

Performance of Bamboo Husk-Reinforced Cement Board as a Sustainable Alternative to Synthetic Fibers

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DOI: <https://doi.org/10.30880/peat.2025.06.02.012>

Article Info

Received: 26 June 2025

Accepted: 11 August 2025

Available online: 30 October 2025

Keywords

Bamboo husk, cement board, physical properties

Abstract

To promote ecologically friendly building methods, this study explores the partial substitution of cement board with bamboo husk, a plentiful and sustainable agricultural waste. Because of its low cost, inherent thermal insulating qualities, and potential to lessen cement's environmental impact, bamboo husk was chosen. Different percentages of bamboo husk treated with NaOH (0%, 2%, 3%, 4%, and 5%) were used to create cement boards, which were then allowed to cure for 28 days. Following ASTM C1185 and ASTM C177 standards, physical attributes such as thickness swelling, water absorption, and thermal conductivity were assessed. The findings indicated that the amount of bamboo husk had an impact on every property that was tested. All samples stayed below the 0.5% threshold, with the 2% husk sample exhibiting the least amount of thickness swelling (0.03%). Higher husk content resulted in a modest increase in water absorption, although it stayed within reasonable bounds. The best thermal insulation was found in the 4% husk sample (0.091 W/m²·°C). Higher husk levels, however, occasionally resulted in decreased performance and increased porosity. The best balanced performance was obtained overall with a 2% bamboo husk composition, suggesting that it has the potential to be a sustainable addition for creating lightweight, environmentally friendly, and thermally efficient cement boards for non-structural uses.

1. Introduction

Environmental sustainability and energy efficiency are becoming major issues for the building sector, particularly in warm regions like Malaysia, where high energy consumption is caused by cooling demands. Cement boards are prized for their longevity, fire resistance, and adaptability and are frequently used in construction for cladding, flooring, and partitioning. However, because of the high temperatures needed to create cement clinker and the chemical transformations involved, their production is extremely energy-intensive and produces a large amount of carbon emissions [3]. Furthermore, non-renewable resources, including sand, limestone, and synthetic fibers, are frequently used in traditional cement boards. These materials' extraction and production methods worsen environmental deterioration by contaminating water, destroying habitats, and increasing carbon emissions.

The building industry is forced to look for eco-friendly alternatives that lessen dependency on non-renewable resources and decrease environmental effects as the emphasis on sustainability develops globally [4]. Common natural fibers like jute, kenaf, and sugarcane are regarded for their sustainability and adaptability in the building sector, where they are used for eco-friendly building materials, insulation, and reinforcement [7]. The use of natural, renewable materials in cement composites, such as bamboo husk, a low-cost, lignocellulosic-

rich by-product of manufacturing bamboo, is one viable approach. Bamboo husk is a sustainable alternative to synthetic fibers since it has been demonstrated to increase the mechanical qualities, lower density, and improve thermal insulation of cement boards [5]. Because of its rich lignocellulosic composition, bamboo husk, a plentiful and inexpensive by-product of processing bamboo, has the potential to be an environmentally acceptable substitute material [2]. Its practical use in sustainable building is limited by issues including fiber deterioration, poor compatibility with cement matrices, and the requirement to tune mix ratios, despite its potential.

The use of fibrous reinforcement in concrete is usually seen from an economic standpoint as it reduces the installation durations of conventional reinforcement and is less expensive than ordinary concrete. Additionally, employing fiber-reinforced concrete (FRC) offers advantages for casting because the fibers are already incorporated into the concrete. In particular, this may be observed in the production of secondary precast concrete components used in civil and industrial structures as well as infrastructure [5]. Fiberglass significantly improves the bending strength, tensile strength, and impact resistance of non-reinforced or cellulose fiber cement boards. By forming a bridge effect across cracks, glass fibers improve toughness and durability [10].

The amount of bamboo husk used has a major impact on the mechanical and physical characteristics of cement boards. Studies show that adding more bamboo fiber can improve impact durability and flexural strength, making it more suitable for partition applications. However, too much bamboo husk might compromise durability and moisture resistance by increasing water absorption and decreasing compressive strength [1]. To achieve building regulations, it is imperative to determine the ideal ratio of bamboo husk to cement that strikes a balance between strength, durability, and insulating performance.

By methodically investigating the impacts of different bamboo husk percentages on the physical attributes of cement boards, such as thickness swelling, water absorption, thermal conductivity, and acoustic qualities, this study seeks to close this research gap. Finding the ideal combination that balances sustainability and functional performance is the goal to support the development of environmentally friendly building materials that encourage energy-efficient building techniques and lessen the construction industry's environmental impact. To evaluate advances in insulation and structural integrity, the study specifically aims to develop cement boards with bamboo husk as a partial substitute for synthetic fibers, determine the ideal bamboo husk content, and compare the physical characteristics of these boards with those of standard samples.

By examining the physical characteristics of cement boards with different proportions of bamboo husk, this study seeks to close this gap. To find the best composition that satisfies building requirements and supports environmental sustainability, the study focuses on important performance indicators such as thickness swelling, water absorption, thermal conductivity, and acoustic qualities. Designing cement boards with bamboo husk as a sustainable alternative to synthetic fibers, figuring out the ideal amount of bamboo husk, and evaluating the boards' physical characteristics against standard samples are the main goals. By doing this, this study helps to create environmentally friendly building materials that promote energy-efficient construction methods and lessen the negative effects of the construction industry on the environment.

2. Methodology

The approach used to examine the physical properties of cement boards with bamboo husk added at different mix percentages is described in this chapter. The study uses a methodical methodology that includes material preparation, manufacture, and testing to assess the impact of bamboo husk, an ecologically friendly and sustainable material, on cement board performance. As shown in the accompanying flowchart, the approach guarantees reliable analysis by outlining every experimental step, from the first treatment of bamboo husk to the final evaluation of physical attributes.

2.1 Materials Preparation

All of the materials required to manufacture cement boards, bamboo husk, fiberglass, fine aggregate, cement, and water are carefully prepared before the mixing process begins. The bamboo husk is sourced, cleaned, and processed to a consistent particle size to ensure compatibility with the cement matrix. Cement, typically Ordinary Portland Cement, is bought and stored in a dry environment to maintain its quality. Potable water is also saved and metered according to the required water-to-cement (w/c) ratio to provide uniformity in the mixing operation. Preparing these elements ensures the precision and reliability of the mixing procedures, lowering the chance of errors and promoting accurate evaluation of the cement board's properties.

2.1.1 Bamboo Husk

In accordance with sustainable building principles, bamboo husk was gathered straight from UTHM-owned plants in Pagoh to guarantee constant material quality and minimize environmental waste. To guarantee that only pure, premium fibers were utilized, the husks were meticulously combed during collecting to get rid of

contaminants like leaves, twigs, and dirt. Following that, the husks were shredded into pieces of around 6 mm in size. This size was selected to allow for easy handling, consistent treatment, and successful incorporation into the cement matrix.

A 5% sodium hydroxide (NaOH) solution was used for chemical treatment, which was carried out for two to four hours at temperatures ranging from 50°C to 80°C. By eliminating lignin and hemicellulose, this alkaline treatment increased the amount of cellulose and enhanced the durability and adherence of the fiber-matrix. In order to neutralize any leftover alkali and get rid of any chemicals, the husks were carefully cleaned with deionized water after treatment. In order to guarantee even drying and avoid contamination, the fibers were then sun-dried for two to three days while being turned occasionally. Figure 1 shows the dried bamboo husk after the treatment process. The physical and chemical characteristics of bamboo husk fibers are improved by this thorough processing, increasing their potential as a sustainable reinforcing material in cement board composites.



Figure 1: Bamboo husk before the treatment process. (a) Dried bamboo husk after the treatment process. (b)

2.1.2 Fiberglass

The 6mm fiberglass utilized in this project pertains to chopped glass fibers measuring 6 millimeters in length. These fibers are integrated into cement-based materials to improve their mechanical characteristics, including enhanced strength, crack resistance, and durability. The 6mm length is ideal for reinforcing cement boards, ensuring effective distribution within the cement matrix and aiding in the prevention of cracking and structural failure. This specific size of fiberglass is frequently selected due to its balance between ease of mixing with the cement and its capacity to substantially enhance the toughness and impact resistance of the composite.

2.2 Design mix

A mix design was created to determine the ideal ratio of bamboo husk to cement, taking workability, fiber distribution, and strength into account, to assess the effectiveness of treated bamboo husk in cement boards. A control mix devoid of bamboo husk was included, and the amount of treated bamboo husk in the cement ranged from 0% to 5% by weight. In compliance with ASTM C1186, which outlines specifications for flat non-asbestos fiber-cement sheets used in external applications, all mixes maintained a cement-to-sand ratio of 1:3, aiming for a density of around 1500 kg/m³. According to this specification, Grade II fiber cement boards are appropriate for applications requiring moderate strength and durability since their densities range from 1,150 kg/m³ to 1,500 kg/m³. The table shows the design mix by percentage.

Table 1: Design mix of every sample.

	Treated Bamboo Husk (%)	Cement (%)	Sand (%)	Fiberglass (%)
Control	0	50	45	5
Sample 1	2	50	45	4
Sample 2	3	50	45	3
Sample 3	4	50	45	2
Sample 4	5	50	45	0

From the percentage in Table 1, the following Table 2 shows the design mix calculated by weight for casting the cement board for 6 different samples to be tested.

Table 2: Design mix by weight.

	Treated Bamboo Husk (%)	Treated Bamboo Husk (g)	Cement (g)	Sand (g)	Fiberglass (g)
Control	0	0	0.81	0.729	0.081
Sample 1	2	0.032	0.81	0.729	0.049
Sample 2	3	0.049	0.81	0.729	0.032
Sample 3	4	0.065	0.81	0.729	0.016
Sample 4	5	0.081	0.81	0.729	0

2.3 Sample Preparation

In accordance with ASTM C1186, the sample preparation procedure for bamboo husk cement boards was carefully planned to guarantee precision, uniformity, and repeatability. The 300 mm x 300 mm x 12 mm hardwood molds used for the casting were chosen for their price, durability, and sustainability. During the curing process, timber molds offer exceptional dimensional stability, avoiding deformation and maintaining the desired board shape and surface polish. A release agent, such as oil or wax, was added to the inside surfaces of the molds to aid in demoulding and stop the cementitious mixture from adhering.

To give the cement time to hydrate and gain early strength, the boards were subjected to an initial curing period of 24 to 48 hours following casting. As a normal procedure to guarantee full hydration and ideal mechanical performance, the samples were placed in a controlled curing environment for 28 days at room temperature after demoulding. Achieving the appropriate density, strength, and durability needed for ensuing mechanical and physical testing requires this curing process.

After the big cement boards had completely dried, they were carefully chopped into 50 mm x 50 mm specimens to meet the specifications needed for standardized testing as shown in Figure 3, including thickness swelling and water absorption. To provide a reasonable dimension for soaking and precise measurement of dimensional changes, this sample size was selected based on the standard procedure in related investigations. To increase the test results' statistical reliability, many specimens were made from each board. By keeping mix ratios and curing conditions constant, the homogeneity of sample size and preparation circumstances guarantees that every specimen is typical of the same batch. All things considered, this thorough and uniform sample preparation process aids in the production of accurate, comparable data that is essential for assessing the effectiveness of bamboo husk cement boards.



Figure 3: Cement board after cutting to size 50mm x 50mm.

2.4 Testing

This study aims to comprehensively evaluate the physical properties of cement boards containing varying percentages of bamboo husk by conducting a series of standardized tests focusing on density, water absorption, thickness swelling, and thermal conductivity. All testing procedures were carried out at the UTHM laboratory under the supervision of qualified staff, ensuring adherence to established ASTM standards for accuracy and reliability.

Each cement board sample was separated into six specimens, each measuring 50 mm by 50 mm, to conduct thickness swelling and water absorption tests in accordance with ASTM C1185. The samples were oven-dried

for 24 hours at $100^{\circ}\text{C} \pm 5^{\circ}\text{C}$ in order to provide reliable measurements of dry weight and thickness. Prior to completely submerging the specimens in room-temperature water for a full day, preliminary measurements were taken after they had cooled to room temperature. The percentages of thickness swelling and water absorption were determined by post-immersion weight, thickness, and thickness measurements. The use of numerous specimens improves the accuracy of the findings and aids in locating any significant discrepancies in the samples.

In compliance with ASTM C177, a guarded hot plate apparatus was used to measure thermal conductivity. To provide steady-state thermal conditions, 300 mm x 300 mm x 12 mm specimens were placed within the testing apparatus, and the temperature was maintained at 50°C . Using established equations linking heat transfer, specimen thickness, and surface area, thermal conductivity was calculated by recording heat flow and temperature differentials. For this, the HE110 equipment model was used. This technique offers a trustworthy assessment of the cement boards' insulating qualities, which is essential for determining whether or not they are appropriate for use in energy-efficient construction applications.

The study guarantees a thorough and methodical assessment of how different bamboo husk contents affect the physical and thermal performance of cement boards by using these standardized testing techniques. The findings provide important new information on bamboo husk's potential as a sustainable cementitious composite ingredient.

3. Results and Discussion

This study tests five different bamboo husk contents (0%, 2%, 3%, 4%, and 5%) by ASTM C1186 and ASTM C177 standards to determine the ideal degree of synthetic fiber substitution with bamboo husk in commercial cement boards. Thermal conductivity, which is related to the boards' insulating function, and thickness swelling and water absorption are among the physical characteristics evaluated. These factors are crucial for comprehending the boards' dimensional stability and endurance when exposed to moisture. The effect of bamboo husk content on overall board performance is ascertained by comparing the outcomes for each composition. To determine the most effective and sustainable material combination and to explain the patterns that have been noticed, the interior microstructure and bonding properties are also examined.

3.1 Thickness Swelling Test

The thickness swelling test evaluated the dimensional stability of cement boards with varying bamboo husk contents (0%, 2%, 3%, 4%, and 5%) after 24 hours of water immersion, following ASTM C1185 standards. Figure 4 shows the result testing for the thickness swelling test for all six samples with different percentages of bamboo husk.

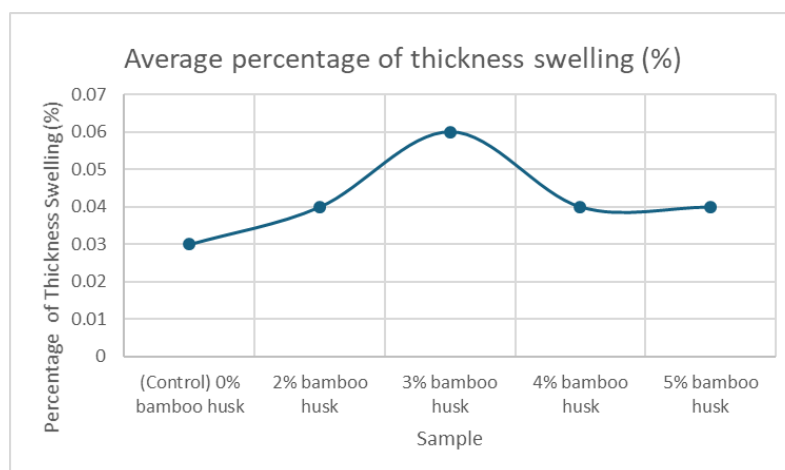


Figure 4: Graph of the result for the thickness swelling test.

All samples exhibited excellent stability, with swelling values between 0.03% and 0.06%, well below the ASTM limit of 0.5%. The swelling increased gradually up to 3% bamboo husk, peaking at around 0.06%, then decreased at higher percentages, indicating that moderate fiber addition may increase swelling, while higher levels improve internal bonding and reduce it. The 2% bamboo husk sample showed the lowest swelling, suggesting optimal fiber-matrix interaction and reduced porosity. Compared to other natural fiber composites, these results demonstrate superior dimensional stability and water resistance, highlighting that low bamboo husk content effectively enhances board durability without compromising structural integrity.

3.2 Water Absorption Test

Finding out how effectively cement boards with varying amounts of bamboo husk could resist water absorption was the aim of the water absorption test. Six samples were created using different percentages of bamboo husk (0%, 2%, 3%, 4%, and 5%). Each sample has six specimens. The water absorption test follows ASTM C1185 standards. Figure 5 shows the result for all samples after immersion for 24 hours.

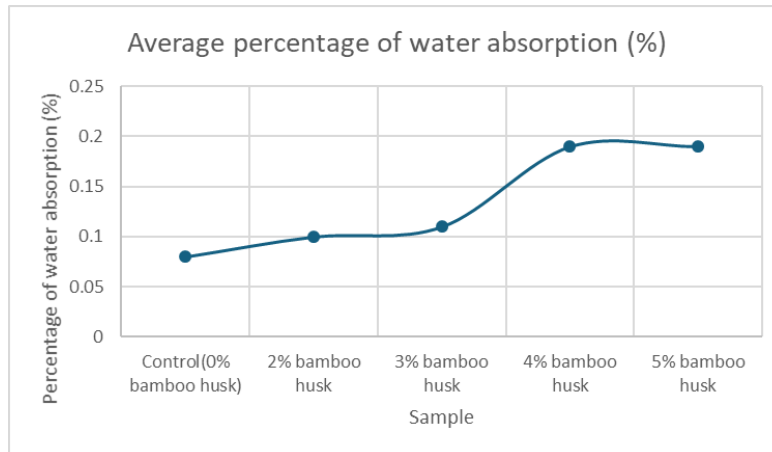


Figure 5: Graph of the result for the water absorption test.

By calculating the proportion of water absorbed during immersion, the water absorption test evaluated the moisture resistance of cement boards with different bamboo husk contents (0%, 2%, 3%, 4%, and 5%). There were six specimens in each sample, and the data indicated that the more bamboo husk there was, the more water absorption there was. With the lowest absorption of 0.07%, the control sample demonstrated high moisture resistance and little porosity. A modest increase in absorption (0.10% and 0.11%, respectively) was seen in samples containing 2% and 3% bamboo husk, indicating slight changes in matrix density and porosity. But at 4% and 5% bamboo husk, there was a noticeable increase, with absorption levels hitting 0.19% and 1.16%, respectively. Greater porosity and reduced fiber-matrix bonding, which significantly lowers water resistance, are the causes of this abrupt rise at larger fiber concentrations. These results demonstrate that while small applications of bamboo husk have no effect, larger amounts hurt the cement board's capacity to withstand moisture.

3.3 Thermal Conductivity Test

In compliance with ASTM C177, the guarded hot plate method was used to assess the heat conductivity of cement boards with different quantities of bamboo husk. Figure 6 shows the result for thermal conductivity test for all the samples.

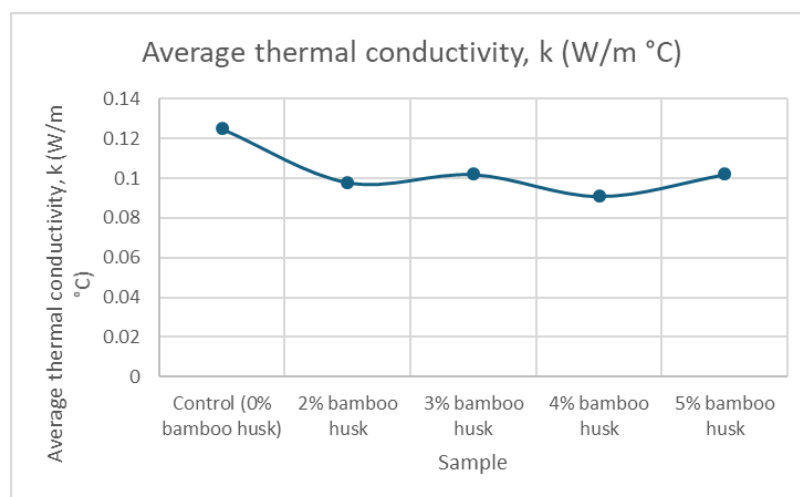


Figure 6: Graph of the result for the thermal conductivity test.

To guarantee accuracy, samples with dimensions of 300 mm × 300 mm × 12 mm were examined six times each. With an average heat conductivity of 0.125 W/m·°C, the control sample, which was devoid of bamboo husk, showed the lowest thermal insulation effectiveness. Thermal conductivity significantly decreased when bamboo husk was added; values decreased to 0.098 W/m·°C at 2% bamboo husk and reached a minimum of 0.091 W/m·°C at 4% bamboo husk. The conductivity of the 3% and 5% bamboo husk samples was somewhat greater than that of the 4% sample, although it was still below the control. According to this trend, adding bamboo husk to cement boards improves their insulating qualities. This is probably because bamboo husk is porous and fibrous, creating air pockets that prevent heat transfer. However, the improvement reaches a plateau at larger fiber percentages, like 5%, which may be caused by unequal distribution or fiber aggregation. Overall, the findings show that adding bamboo husk, especially at a rate of around 4%, significantly lowers thermal conductivity and enhances cement boards' ability to insulate against heat.

3.4 Comparison of Testing Results

At 4% husk, thermal conductivity drops from 0.125 W/m°C to at least 0.091 W/m°C, suggesting better insulating qualities. According to ASTM C1185 testing for thickness swelling and water absorption and ASTM C177 testing for thermal conductivity, the current data on cement boards with bamboo husk indicates that adding 5% to 0% bamboo husk content causes a slight increase in thickness swelling (from 0.08% to approximately 0.19%) and water absorption (from approximately 0.03% to 0.06%). The entire data for the testing that was done is displayed in Figure 7.

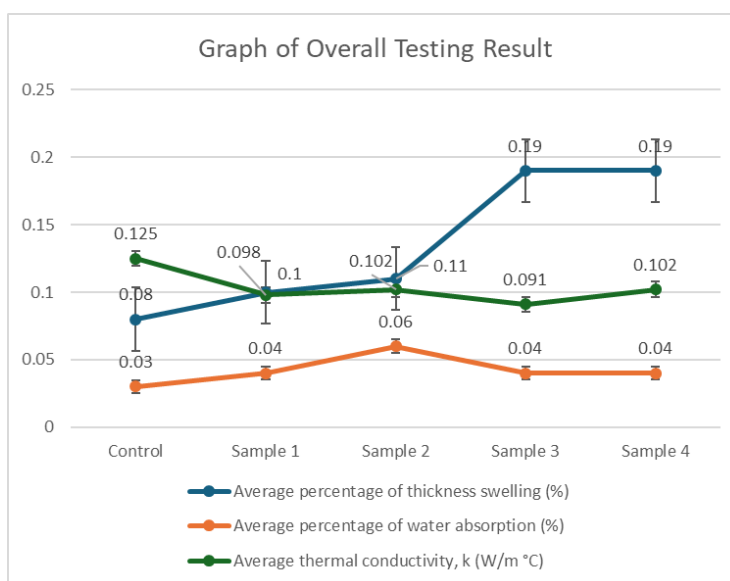


Figure 7: Comparison graph for all testing.

According to the study, adding bamboo husk to cement boards greatly enhances their thermal and physical characteristics. At 4% bamboo husk, thermal conductivity drops from 0.125 W/m°C in the control sample to at least 0.091 W/m°C, suggesting improved insulation effectiveness. Higher bamboo husk content results in a minor rise in thickness swelling and water absorption, which range from 0.08% to 0.19% and 0.03% to 0.06%, respectively. However, these values are still much below those found in recent research on bamboo fiber and shoot sheath composites. For example, Taiwo et al. (2024) found that bamboo fiber cement boards had higher thickness swelling and water absorption of up to 23.85%, suggesting a poorer level of moisture resistance [8]. Similar to this, Srichan et al. (2020) found that bamboo shoot sheath particleboards swelled and absorbed a lot of water, with several samples falling short of the required standards [9]. The higher performance of bamboo husk cement boards is probably caused by variations in the kind of bamboo and the nature of the cement matrix. In comparison to previous bamboo-based composites, our results imply that bamboo husk is a viable sustainable ingredient for cementitious materials, providing enhanced moisture endurance, dimensional stability, and thermal insulation.

4. Conclusion

According to the study's findings, adding bamboo husk to cement boards greatly improves their dimensional stability and thermal insulation. The 2% bamboo husk sample had the least amount of swelling (0.03%),

suggesting improved moisture resistance, while all tested samples displayed thickness swelling well below the ASTM C1185 standard of 0.5%. Better bamboo husk content typically resulted in better water absorption; nevertheless, the 2% and 3% samples continued to have modest absorption rates (0.10% and 0.11%, respectively), with a significant rise at 5% (1.16%). Bamboo husk enhances insulating qualities, according to thermal conductivity testing; the sample with 4% bamboo husk had the lowest conductivity (0.091 W/m·°C). The ideal composition was determined by balancing these physical and thermal properties; a 2% bamboo husk content provided a good trade-off between decreased thickness swelling, regulated water absorption, and improved thermal insulation without sacrificing structural integrity. This study supports the use of bamboo husk as a sustainable and feasible addition in the manufacturing of high-quality cement boards.

In order to ensure structural integrity, it is advised that future research:

- (i) Elucidate fiber-matrix interactions and explain observed property variations through microstructural analysis (e.g., XRD, SEM);
- (ii) Thoroughly evaluate mechanical properties (e.g., flexural strength, impact resistance, tensile strength);
- (iii) Investigate weathering effects and long-term durability through exposure to UV light, freeze-thaw cycles, and cyclic wetness; and
- (iv) Investigate additional composite formulations, including hybrid composites with other natural fibers or additives to improve board qualities in a synergistic manner.

Acknowledgement

The author would like to express gratitude Sunway Geo Tower and Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

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