JSMBE

JOURNAL OF STRUCTURAL MONITORING AND BUILT ENVIRONMENT
e-ISSN: 2821-3432

Vol. 6 No. 1 (2026) 1-8
https://publisher.uthm.edu.my/ojs/index.php/jsmbe

The Effect of Hot Water Treatment on Oil Palm Empty Fruit Bunch Fibre on Tensile Strength and Cement-Fibre Hydration Rate

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DOI: https://doi.org/10.30880/jsmbe.2026.06.01.001

Article Info

Received: 17 January 2026
Accepted: 18 May 2026
Available online: 30 June 2026

Keywords

OPEFB fibres, hot water treatment, tensile strength, hydration rate, sustainable construction, fibre-cement bonding

Abstract

The oil palm industry generates substantial waste, including oil palm empty fruit bunch (OPEFB) fibres, which are underutilized despite their potential in sustainable construction. This study examines the effects of hot water treatment 1, 2, and 3 hours at 100°C on the tensile strength and hydration rate of OPEFB fibres in cement composites. Results showed that 2 hours of treatment achieved optimal tensile strength (910 N/mm^2) and hydration rate (41.4°C), improving fibre-cement bonding. SEM analysis confirmed effective removal of surface impurities. Hot water treatment offers a sustainable approach to enhancing OPEFB fibres for eco-friendly construction materials.

1. Introduction

The oil palm industry plays a crucial role in global agricultural production, generating approximately 73 million tonnes of oil annually [1]. However, it also produces substantial waste, including oil palm empty fruit bunch (OPEFB) fibres, which are often discarded or burned, contributing to environmental degradation. These fibres have untapped potential as sustainable construction materials due to their abundance, renewability, and biodegradability. Their incorporation into cement composites aligns with the construction sector's increasing emphasis on sustainability. Despite their potential, untreated OPEFB fibres exhibit limitations such as high moisture content and surface impurities like silica bodies, which hinder compatibility with cement matrices. These issues weaken fibre-cement bonding, reducing the overall mechanical performance of composites [2]. Addressing these challenges is vital to unlocking the full potential of OPEFB fibres. The construction industry, responsible for high embodied energy and carbon emissions, urgently seeks eco-friendly alternatives to traditional materials like steel and concrete [3]. This study investigates the effects of hot water treatment, a simple and sustainable pre-treatment method, on the mechanical and chemical properties of OPEFB fibres. By varying soaking durations 1 hour, 2 hours, and 3 hours at 100°C, the study evaluates improvements in tensile strength, hydration rate, and surface morphology, focusing on their application in cement composites. This research contributes to sustainable development by addressing agricultural waste management and reducing environmental pollution. It supports Sustainable Development Goals (SDGs) such as SDG 11, Sustainable Cities and Communities and SDG 12, Responsible Consumption and Production, emphasizing resource efficient practices. By enhancing OPEFB fibres performance in cement composites, this study paves the way for integrating agricultural by-products into the construction industry, advancing eco-friendly solutions to global challenges [4].

2. Materials and Methods

This study utilized oil palm empty fruit bunch (OPEFB) fibres sourced from a local oil palm factory in Batu Pahat, Johor. The fibres underwent preparation processes, including shredding, sieving, and drying, to ensure uniformity and remove impurities. Hot water treatment was applied as a pre-treatment method, with fibres soaked at a constant temperature of 100°C for durations of 1, 2, and 3 hours. Post-treatment processes included rinsing, sun-drying, and oven-drying to eliminate residual moisture. Laboratory analyses were conducted to evaluate the treated fibres mechanical and chemical properties. Tensile strength testing was performed using a Universal Testing Machine (UTM) in compliance with ASTM D3379 standards. Surface morphology was examined using Scanning Electron Microscopy (SEM) at magnifications up to 2000x to identify changes in fibre surface characteristics. A hydration rate test was conducted to assess fibre compatibility with cement, using temperature monitoring during hydration as a measure of performance. These methods were selected to optimize fibre properties for integration into sustainable construction materials.

2.1 Tensile Testing of OPEFB fibre

The tensile properties of EFB fibres were evaluated using a Universal Testing Machine (UTM) in accordance with ASTM D3379 standards (ASTM International, 2020). The test aimed to measure the strength and deformation characteristics of untreated and hot water-treated fibres under controlled conditions. A total of 20 samples were prepared for each treatment condition, including untreated fibres and those treated for 1, 2, and 3 hours. To ensure accurate results, individual fibres were mounted on cardboard frames as shown in Figure 1(a) with proper alignment to avoid torsional strain, which could impact tensile performance. The samples were then subjected to tensile tests as depicted in Figure 1(b) to determine parameters such as tensile strength, Young's modulus, and elongation at break. During testing, the fibres were carefully aligned with the load axis of the UTM, and a constant crosshead speed was maintained to ensure uniform application of force. The procedure provided insights into how the treatment duration influenced the mechanical properties of the fibres, consistent with prior methodologies outlined by [5] and other related studies.

(a) **(b)**

Fig. 1 *Tensile strength testing (a) Samples frame alignment; (b) Arrangement sample of experimental apparatus for tensile testing*

2.2 Scanning electron microscopy testing of OPEFB fibre

The surface morphology of oil palm empty fruit bunch (OPEFB) fibres was analyzed using a Scanning Electron Microscope (SEM) to evaluate the structural changes induced by hot water treatment. Untreated and treated fibres 1 hour, 2 hours, and 3 hours were prepared by mounting them onto conductive stubs and coating them with gold to enhance electron conductivity. The SEM was operated at magnifications ranging from 300x to 2000x [6], providing high-resolution images for detailed observations. The analysis focused on identifying surface impurities such as silica bodies, assessing porosity, and examining surface roughness and damage caused by different treatment durations. The SEM procedure included powering up the equipment, preparing and loading samples, locating areas of interest, and capturing images using the SMARTSEM interface [7].

This methodology aimed to investigate how hot water treatment influenced fibre morphology and its compatibility with cement matrices. Observations revealed key structural changes that impact the fibre's bonding potential and mechanical performance, aligning with prior research on natural fibre treatments [8][5].

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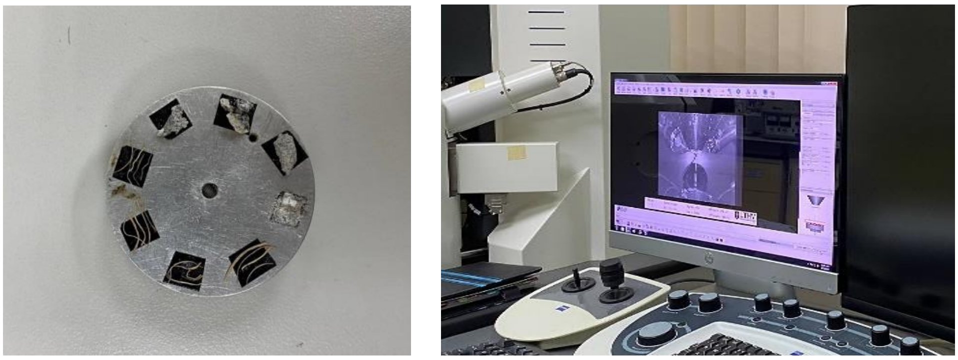


(a) **(b)**

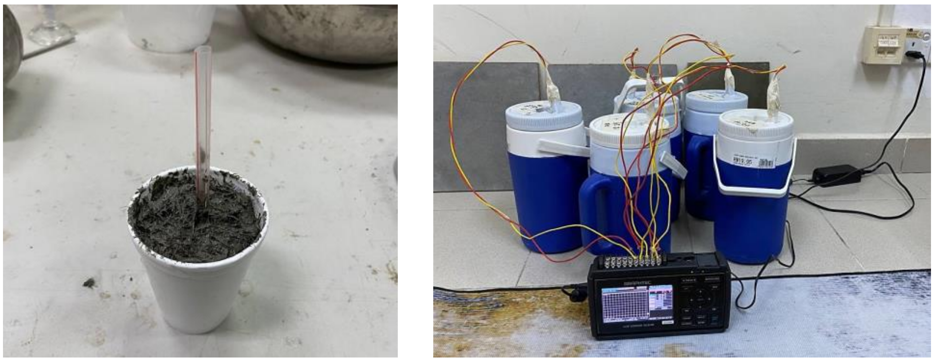
Fig. 2 *SEM testing (a) Fibre samples attached to conductive stub; (b) SEM equipment and software setup*

2.3 Heat hydration rate testing of OPEFB fibre

The heat hydration rate of oil palm empty fruit bunch (OPEFB) fibres was tested to evaluate their compatibility with cement matrices during the hydration process. The test was conducted by measuring the exothermic heat released during the reaction between cement and fibres treated under different conditions untreated, 1 hour, 2 hours, and 3-hour hot water treatments. The setup involved a polyethylene bag containing a mixture of 250 g of cement, 20 g of fibre, and 114 mL of water, thoroughly mixed for 2 minutes to ensure uniformity as displayed in Figure 3.

Thermocouples (Type T) were attached to the exterior of the sample bags to record temperature changes over 24 hours. The sample bags were placed in polystyrene cups and sealed within insulated thermos flasks to maintain consistent environmental conditions. A data logger (Graphtec GL220) was used to continuously monitor and record the temperature profiles of the hydration process.

The primary objective of this test was to determine the inhibition index as shown in table 1, which classifies fibre-cement compatibility based on the maximum hydration temperature, time to reach peak temperature, and slope of the exothermic curve. This method allowed for the assessment of how pre-treatment influences the hydration behavior of OPEFB fibres, providing insights into their potential to improve cement performance in construction applications.



(a) **(b)**

Fig. 3 *Heat hydration testing (a) Samples frame alignment; (b) Arrangement sample of experimental apparatus for tensile testing*

Table 1 *Inhibition index to classify fibre compatibility [9]*

Inhibition index (%)	Grading
0 - 10	Low inhibition
10 - 50	Medium inhibition
50 - 100	High inhibition
>100	Extreme inhibition

3. Result and Discussion

The results reveal significant improvements in the properties of OPEFB fibres after hot water treatment, with optimal performance achieved at a 2-hour soaking duration. Surface morphology analysis showed enhanced roughness and impurity removal, while tensile testing highlighted improved mechanical strength. Hydration rate testing confirmed better fibre-cement compatibility due to optimized treatment. However, over-treatment resulted in fibre degradation, emphasizing the importance of balancing treatment conditions. These findings align with prior studies and demonstrate the potential of treated OPEFB fibres for sustainable construction applications.

3.1 Effect OPEFB with Various Soaking Duration of Hot Water Treatment on The Tensile Strength

Figure 4.1 shows the average tensile strengths of untreated and treated OPEFB fibres at a constant temperature of 100°C with soaking durations of 1 hour, 2 hours, and 3 hours. The tensile strength of untreated fibres was recorded at 579 N/mm^2. After 1 hour of soaking, the tensile strength improved to 702 N/mm^2 due to the removal of surface impurities and partial enhancement of the fibre's crystallinity. The highest tensile strength of 910 N/mm^2 was achieved after 2 hours of soaking, attributed to optimal removal of hemicellulose and lignin layers, improving fibre bonding. However, at 3 hours, the tensile strength declined to 816 N/mm^2, likely due to over-treatment, which weakened the fibre structure and reduced its load-bearing capacity. This decline aligns with findings by [10], who noted that prolonged soaking durations can degrade the cellulose and lignin layers. These results suggest that 2 hours is the optimal soaking duration for achieving maximum tensile strength while maintaining fibre integrity.

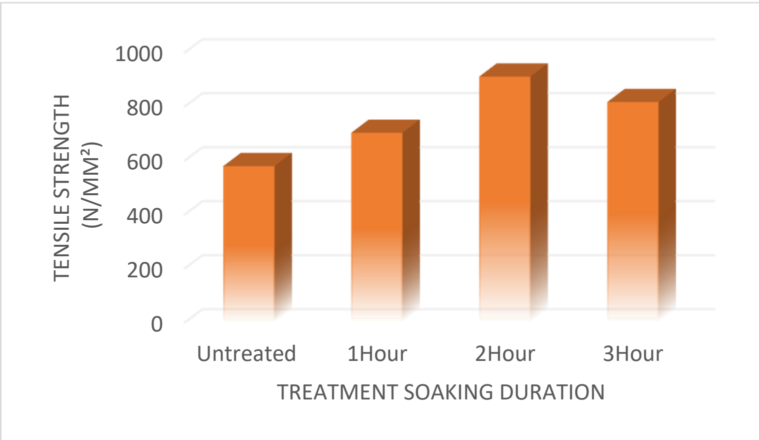


Fig. 4 *Effects on tensile strength with varying durations of concentration in hot water treatment*

3.2 Effect OPEFB with Various Soaking Duration of Hot Water Treatment on Surface Morphology Analyses

The surface morphology of untreated and treated oil palm empty fruit bunch (OPEFB) fibres was analyzed using Scanning Electron Microscopy (SEM) at magnifications of up to 2000x. Untreated fibres exhibited smooth surfaces with significant amounts of impurities, including visible silica bodies, which hinder fibre cement bonding by blocking the interaction of the fibres with the cement matrix. SEM images revealed that these impurities created a barrier, limiting the potential for mechanical interlocking within the composite material. After 1 hour of hot water treatment, the fibre surfaces showed moderate roughness with partial removal of silica bodies and other surface impurities. These changes improved the surface conditions, making the fibres more suitable for bonding. Fibres treated for 2 hours demonstrated the most significant improvements, with the SEM images revealing enhanced surface roughness and near-complete removal of silica bodies. This treatment exposed hydroxyl groups on the fibre surface, promoting better adhesion with the cement matrix.

However, fibres treated for 3 hours displayed excessive porosity and structural degradation, as evidenced by cracks and weakened fibre walls observed in SEM images. Over-treatment led to the removal of too much lignin and hemicellulose, which are essential for maintaining the structural integrity of the fibres. This degradation compromised the fibres mechanical strength and bonding potential. These observations confirm that treatment duration plays a crucial role in determining the surface morphology and, consequently, the performance of OPEFB fibres in cement composites. SEM images illustrating these morphological changes are presented in Figure 5,6,7,

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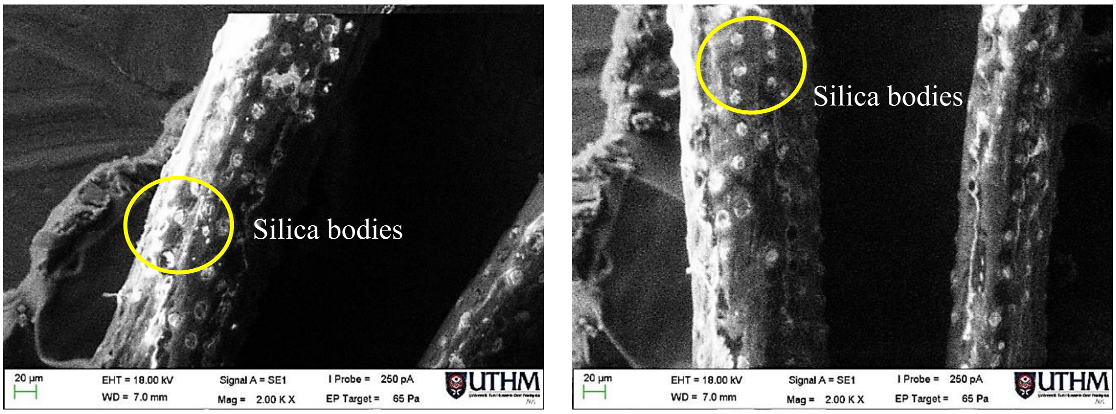
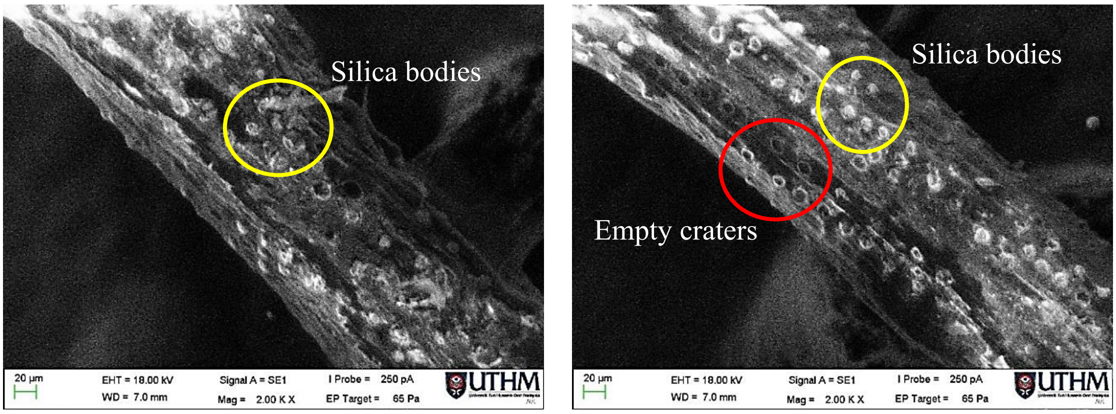
and 8, showing the progression from untreated to optimally treated fibres, followed by the structural degradation caused by over-treatment.



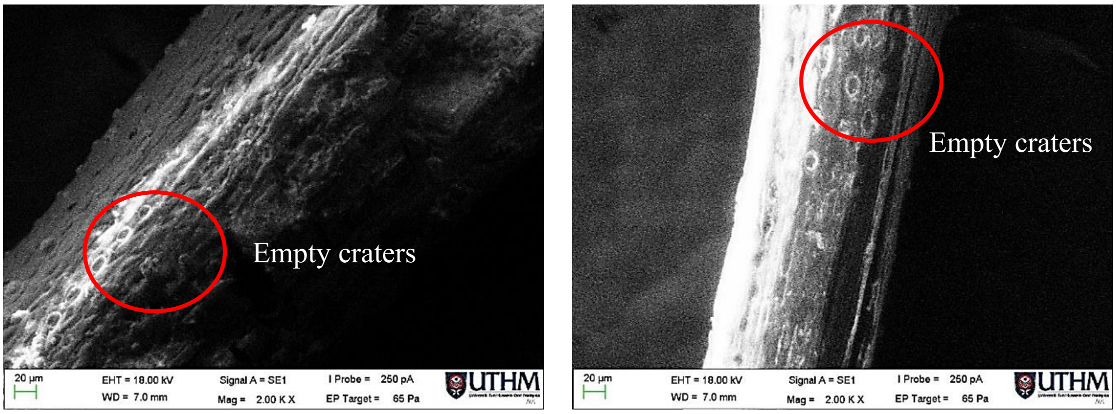
(a) **(b)**

Fig. 5 *Untreated samples*



(a) **(b)**

Fig. 6 *1-hour samples*



(a) **(b)**

Fig. 7 *2 hours samples*

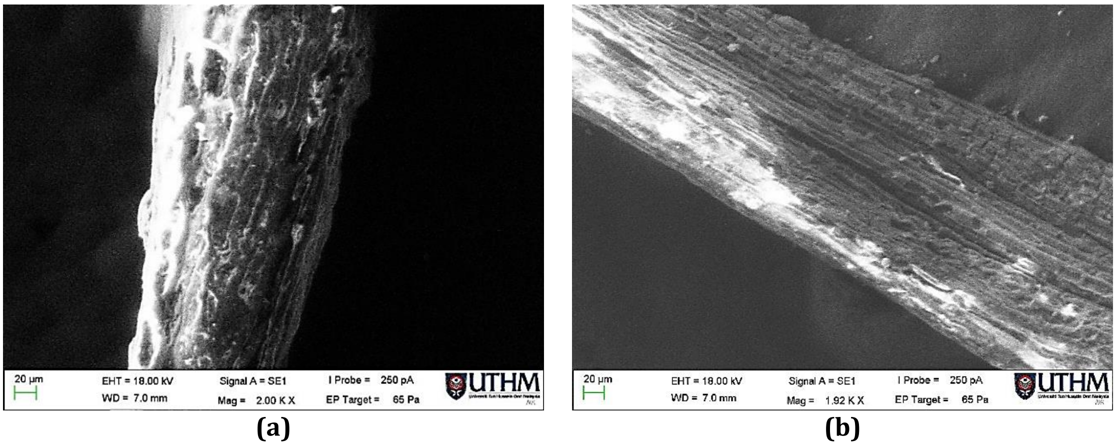


Fig. 8 *3 hours samples*

3.3 Effect OPEFB with Various Soaking Duration of Hot Water Treatment on Cement Fibre Hydration Rate

The heat hydration rate testing revealed significant differences in fibre-cement compatibility across untreated and treated fibres. Untreated fibres exhibited a delayed hydration process, as indicated by lower peak hydration temperatures and extended times to reach the peak. This delay was attributed to the presence of surface impurities such as silica bodies, which inhibited effective bonding between the fibres and the cement matrix. Fibres treated for 1 hour demonstrated some improvement in hydration compatibility, with a moderate increase in peak hydration temperature and reduced time to peak hydration. However, the most notable performance was observed in fibres treated for 2 hours. These fibres achieved the highest hydration temperature, indicating enhanced chemical bonding and compatibility with the cement. The shorter time to peak hydration and a steeper slope in the heat release curve further emphasized the improved reactivity of 2-hour treated fibres.

In contrast, fibres treated for 3 hours exhibited a decline in hydration performance. The peak hydration temperature was lower than that of the 2 hours treated fibres, and the time to peak hydration increased. This reduction in performance was likely due to over-treatment, which led to excessive removal of structural components such as lignin and hemicellulose, thereby weakening the fibres interaction with the cement matrix. The inhibition index further classified results are shown in table 2. These findings are supported by the heat release curves presented in Figure 9, which illustrate the differences in hydration behavior across all treatment durations, highlighting the superior performance of 2 hours treated fibres.

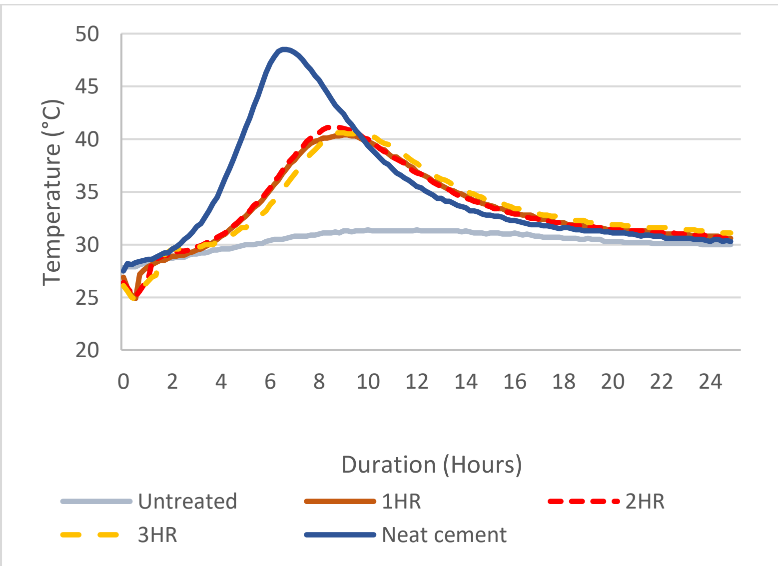


Fig. 9 *Effect on heat hydration rate with varying durations of concentration in hot water treatment*

Table 2 *Result of inhibition index to classify fibre compatibility*

Treatment	Hm (h)	Tm (°C)	Sm (°C)	Ii (%)	Inhibition Index
Neat Cement	6.3	48.5	7.7		
Untreated	10.0	31.4	3.1	12.3	Medium
1 HR	9.0	40.4	4.5	3.0	Low
2 HR	8.2	41.4	5.0	1.6	Low
3 HR	8.4	40.6	4.8	2.0	Low

3.4 Discussion

The results demonstrate that hot water treatment effectively improves the surface morphology, tensile strength, and hydration compatibility of OPEFB fibres, provided the treatment duration is carefully optimized. The enhanced surface roughness and removal of impurities improve interfacial bonding with the cement matrix, leading to better mechanical and chemical performance. However, excessive treatment leads to fibre degradation, reducing overall effectiveness.

Comparison with prior studies corroborates these findings. [8] highlighted the importance of balancing impurity removal with structural integrity during natural fibre treatments. Similarly, [7] emphasized the role of surface roughness in improving cement bonding. This study adds to the body of knowledge by confirming that a 2-hour hot water treatment duration offers the best performance for OPEFB fibres in cement composites.

4. Conclusion

This study demonstrates that hot water treatment significantly enhances the properties of oil palm empty fruit bunch (OPEFB) fibres for use in cement composites. Among the treatment durations tested, 2 hours at 100°C proved to be optimal, yielding the best results in terms of tensile strength, surface morphology, and hydration rate. The treatment effectively removed surface impurities such as silica bodies, enhanced surface roughness, and exposed hydroxyl groups, which improved fibre-cement bonding. Tensile strength tests confirmed that 2-hour treated fibres achieved the highest mechanical performance, while over-treatment at 3 hours led to fibre degradation. Similarly, hydration rate testing revealed that 2-hour treated fibres exhibited the fastest reaction times, highest peak hydration temperatures, and minimal inhibition indices, indicating superior compatibility with cement matrices. These findings highlight the importance of balancing treatment conditions to optimize fibre performance while maintaining structural integrity. By addressing the challenges of agricultural waste management, this research supports the integration of treated OPEFB fibres into sustainable construction materials, contributing to global sustainability goals and promoting eco-friendly innovations in the construction industry.

Acknowledgement

This research was made possible with the support and facilities provided by Universiti Tun Hussein Onn Malaysia (UTHM). The authors express their deepest gratitude to the Faculty of Civil Engineering and Built Environment for providing laboratory resources and technical assistance. Special thanks are extended to Dr. Nik Mohd Zaini Bin Nik Soh for his invaluable guidance throughout this study.

Conflict of Interest

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

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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