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Determination of Optimum Material Usage in Sandwich Panel to Resist Higher Flexural Strength

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Abstract

Sandwich panels are known for their lightweight structure and impressive strength, making them useful in many construction and engineering applications. However, there is limited research on the use of affordable and readily available materials, such as plywood and foam, in sandwich panel construction, especially in understanding how these materials perform under flexural loads. In this project, we explore the performance of sandwich panels made with plywood as the outer layers and a foam core in between. The main aim is to examine the behavior of these panels under bending loads and to understand how core thickness affects their strength and flexibility. Experiments were carried out using a three-point bending test setup with commonly available plywood and rigid foam. The results indicated improvements in both stiffness and strength of the panels with changes in design. Typical failure patterns, such as increased deflection and material distortion under load, suggest deformation concentrated in the core and face layers were observed. Overall, the plywood-foam sandwich panels demonstrated good performance and appear promising as a lightweight option for structural use. This project highlights the potential of simple, easily accessible materials in modern construction solutions.

1. Introduction

Sandwich panels are popular in many areas of engineering and construction because they are both lightweight and strong [1]. They are usually made up of two outer layers with a lightweight core in between foam or a honeycomb material. This design offers several advantages, like easy handling, thermal insulation, and good structural performance [2]. But despite their benefits, sandwich panels also come with challenges, especially when it comes to how they handle mechanical loads over time [3]. One ordinary problem is that the layers of the panel can start to separate, especially under stress. If the bond between the core and outer layers fails, the panel loses its strength and can even collapse in extreme cases [1]. Another issue is the core itself, while it helps keep the panel light, it is not always strong enough to handle high loads and can crush or deform [4]. These panels are also sensitive to impacts, even a strong bump can crack the surface or damage the core inside. In Malaysia, sandwich panels are being used more and more in construction because they are affordable and easy to work with [5]. However, much remains unknown about how well these materials perform in the local climate [6].

Malaysia's hot, humid, and rainy weather can affect materials in ways that are not always obvious [2]. Moisture and heat can weaken the bonding between layers, cause the panels to warp or deform, and eventually lead to failure, especially under bending loads [7]. Another challenge is that local building practices and manufacturing quality can vary, which means not all panels are made or installed the same way. Without consistent quality, it is hard to predict how a panel will perform. On top of that, most of the testing standards we have are based on cooler, drier climates, not the kind of extreme conditions we get here in Malaysia because of all this, there is a lack of reliable data and guidelines for using sandwich panels in our construction industry [8]. That is why this project focuses on testing the flexural strength of sandwich panels made with plywood and foam core. These materials are not only affordable but also commonly available, making them suitable for testing under conditions similar to those experienced in this region [9]. The aim of this research is to determine the optimum design of sandwich panels. In order to achieve this aim, the objectives are to build a mini moel of sandwich panel, to analyze the flexural strength of sandwich panels and to determine the optimal use of materials in the sandwich panel.

2. Material and Method

2.1 Materials and Sandwich panel

Most modern construction prefers using sandwich panel over normal concrete because they are strong, lightweight, and good at insulating buildings [10]. They are made up of two outer layers and a core material in the middle. Each part has its own role to play, and the choice of materials can make a big difference depending on what the project needs. The outer layers are usually made from materials like aluminum, galvanized steel, or fiber-reinforced plastics (FRP) [1]. Aluminum is a great option for something light and resistant to rust, but it can be costly and does not handle impact as well. Galvanized steel is more affordable and offers flexibility in design, though it is heavier and can rust if the protective coating gets damaged. FRP materials stand out for their excellent resistance to corrosion and design versatility, but they might not hold up as well under long-term stress. Plywood is another widely used skin material in sandwich panels, especially valued for its high strength, durability, cost-effectiveness, and easy workability [3]. It bonds well with foam cores and provides a balanced combination of performance and affordability [4]. When used as the facing material, plywood gives the panel added stiffness and helps it withstand heavy loads without significant deformation. The bond between the plywood and the foam core plays a key role in overall panel performance. Strong bonding ensures stable load transfer and reduces the risk of delamination or failure under stress. Choosing the right adhesive is important to maintain this bond and ensure structural reliability [4].

The core material in the middle is what gives the panel its insulation and helps support the structure. Some of the most common core materials include polyurethane (PU) foam, expanded polystyrene (EPS), mineral wool, and honeycomb structures [11]. PU foam, especially when mixed with geopolymers, is becoming popular because it is more sustainable, offers good insulation, and improves fire safety while keeping the weight low. However, using too much PU or certain curing methods can make the material weaker. EPS is lightweight, affordable, and energy efficient, which makes it a good fit for housing projects, especially in earthquake-prone areas. That said, it is not very fire-resistant and may not hold up well under heavy loads. Mineral wool is excellent for fire resistance and soundproofing, but it is heavier and not as good at keeping in heat. Honeycomb cores are strong and light, but they do not insulate very well and can be expensive [12]. Ultimately, choosing the right combination of skin and core materials depends on the project's needs, whether it is about keeping costs low, improving fire safety, dealing with a hot and humid environment, or supporting heavy loads. Each material comes with trade-offs, so it is all about finding the right balance (Fig. 1).

(a) **(b)**

Fig. 1 *Materials for Sandwich Panel (a) PU Foam; (b) Plywood*

2.2 Sandwich Panel Design

The sandwich panel was built by combining two outer layers of plywood with a core made of polyurethane (PU) foam. This simple yet effective design was chosen to explore how different material combinations can offer both strength and lightness [1],[11]. Plywood was used for the face sheets because it's sturdy and bonds well with adhesives, while the PU foam core helps keep the panel lightweight and offers good insulation. Two different panel models were created for testing. The first model, Fig. 2(a) has a thickness of 5 cm, while the second model Fig. 2(b) is slightly thinner at 3.4 cm. Both were assembled carefully to make sure the layers were bonded securely, as the strength of a sandwich panel depends a lot on how well the materials stick together. The objective of testing these two designs is to evaluate the impact of core thickness on panel performance, which is an essential consideration for real-world applications where weight, strength, and material efficiency are critical.

(a) **(b)**

Fig. 2 *Design for Sandwich Panel (a) Model thickness 5 cm; (b) Model thickness 3.4 cm*

2.3 Testing of Sandwich Panel

The strength and durability of sandwich panels rely heavily on how well the face sheets and the core material work together. A strong bond between these layers is essential for efficient load transfer and to prevent structural failures. When this bond is weak or the panel is exposed to excessive stress, common failure modes can occur, such as delamination (where layers separate), face sheet wrinkling, or core buckling [13]. These issues are more likely to happen if the bonding is poor or the panel experiences high stress concentrations. To address these problems, advanced manufacturing techniques like vacuum bagging and autoclaving are often used to improve bonding quality and enhance the overall reliability of the panels [12]. Testing plays a crucial role in evaluating how sandwich panels perform under different conditions. These tests help engineers understand the mechanical strength, thermal insulation, and long-term durability of the panels, especially in real-world environments. To achieve the aim of this research, only mechanical testing was conducted [3]. As sandwich panels continue to be used in more advanced and demanding applications, testing methods must also evolve. Future research is expected to focus on creating more realistic testing scenarios that mimic complex, real-life conditions [14]. There is also ongoing development in improving the materials themselves such as stronger cores, better adhesives, and more resilient facing materials. All aimed at making sandwich panels even more reliable and versatile for the construction and engineering industries.

2.3.1 Mechanical Testing

Mechanical tests assess how sandwich panels behave under various loads, including bending, compression, shear, and impact. These tests reveal how strong and stiff the panels are and help identify potential failure points.

Bending Tests are among the most common and are used to evaluate a panel's flexural strength and stiffness. The core material, especially its density and thickness, plays a key role in resisting deformation. Three-point and four-point bending tests are typically used to measure how much the panel bends and how much load it can carry before breaking. The quality of the bond between the core and the skins also significantly affects the panel's ability to resist bending [12],[15].

Compression Tests measure how the panel responds to forces that push it inward. These tests are important because sandwich panels in construction often experience compressive loads. Low-density foam cores may struggle under high compression, leading to a drop in strength or crushing of the core. A universal testing machine (UTM), as in Fig. 3, is commonly used to determine how much compression a panel can handle before failing [4].

Fig. 3 *Mechanical testing UTM*

3. Results and Discussion

Using a universal testing machine, two sandwich panel samples were subjected to the same flexural test conditions (Fig. 4). Sample 2 could withstand a maximum load of 2.23 kN and reported a greater flexural strength of 8.69 MPa. Conversely, Sample 1 carried a somewhat lower load of 2.03 kN and displayed a lower flexural strength of 3.65 MPa. Sample 1 showed higher extension (20.79 mm) than Sample 2 (15.09 mm), while having less strength. In contrast to Sample 2, which withstood bending better, Sample 1 may distort more under stress, according to this. Table 1 shows the result of the UTM testing.

Table 1 *Results from UTM testing*

Sample	Width (mm)	Depth (mm)	Span (mm)	Max Load (kN)	Max Extension (mm)	Flexural Strength (MPa)
Sample 1	100	50	300	2.03	20.79	3.65
Sample2	100	34	300	2.23	15.09	8.69

Fig. 4 *UTM testing*

In the deflection test, a 15 kg load was applied to both samples, and the deflection was measured using a dial gauge (Fig. 5). Sample 1 showed a much larger deflection of 19.2 mm, while Sample 2 had a deflection of only 0.89 mm. These values clearly demonstrate that Sample 1 is less stiff and bends more under the same load, whereas Sample 2 is more rigid and stable. This test highlights the difference in structural behavior between the two sandwich panels when subjected to bending forces. Table 2 shows the result from the deflection of beam testing.

Table 2 *Results from the deflection of beam test*

Sample	Load (kg)	Deflection (mm)
Sample 1	15	-0.89
Sample 2	15	-19.2

Fig. 5 *Deflection of Beam Testing*

The flexural and deflection test results unequivocally demonstrate that the two sandwich panel samples' mechanical behaviour differs significantly. In terms of maximum load capacity, deflection resistance, and flexural strength, Sample 2 performed better than the others. It is more rigid and can bear bending pressures without deforming much, as seen by its higher flexural strength of 8.69 MPa and smaller deflection of just -0.89 mm under a 15 kg load. Because of this, Sample 2 is a better option for structural uses, including load-bearing parts, wall panels, and flooring systems where strength and rigidity are crucial [16],[17].

Sample 1 had much less strength, while being more flexible, as seen by its substantial deflection (19.2 mm) and greater extension value (20.79 mm). According to this, it could nevertheless be helpful in situations where some flexibility and energy absorption are advantageous, including in protective or cushioning constructions, even if it might not be appropriate for applications that call for great stiffness or strength. The samples' internal bonding or thickness, especially the interaction between the foam core and plywood skin, may have an impact on the performance variations. In order to get the intended mechanical behaviour in sandwich panels, the results further emphasize how crucial it is to optimize core thickness and material qualities [18]. Overall, the study backs up the notion that careful material selection is essential to fulfilling certain structural requirements and that panel design has a significant impact on flexural and deflection performance.

4. Conclusion

This study demonstrated how material selection and panel design significantly affect the mechanical performance of sandwich panels, especially in terms of flexural strength and deflection. The comparison between two samples showed that Sample 2, with a thinner depth and better internal bonding, had higher flexural strength and lower deflection under load, making it more suitable for structural applications requiring stiffness and strength [3],[18]. In contrast, Sample 1 showed greater flexibility and deformation, which may be beneficial in applications where energy absorption is needed. These findings highlight the importance of optimising core thickness and bonding quality between the core and face materials to achieve the desired mechanical behaviour. The results are especially relevant in the context of Malaysia's challenging climate, where heat and moisture can affect panel integrity [19],[20]. Overall, the study reinforces the need for tailored design and material choices in sandwich panels to meet specific structural demands and environmental conditions.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Nur Alyaa Rosman, Farah Husna Mohd Hafez, Farhani Husna Azhar;* ***data collection****: Nur Alyaa Rosman, Farah Husna Mohd Hafez, Farhani Husna Azhar;* ***analysis and interpretation of results****: Nur Alyaa Rosman, Farah Husna Mohd Hafez, Farhani Husna Azhar, Suhaila Sahat;* ***draft manuscript preparation****: Nur Alyaa Rosman, Farah Husna Mohd Hafez, Farhani Husna Azhar, Suhaila Sahat. All authors reviewed the results and approved the final version of the manuscript.*

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