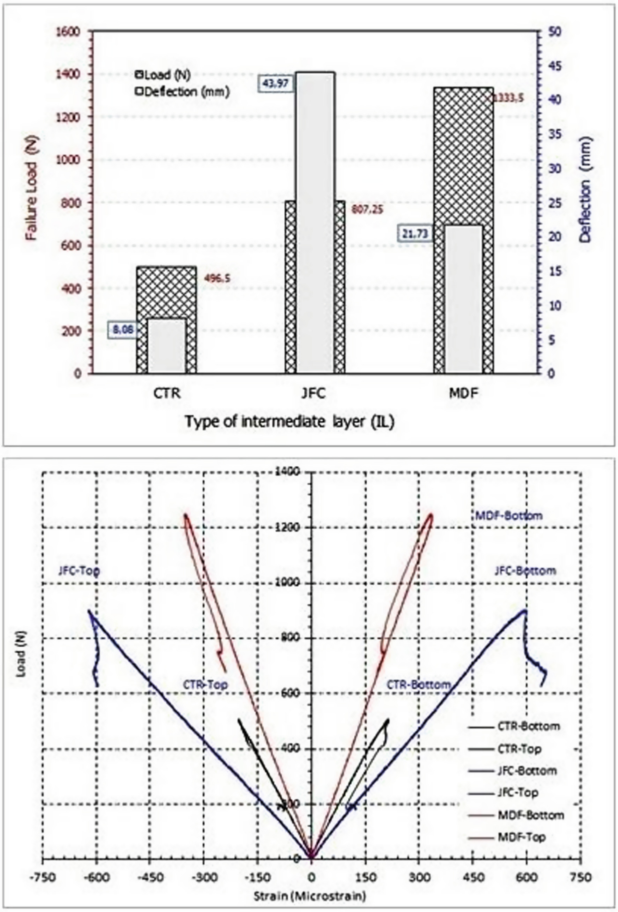

Fig. 3. The comparison of ultimate load-deflection and load-strain behavior of conventional and hybrid SIPs under flexural testing

thickness. The skins were made of 0.5 mm thick aluminum sheets. As the control, the conventional panels also prepared with the same thickness without intermediate layer. A total of 15 specimens were thoroughly tested and the results depicted in Fig. 4.

Figure 5 depicts the average ultimate diagonal load and vertical deformation for each sandwich panel type. The ultimate diagonal loads for hybrid panels with JFC and MDF intermediate layers were 49816 N and 22369 N, respectively, as shown in the figure. These values were significantly higher than the ultimate load of conventional panels, which is around 10252.8 N. In general, adding JFC and MDF as intermediate layers increases the diagonal load carrying capacity of sandwich panels by 385.87 and 118.17 percent, respectively. Furthermore, the ultimate load of hybrid sandwich panels with JFC intermediate layers was 122.7 percent higher than that of hybrid sandwich panels with MDF intermediate layers. This observable fact suggests that the material used for the intermediate layer has a significant impact on the overall performance of the hybrid

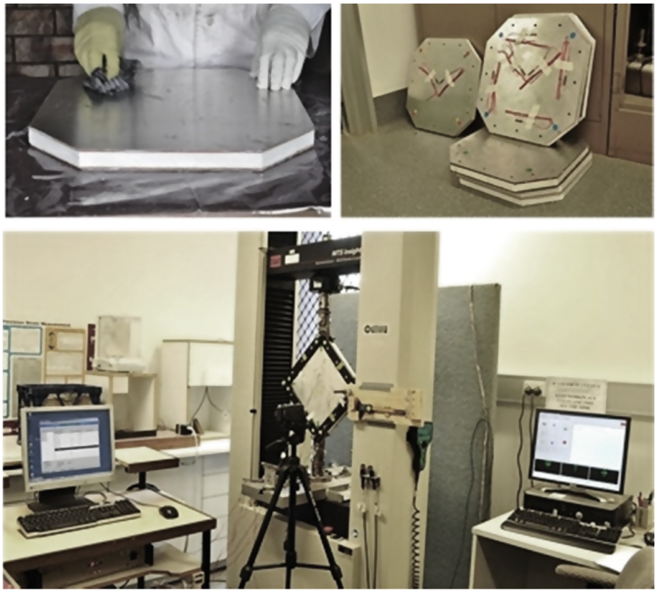

Fig. 4. Sandwich panels preparation and the actual set-up of diagonal shear test

sandwich panels. It is also clearly demonstrated that hybrid sandwich panels with a JFC intermediate layer were stiffer than hybrid sandwich panels with MDF intermediate layer and conventional panels. In comparison to the other two sandwich panels, the hybrid sandwich panels with JFC intermediate layer reached their maximum loads with less deformations.

Comparing the tension-compression strains for each panel types is considered as a valuable way to demonstrate how the addition of the intermediate layer significantly improved the sandwich in-plane shear behavior of the panels. Figure 5 clearly shown that the deformation capability of hybrid sandwich panels is substantially higher than that of conventional sandwich panels. The representative curve for conventional panels exhibits linear elastic behavior up to the maximum load. At a load of approximately 10,000 N, the maximum compression strain was approximately 380 microstrains, while the peak tension strain was approximately 500 microstrains.

Hybrid panels with MDF intermediate layers, on the other hand, achieved relatively similar tension and compression strains, both measuring around 800 microstrain at the load of approximately 18500 N. The strain initially rose in a similar linear fashion. The graph's shape then changed dramatically until the maximum load was reached. Similarly, the load-strain behavior of hybrid panels with JFC intermediate layers exhibits linear elastic behavior up to 45000 N before deviating slightly before reaching the ultimate load. The maximum tension and compression strain were around 1200 and 1450, respectively. It is also observed that the deformation capability in tension, which is measured as maximum tension strain that the panels can withstand, of hybrid sandwich panels with MDF intermediate layer is 1.6 times higher than the deformation capability of conventional sandwich panels, and 2.4 times for the hybrid panels with JFC intermediate layer. When

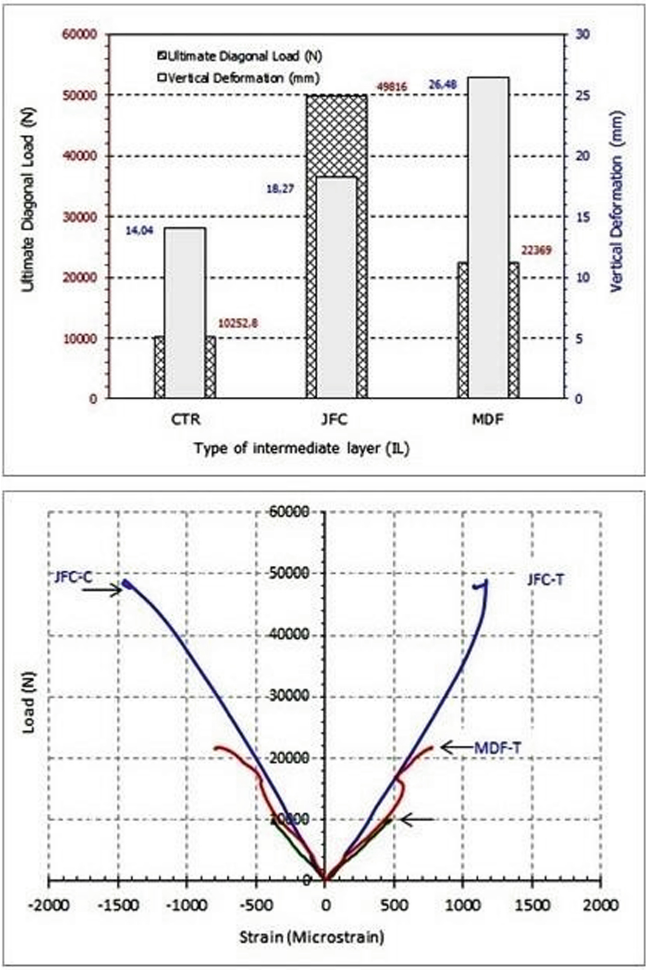

Fig. 5. The ultimate diagonal load-vertical deformation and load-strain relationship of sandwich panels under diagonal tension shear test

the compression strain is used to calculate the deformation capability, hybrid sandwich panels with MDF and JFC intermediate layers outperform conventional sandwich panels by 2.1 and 3.8 times, respectively. When subjected to the same load, hybrid sandwich panels with JFC and MDF intermediate layers distort less than conventional sandwich panels. The deformation capability of a structure is actually related to its ability to withstand significant deformation before collapsing, which is especially important when the panel is designed as a component of a structure in a seismically active region. Overall, the hybrid sandwich panel deforms better than the conventional sandwich panel.

4 Conclusions

The key finding from the reported experimental works is that the hybrid composite sandwich panel outperforms the traditional sandwich panel in terms of performance. Under a flexural load, the addition of an intermediary layer allows the sandwich panels to withstand greater compression strain before reaching their ultimate loads, preventing them from early failure due to buckling or indentation. The results of the diagonal shear test demonstrated that using intermediate layers greatly improved the load carrying capacity of sandwich panels.

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