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The Effect of Curing Process on Oil Palm Empty Fruit Bunch Fibre Cement Board Performance and Microstructure Appearance

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Abstract

This research investigates the potential of utilizing oil palm empty fruit bunch (EFB) fibres as sustainable materials for construction, addressing both environmental and industrial challenges associated with waste management in the palm oil industry. EFB fibres were processed through filtering to remove impurities, sun-drying to reduce moisture content, and hot water treatment at 100°C for 2 hours. These fibres were fabricated into cement boards (EFBCB) with a cement-to-fibre ratio of 3.5:1 and a target density of 1,300 kg/m^3. The study examined the physical and mechanical properties of EFBCB across curing durations of 7, 14, and 28 days. Results for 7-day curing indicated moderate density and mechanical performance due to partial hydration. At 14 days, increased moisture evaporation and fibre bonding improved mechanical properties but revealed early microcracking. By 28 days, prolonged curing led to further porosity, reduced density, and microstructural degradation, impacting dimensional stability and mechanical integrity. Microstructural analysis using Scanning Electron Microscopy (SEM) highlighted the evolving fibre-matrix interactions across curing periods. These findings emphasize the potential of EFB fibres as eco-friendly construction materials and the need to optimize curing durations for enhanced performance.

1. Introduction

The oil palm industry is a cornerstone of economic activity in tropical regions, particularly in countries like Malaysia and Indonesia. However, the industry's rapid growth has brought significant environmental challenges, including the management of its biomass waste. Among the byproducts of palm oil production, empty fruit bunches (EFB) represent a substantial fraction of this waste. If improperly managed, these fibrous residues contribute to environmental pollution and greenhouse gas emissions. Hence, finding sustainable and practical uses for EFB fibres has become a pressing concern.

EFB fibres possess inherent properties, such as biodegradability, low density, and good mechanical performance, making them ideal candidates for use in composite materials. Cement boards reinforced with EFB fibres can potentially offer an eco-friendly alternative to conventional building materials. Nevertheless, untreated fibres are prone to high moisture absorption, weak bonding with cement matrices, and dimensional instability. These limitations necessitate pre-treatment processes to improve fibre compatibility and performance.

Curing is a critical step in the production of cement-based composites, as it directly impacts the material's mechanical strength, dimensional stability, and overall durability. By systematically examining the effects of curing durations (7, 14, and 28 days) on EFB cement boards, this study aims to elucidate the relationship between curing conditions and material performance. This work not only contributes to the body of knowledge in sustainable construction but also proposes a solution to biomass waste management in the palm oil industry.

2. Relevant Previous Studies

Previous studies have established the utility of natural fibres in composite materials, emphasizing their economic and environmental benefits.[7] highlighted the role of natural fibre composites in reducing environmental impact while providing sustainable construction solutions. Similarly, [3] demonstrated the mechanical advantages of natural fibre-reinforced composites, identifying improvements in strength and stability.

The incorporation of EFB fibres into cement-based products has been explored extensively. [19] showed that EFB fibres enhance the mechanical properties of cement bricks, while [2] demonstrated improvements in both physical and mechanical properties of fibre-cement boards. Studies by [6] revealed that lightweight foamed concrete reinforced with EFB fibres provides superior performance, including increased durability and strength. Additionally,[1] noted that pre-treatment of fibres significantly enhances their thermal insulation and structural properties.

Critical parameters such as modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding (IB), and thickness swelling (TS) have been widely studied in relation to EFB fibre composites.[4] reported that treated fibres exhibit improved MOR and MOE values due to enhanced fibre-matrix adhesion. [5] confirmed that density and pre-treatment methods directly influence these properties, with higher densities yielding better dimensional stability and mechanical performance. SEM analyses have further elucidated the effects of curing and pre-treatment on fibre-cement interactions, showing that treated fibres result in reduced voids and superior bonding interfaces compared to untreated fibres.

3. Experimental Materials and Method

The preparation of oil palm empty fruit bunch (EFB) fibres involved several stages to ensure they were clean, uniform, and suitable for incorporation into the cement matrix. The process began with the collection of EFB fibres from a palm oil factory, which were then transported to the laboratory for processing. Initially, the fibres were sun-dried for one week to reduce their moisture content significantly, as excessive moisture could hinder their performance during cement board fabrication. Following this, the dried fibres were shredded into smaller, more manageable lengths using a shredder and subsequently processed with a hammer mill to achieve a finer, consistent fibre texture. This step was critical in improving the uniformity and workability of the fibres. To eliminate impurities such as dust and ensure a standardized size, the fibres were sieved through a 3 × 3 mm wire mesh. These preparatory steps ensured that the EFB fibres were well-processed and ready for further treatment and integration into the cement matrix.

After preparation, the EFB fibres underwent a hot water treatment to enhance their compatibility with the cement matrix, a crucial step in improving the overall performance of the cement boards. In this process, the fibres were soaked in water maintained at 100°C for a duration of two hours. This high-temperature treatment effectively removed natural oils, pectins, lignin, hemicellulose, and other undesirable components present on the fibre surface. These substances, if not removed, could interfere with the bonding between the fibres and the cement matrix, compromising the structural integrity of the boards. The treatment not only cleaned the fibres but also modified their surface properties, making them more hydrophilic and capable of forming stronger bonds with the cement. By ensuring that the fibres were clean and had improved surface characteristics, the hot water treatment played a vital role in preparing the EFB fibres for the fabrication of high-quality cement boards.

3.1 Fabrication of Cement Boards

The EFB cement boards were fabricated using a cement-to-fibre ratio of 3.5:1 and a target density of 1300 kg/m^3. The raw materials, including cement, fibres, and water, were accurately weighed according to these specifications as shown in Figure 1 (a). The materials were then mixed in a drum mixer for 10 minutes to ensure uniform distribution. The mixture was poured into wooden molds measuring 350 × 350 mm and compressed using a press machine to achieve a thickness of 12 mm as illustrated in Figure 1(b). The compressed boards were left to cure under controlled conditions of 28 ± 1°C temperature and 65 ± 5% relative humidity for periods of 7, 14, and 28 days. The picture below shows the cement board fabrication process.

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(a) **(b)**

Fig. 1 *(a) Weighting the EFB fibre, cement and water; (b) Compressed process using compression machine*

3.2 Testing Procedures

Comprehensive testing was conducted to evaluate the physical and mechanical properties of the EFB cement boards. For physical properties, density was assessed by measuring the mass per unit volume of the cured samples, providing insights into the material's compactness and overall structural integrity. The density test revealed a gradual decrease over curing periods, primarily due to moisture loss and increased porosity as hydration reactions progressed. Thickness swelling (TS) was measured by immersing the boards in water for 24 hours to assess their dimensional stability, while water absorption (WA) was determined by calculating the moisture uptake of the boards after immersion, reflecting their porosity and ability to resist water penetration. For mechanical properties, the modulus of elasticity (MOE) and modulus of rupture (MOR) were tested using a static bending test to determine stiffness and bending strength, respectively. Additionally, internal bonding (IB) tests were performed to evaluate the tensile strength perpendicular to the board's surface, reflecting the quality of adhesion between the fibres and the cement. Together, these tests provided a comprehensive understanding of the EFB cement boards' physical and mechanical performance under various conditions. Figure 2 illustrates the complete test procedure. First, the physical measurements of the samples are taken (a), followed by recording their weight (b). Next, the Internal Bond (IB) test is conducted using a Universal Testing Machine (c). Finally, the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) tests are performed using the same machine (d).

(a) **(b)** **(c)** **(d)**

Fig. 2 *(a) Process of taking the measurement; (b) weight of the samples; (c) IB test using universal testing machine; (d) MOE and MOR test using universal testing machine*

3.3 Microstructural Analysis

To complement the physical and mechanical tests, Scanning Electron Microscopy (SEM) (refer to Figure 3) was used to analyze the microstructural changes in the boards during curing. Samples were taken at curing intervals of 7, 14, and 28 days and prepared to ensure clear imaging. The SEM analysis provided detailed insights into fibre-matrix interactions, revealing the presence of voids, microcracks, and other structural features that influence the board's performance. The observations highlighted changes in bonding quality and porosity over the curing periods, offering a deeper understanding of how curing affects the structural integrity of the boards. The picture below shows the microstructure analysis using Scanning Electron Microscopy (SEM).

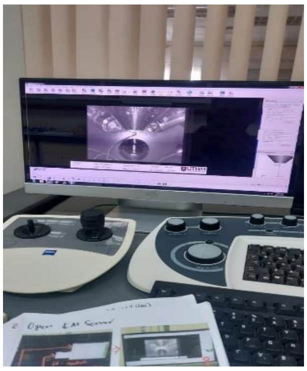


Fig. 3 *Analyze the microstructure of fibrecement boards using a Scanning Electron Microscope (SEM)*

4. Result and Analysis

The results and analysis of this study provide an in-depth understanding of the physical, mechanical, and microstructural behavior of Enhanced Fibre-Based Composite Boards (EFBCB) made with oil palm empty fruit bunch (EFB) fibres across curing durations of 7, 14, and 28 days as shown in Table 1.

Table 1 *Dimension stability of EFBCB through curing duration*

Curing duration	TS (%)	WA (%)	Density (kg/m^2)	IB (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)
7 days	1.27	17.95	1314.12	0.44	7.88	3826.89
14 days	2.32	27.38	1308.98	0.27	4.99	3306.89
28 days	2.56	28.60	1241.14	0.24	3.98	3035.64

The analysis covers physical properties, including density, thickness swelling (TS), and water absorption (WA), which assess the material's dimensional stability and moisture resistance, alongside mechanical properties such as modulus of elasticity (MOE), modulus of rupture (MOR), and internal bonding (IB), evaluating stiffness, strength, and fibre-matrix adhesion. Scanning Electron Microscopy (SEM) was employed to examine microstructural changes, revealing evolving fibre-matrix interactions, increased porosity, and surface degradation. Key findings include a decrease in density due to moisture loss and higher porosity, increased TS and WA with prolonged curing, and a decline in mechanical properties as structural integrity weakened over time. SEM results supported these observations, showing the formation of microcracks, larger pores, and brittle fibres with extended curing. These findings highlight the critical role of curing conditions in optimizing the performance and sustainability of EFB-based cement boards.

4.1 Density of EFB Fibre Cement Board Based on Different Curing Days

Twenty-seven EFBCB samples with dimensions of 50 × 50 mm were prepared for three different densities and carefully cut, weighed, and measured using a vernier caliper. The density of the EFB Cement Board (EFBCB) demonstrated a decreasing trend over curing periods of 7, 14, and 28 days, reducing progressively from 1,314.12 kg/m^3 at 7 days to 1,308.98 kg/m^3 at 14 days, and further to 1,241.14 kg/m^3 at 28 days as shown in the Figure 4. This trend reflects the impact of prolonged curing, primarily driven by moisture loss through evaporation, which reduces the board's total mass while maintaining a stable volume, thereby lowering its density. The effect is further compounded by hydration reactions in the cement matrix, which consume water and cause chemical changes that increase porosity. The increased porosity amplifies the reduction in mass, significantly influencing the overall density as curing progresses. These findings align with [8], who highlighted the role of moisture evaporation in increasing porosity and reducing density in fibre-reinforced composites, and [9], who noted that curing processes lead to substantial moisture loss. By 28 days, the combined effects of moisture loss and hydration reactions significantly decrease the density, making the material lighter but potentially compromising its structural integrity.

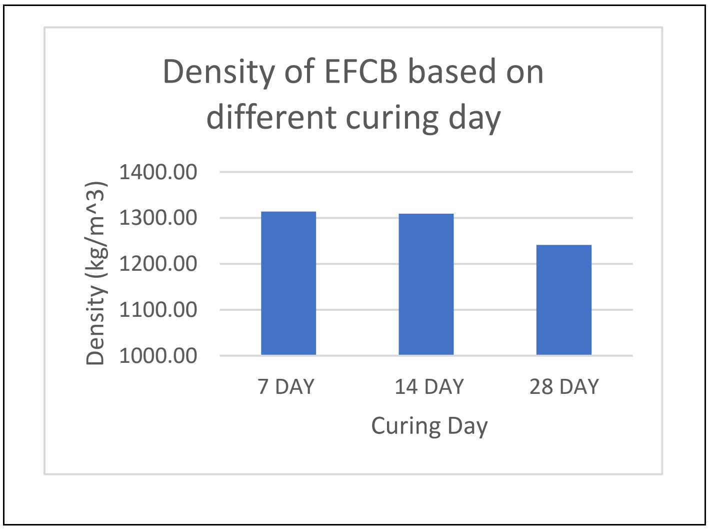


Fig. 4 *Density test results*

4.2 Thickness Swelling of EFB Fibre Cement Board Based on Different Curing Days

All samples were precisely cut to the required dimensions, and their thickness was measured with a Vernier caliper in both dry and wet states (before and after 24 hours of submersion in water). The thickness swelling results indicated a clear increase over time, with swelling percentages rising from 17.95% at 7 days to 28.60% at 28 days as shown in the Figure 5, correlating with higher moisture uptake during prolonged water absorption. This increase can be attributed to several factors, including the hygroscopic nature of the fibre-cement matrix, where water absorption causes dimensional changes and swelling. The material's composition significantly influences this behavior, as composites with hygroscopic fillers tend to absorb more water. Studies by [10] demonstrated that prolonged curing increases porosity in the fibre-cement matrix, which amplifies water absorption and thickness swelling. Similarly, [11] observed that extended curing durations lead to fibre relaxation and expansion, further contributing to the swelling as fibres interact with environmental moisture. These findings highlight the interplay between curing duration, porosity, and the hygroscopic nature of the fibres, which collectively impact the thickness swelling behavior of the material).

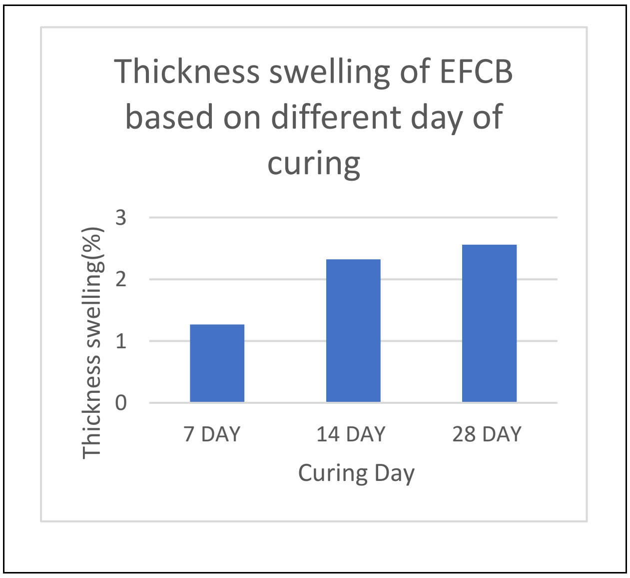


Fig. 5 *Thickness swelling results*

4.3 Water Absorption of EFB Fibre Cement Board Based on Different Curing Days

The water absorption tests, performed in accordance with ASTM D 1037–99 standards, involved soaking samples of each bio-composite type, including control EFBCB samples, in water, followed by periodic removal, drying, and weighing to measure water uptake. The results, averaged across five samples per type, revealed a significant increase in water absorption over time. At 7 days, absorption was relatively low at 17.95%, reflecting minimal porosity and retained moisture within the material. By 14 days, water absorption increased sharply to 27.38%, driven by the formation of pores as moisture evaporated and structural changes occurred. At 28 days, absorption stabilized at 28.60%, suggesting near-maximum saturation due to extensive porosity and a weakened fibre-matrix bond as illustrated in Figure 6. These findings align with [12], who reported that curing-induced porosity enhances water uptake in natural fibre composites, highlighting the critical role of curing in influencing the moisture-related properties of the material.

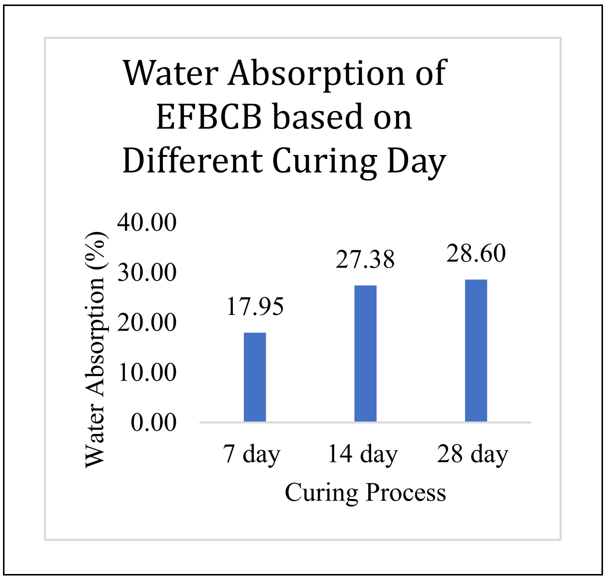


Fig. 6 *Water absorption results*

4.4 Internal Bonding of EFB Fibre Cement Board Based on Different Curing Days

The internal bonding (IB) test, conducted according to BS EN 319-1993, assessed the adhesive strength between the fibres and the matrix in Enhanced Fibre-Based Composite Boards (EFBCB) by measuring tensile strength as the maximum load at breaking divided by the sample's cross-sectional area. The results showed a significant decline in IB strength over time, dropping from 0.43649 N/mm^2 at 7 days to 0.235937 N/mm^2 at 28 days as shown in the Figure 7. This reduction is primarily attributed to moisture absorption, which weakens the fibre-matrix bonds, as well as incomplete polymerization due to curing conditions that may not fully optimize adhesion. [13] noted that environmental moisture absorption disrupts fibre-matrix bonding, reducing mechanical performance in fibre-reinforced polymer composites. Similarly, [14] highlighted that prolonged exposure to moisture increases porosity in the composite structure, compromising interfacial adhesion between the fibres and the matrix. These combined factors explain the observed reduction in IB strength over the curing duration, emphasizing the critical role of moisture management and optimal curing in maintaining composite integrity.

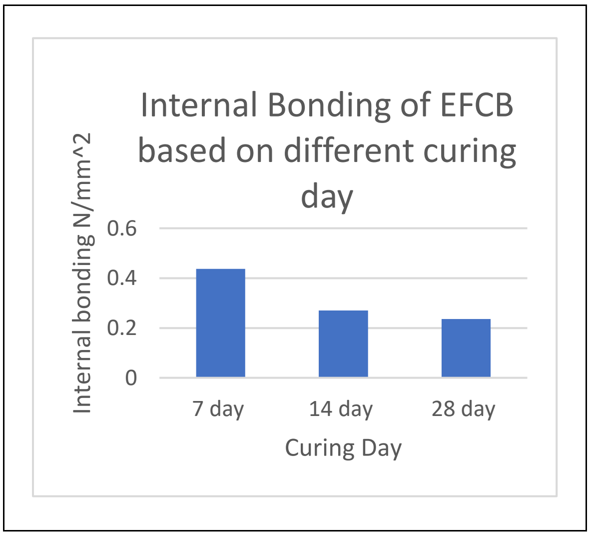


Fig. 7 *Internal bonding (IB) result*

4.5 Modulus of Elasticity of EFB Fibre Cement Board Based on Different Curing Days

The modulus of elasticity (MOE), tested according to BS EN 310-1993 guidelines, measures the stiffness and resistance to bending of Enhanced Fibre-Based Composite Boards (EFBCB) after a load is applied and released. The test results indicate a decline in MOE over time, decreasing from 3826.89 N/mm^2 at 7 days to 3306.89 N/mm^2 at 14 days, and further to 3035.64 N/mm^2 at 28 days as shown in the Figure 8. This reduction suggests that as the material cures and absorbs moisture, it becomes less rigid due to structural changes within the composite. Moisture absorption plays a significant role by weakening the fibre-matrix interface, increasing porosity, and softening the cement matrix.[15] reported that moisture exposure reduces stiffness as the interaction between moisture and the cement matrix alters the composite structure. Similarly,[16] highlighted that moisture uptake weakens the matrix structure, causing a gradual decline in mechanical rigidity.[8] further noted that moisture absorption increases interfacial gaps between fibres and the matrix, degrading bonding and contributing to the reduction in stiffness over time. These factors collectively explain the observed decrease in MOE, underscoring the critical impact of moisture on the mechanical properties of EFB cement boards.

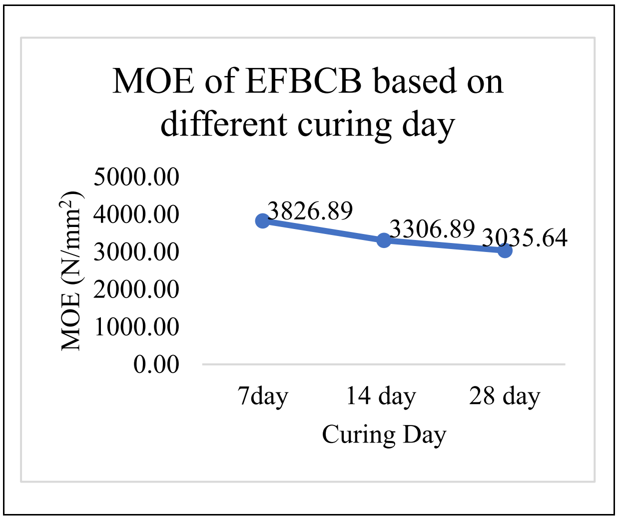


Fig. 8 *Modulus of elasticity (MOE) results*

4.6 Modulus of Rupture of EFB Fibre Cement Board Based on Different Curing Days

The modulus of rupture (MOR), tested according to BS EN 310-1993 guidelines, measures the maximum load a material can bear under bending or flexural stress before failure. Unlike the modulus of elasticity (MOE), which evaluates deflection, the MOR determines the ultimate strength of the material. For empty fruit bunch (EFB) cement boards, the MOR data shows a steady decline over time, starting at 7.88 N/mm^2 at 7 days, decreasing to 4.99 N/mm^2 at 14 days, and further dropping to 3.98 N/mm^2 at 28 days as shown in the Figure 9. This decline indicates a reduced ability of the material to resist bending or breaking as curing progresses. The reduction in MOR can be attributed to the weakening of the internal bonding and softening of the cement matrix due to moisture absorption, which compromises the strength of the fibre-matrix interface. Studies corroborate these findings, with [17] reporting a decrease in bending strength in agro-waste reinforced composites due to water absorption. Similarly, [18] found that moisture uptake in bionanocomposites significantly reduced MOR, supporting the observation that increased water absorption weakens the material's structural integrity and resistance to failure under load. These factors collectively explain the decreasing MOR in EFB cement boards over time.

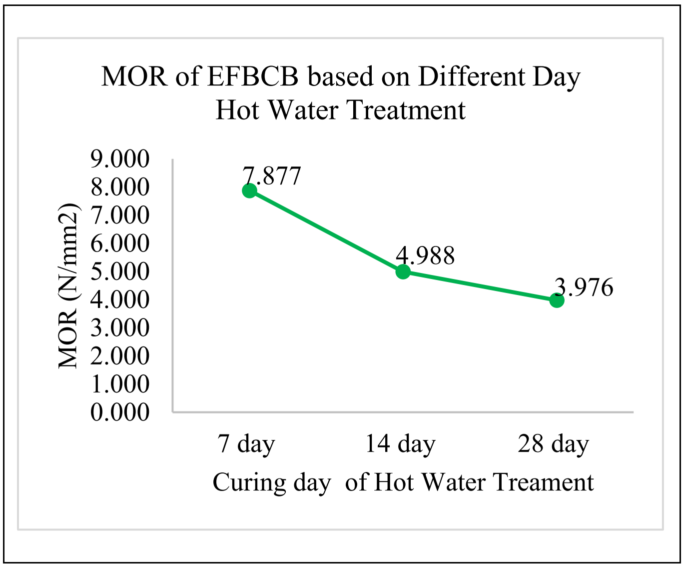
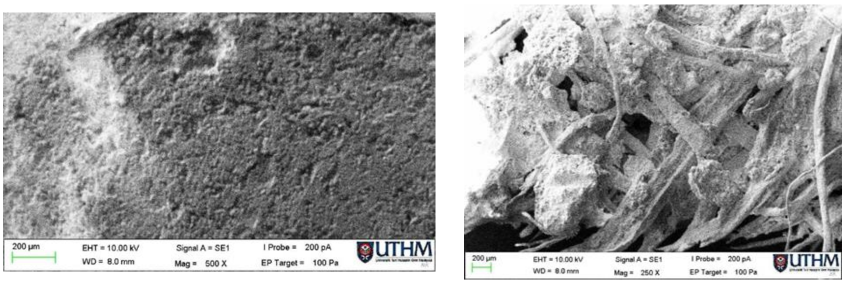


Fig. 9 *Modulus of rupture (MOR) results*

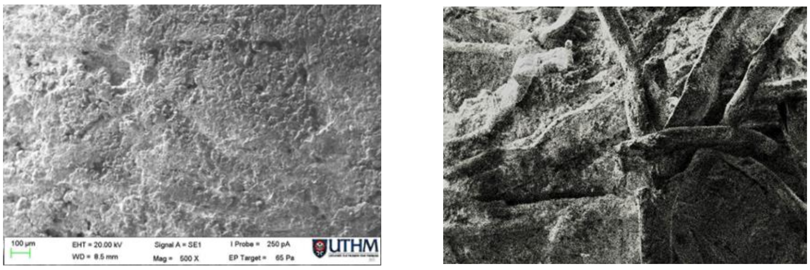
4.7 Microstructure Image of EFB Cement Board During Curing Process for 7, 14, and 24 Days

Comprehensive testing, complemented by Scanning Electron Microscopy (SEM) analysis, was conducted to evaluate the physical, mechanical, and microstructural properties of the EFB cement boards. For physical properties, density was measured to determine the mass per unit volume, revealing a decreasing trend over curing periods due to moisture loss and increased porosity. Thickness swelling (TS) was assessed by immersing samples in water for 24 hours, reflecting their dimensional stability, while water absorption (WA) tests measured the boards' ability to absorb moisture, highlighting their porosity. SEM analysis provided critical insights into microstructural changes at curing intervals of 7, 14, and 28 days. At 7 days as shown in the Figure 10, the surface was smooth with minimal roughness, small irregular pores, and intact fibres. By 14 days, the surface became slightly rough due to shrinkage, with larger pores and minor fibre shrinkage as illustrated in Figure 11. At 28 days, the surface displayed visible microcracks, extensive porosity, and fractured, brittle fibres, indicating significant structural degradation as shown in Figure 12. For mechanical properties, modulus of elasticity (MOE) and modulus of rupture (MOR) were tested to evaluate stiffness and bending strength, respectively, while internal bonding (IB) tests examined tensile strength and fibre-matrix adhesion. Together, these tests and SEM findings provided a comprehensive understanding of how curing durations affect the physical, mechanical, and microstructural performance of EFB cement boards.



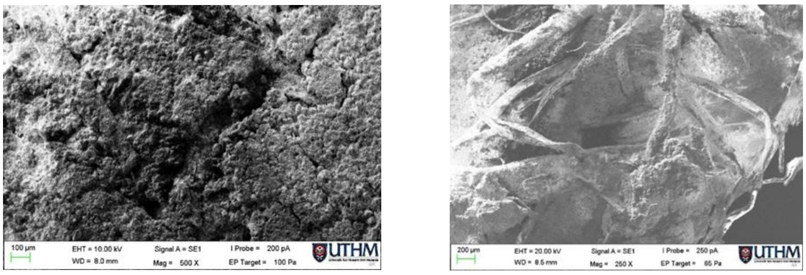
(a) **(b)**

Fig. 10 *(a) Surface Texture for 7 days; (b) Fibre Condition for 7 days*



(a) **(b)**

Fig. 11 *(a) Surface Texture for 14 days; (b) Fibre Condition for 14 days*



(a) **(b)**

Fig. 12 *(a) Surface Texture for 28 days; (b) Fibre Condition for 28 days*

5. Conclusion

This study demonstrates the potential of Enhanced Fibre-Based Composite Boards (EFBCB) made with oil palm empty fruit bunch (EFB) fibres as sustainable construction materials while highlighting the critical influence of curing durations on their performance. The results revealed significant trends, including a progressive reduction in density due to moisture loss and increased porosity, as well as heightened thickness swelling and water absorption with extended curing periods. Mechanical properties, such as the modulus of elasticity (MOE), modulus of rupture (MOR), and internal bonding (IB), showed a gradual decline over time, attributed to weakened fibre-matrix adhesion and structural degradation. Scanning Electron Microscopy (SEM) analysis provided valuable insights into microstructural changes, showing the development of pores, microcracks, and fibre brittleness, further supporting the observed reductions in physical and mechanical performance.

These findings emphasize the need for optimized curing processes to balance dimensional stability, mechanical strength, and microstructural integrity. The incorporation of EFB fibres not only offers an eco-friendly alternative to conventional materials but also contributes to addressing biomass waste management in the palm oil industry. Future research should focus on enhancing fibre treatment and exploring innovative curing techniques to further improve the durability and performance of EFB-based cement boards for broader applications in sustainable construction.

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Conflict of Interest

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

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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