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Effect of Adding Oil Palm (*Elaeis guineensis* Jacq.) Mesocarp Fibers to Cement Composites

Efecto de la adición de fibras del mesocarpio de palma aceitera (*Elaeis guineensis* Jacq.) en compuestos de cemento

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Highlights

- The FCC containing 3%-OPMF exhibited the most favorable performance.
- Incorporating 9% OPMF in FCCs showed no alteration in volumetric swelling.
- The addition of 9% of OPMF in FCCs yielded a thickness reduction of up to 132%.
- FCC electronical images revealed microcracks and interfacial gaps when fibers were added.
- The FTIR results showed that higher OPMF proportions lead to increased vibrations of the OH- group.

Abstract

The construction industry's ongoing pursuit of eco-friendly materials has led to extensive research into fiber cement composites (FCC), particularly those utilizing natural fibers such as oil palm (*Elaeis guineensis* Jacq.) mesocarp fiber (OPMF) from Peru. This study examined the physical, mechanical, and chemical effects of adding different proportions of OPMF (0, 3, 6, and 9%) in manufacturing FCCs. This addition resulted in reduced values regarding density, porosity, and modulus of rupture, as well as in increased moisture content and thickness reduction. The FCC containing 3% OPMF exhibited the most favorable performance thanks to its higher density and its lower water absorption and porosity when compared to the

control board (0%-OPMF). Micro-images revealed minor microcracks and interfacial gaps, indicative of debonding, which compromises the properties of the FCC. Furthermore, an infrared spectrum analysis demonstrated an increase in hydroxyl group vibrations with an increased fiber proportion.
Keywords: fiber cement composite, lignocellulosic fiber, mesocarp fiber, physical and mechanical properties.

Resumen

La constante búsqueda de materiales ecológicos en la industria de la construcción ha llevado a una amplia investigación sobre los compuestos de fibrocemento (FCC), especialmente aquellos que utilizan fibras naturales como la fibra del mesocarpio de la palma de aceite (*Elaeis guineensis* Jacq.) (OPMF) de Perú. Este estudio examinó los efectos físicos, mecánicos y químicos de añadir diferentes proporciones de OPMF (0, 3, 6 y 9 %) en la fabricación de FCC. Esta adición resultó en valores reducidos en cuanto a densidad, porosidad y módulo de ruptura, así como un aumento en el contenido de humedad y una reducción del espesor. El FCC que contenía 3 % de OPMF mostró el rendimiento más favorable gracias a su mayor densidad y su menor absorción de agua y porosidad en comparación con la placa de control (0 % de OPMF). Las microimágenes obtenidas revelaron microfisuras menores y huecos interfaciales, indicativos de desprendimiento, lo que compromete las propiedades del FCC. Además, un análisis del espectro infrarrojo demostró un aumento en las vibraciones del grupo hidroxilo con el aumento en la proporción de fibra.
Palabras clave: compuesto de fibrocemento, fibra lignocelulósica, fibra de mesocarpio, propiedades físico-mecánicas.

INTRODUCTION

The oil palm (*Elaeis guineensis* Jacq.) is a highly productive and economically valuable crop, as it produces 10 times more than other oilseed crops. It produces 36% of the world's oil, and its replantation cycle generally lasts 25-30 years. The oil palm is a tropical and perennial crop from the tropical rainforest regions of West Africa, and it has spread to every tropical region worldwide (Aguilar Gallegos *et al.*, 2013; Goh *et al*., 2017; Wahab *et al.*, 2019; Ritchie & Roser, 2021). Oil palm is one of the most important commodities in the world. It is a raw material in the food, chemical, and energy industries (Aguilar Gallegos *et al.*, 2013; La Rosa Salazar, 2021). In 2019, the world produced 74.58 million tons of palm oil (Ritchie & Roser, 2021).

Peru has not been the exception to the rapid expansion of the oil palm, especially during the last 20 years (La Rosa Salazar, 2021). In 2022, the national production was 1.40 million tons, and it has shown an upward trend throughout this century (BCRP, 2023). Ucayali leads in oil palm fresh fruit bunch production, accounting for 19.23% of the national annual growth rate during the 2015-2021 period (JUNPALMA, 2022). This crop produces a huge amount of waste, which is not fully utilized and generally left to rot (Wahab *et al.*, 2019; Neyra-Vasquez *et al.*, 2022). However, this waste can be a raw material source, in the form of useful by-products, and its disposal can be economically, socially, and environmentally beneficial (Van Dam, 2016).

In the Peruvian Amazon, the palm oil extraction industry generates byproducts, including oil palm mesocarp fiber (Neyra-Vasquez *et al.*, 2022), a bulky, lignocellulosic, and fibrous biomass that remains after the pressing of oil palm fruits (Van Dam, 2016). The yield of fresh fruit bunches to mesocarp fibers is 12-14% (Vargas & Zumbado, 2003; Ramírez Contreras *et al.*, 2015). Mesocarp fiber is typically burned to produce energy (steam), although it can be alternatively used as soil fertilizer, for briquettes and pellets, as fast pyrolysis oil, as biocrude, in paper pulp, and in fiber composites (Ramírez Contreras *et al.*, 2015; Van Dam, 2016).

The construction industry is responsible for the depletion of a significant number of non-renewable resources, and it emits millions of tons of carbon dioxide into the atmosphere (Pacheco-Torgal & Jalali, 2011). Decarbonizing this industry is an important step towards achieving the net-zero goals of many countries (Awad *et al.*, 2022). In this context, the valorization of oil palm fibers in reinforcement cement composites could provide low-cost, sustainable construction and building materials from an underutilized resource (Awad *et al.*, 2022). Furthermore, this approach could contribute to mitigating the environmental issues associated with waste disposal (Ali-Boucetta *et al.*, 2021).

Plant fibers are collectively termed as *lignocellulosic fibers* due to their three major organic constituents (hemicellulose, cellulose, and lignin), and they provide a good mechanical performance of cement composites (Kriker *et al.*, 2005; Abdelmajeed Labib, 2019; Momoh & Osofero, 2020; Hasan *et al.*, 2022). In addition, natural fibers exhibit excellent thermal, acoustic, and electrical insulation properties. They are also biodegradable and can be burned and disposed of easily (Komuraiah *et al.*, 2014). The key mechanical aspects for selecting suitable reinforcing fibers in cement composites are tensile strength and flexural properties. Oil palm fibers exhibit superior properties that enhance their potential for utilization as reinforcement in cement composites (Kriker *et al.*, 2005; Abdelmajeed Labib, 2019). This research aimed to assess the physical and mechanical properties of fiber cement composites (FCC) with different proportions (0, 3, 6, and 9%) of oil palm mesocarp fibers (OPMF).

OBJECTIVES

The objectives of this study were to manufacture fiber cement composite materials with varying proportions of oil palm (*Elaeis guineensis* Jacq.) mesocarp fibers and to evaluate their physical and mechanical properties.

MATERIALS AND METHODS

Fiber characterization

Oil palm mesocarp residues, which contain fibers, were collected from a palm oil factory in Ucayali, Peru. The sieve size used to select the fibrous material with ambient moisture was N°8 (2830 µm). The selected material was immersed in water for 24 h to facilitate a mechanical pulping process at 10% consistency, using the 30 HP Bauer Disc Refiner with a disc diameter and a gap of 305 and 0.30 mm, respectively. The resulting fiber bundles are hereafter denoted as *oil palm mesocarp fibers* (OPMF).

The chemical composition of the OPMF is shown in Table 1. The following parameters were determined: holocellulose (Jayme-Wise's method), Klason lignin (T 222 om-98; TAPPI, 1998), ash (T 211 om-93; TAPPI, 1993), ethanol extractives (T 204 cm-97; TAPPI, 1997), and water extractives (T 207 cm-99; TAPPI, 1999). The values of chemical constituents were found to be consistent with those reported by Momoh and Osofero (2020).

Table 1. Chemical composition of the OPMF

Chemical constituents	Value (%)
Holocellulose	51.34
Klason lignin	31.03
Ash	5.79
Ethanol extractives	11.77
Water extractives	2.78

Furthermore, the physical dimensions of the OPMF were obtained using a digital USB microscope (model XA24) (Table 2). In comparison with the values reported by Asyraf *et al.* (2022) for oil palm empty fruit bunch, the diameter of the OPMF was similar, but they were shorter. Consequently, the aspect ratio was notably lower.

Table 2. Physical dimensions of the OPMF

Dimension	Value
Length (mm)	15.8
Diameter (mm)	0.3
Aspect ratio (length/diameter)	48

Fiber cement composite manufacturing

Prior to FCC production, the OPMF were mineralized in a calcium chloride (Cl_2Ca) solution at a concentration of 4% for a period of 15 min. Type I Portland cement paste (with a water/cement ratio of 0.4 w/w) was mixed with the OPMF at 0, 3, 6, and 9% by weight to produce the FCC. The resulting composite had a size of 350 x 350 x 10 mm and a final moisture content of 8.5% after three days of

Physical and mechanical characterization of the fiber cement composite

The following tests were conducted: moisture content (gravimetric method), density (DIN 52361; DIN, 1965a), water absorption (DIN 52364; DIN, 1965c), and porosity and volumetric swelling after 24 h of water immersion. Furthermore, the reduction in thickness was determined, following the application of a 39.23 MPa (400 $Kg.cm^{-2}$) load (DIN 53291; DIN, 1982), as well as the modulus of rupture (MOR), at a speed of 6.35 mm/min (0.25 inch/min) (DIN 52362; DIN, 1965b).

Scanning electron microscopy (SEM)

The interplay between cement and fibers was examined, as well as the internal structure of the FCC, using a scanning electron microscope (SEM; Thermo Scientific, Quantum 250, USA) with 12.5 and 15 kV acceleration voltages and 34X and 140X magnification. The samples were previously prepared and coated with a diluted gold solution.

Fourier transform infrared spectroscopic analysis

A Bruker Alpha II (Germany) Fourier transform infrared (FTIR) spectrometer was employed to examine the molecular vibrations of samples while applying the attenuated total reflection (ATR) method. The spectra were recorded via successive scans in the wavenumber range between 400 and 4000 cm^{-1}, with a resolution of 4 cm^{-1}. The analyzed samples were the control board (0% OPMF), the FCC containing 3, 6, and 9% OPMF, and the OPMF.

Data analysis

An analysis of variance (ANOVA) was performed to identify disparities between the mean values of the FFCs' physical and mechanical properties. Afterwards, the Tukey test was conducted to determine the significance in the mean values, as indicated by different letters in each of the presented graph. The R programming language version 4.2.3 (RStudio Team, 2023) was used for data analysis.

RESULTS

Physical properties

The physical properties tested were density, moisture content, volumetric swelling, water absorption, and porosity. The results are shown in Figure 1. The highest density was found in the FCC with 3% OPMF (1.60 ± 0.05 $g.cm^{-3}$). The moisture content was not significantly different between FCCs, and the addition of 9% OPMF did not affect volumetric swelling or water absorption. The lowest porosity was found in the FCCs with 3% OPMF (25.13 ± 1.08%) and 6% OPMF (24.47 ± 0.52%).

Mechanical properties

The mechanical properties tested were thickness reduction and modulus of rupture (MOR). The results are shown in Figure 2.

The highest thickness reduction was found in the FCC with 9% OPMF (5.79 ± 1.18%). The MOR of the FCC with 3% OPMF (4.35 ± 0.65 MPa) was greater than those of the FCCs with 6% OPMF (2.98 ± 0.37 MPa) and 9% OPMF (3.19 ± 0.31 MPa), as well as similar to that of the control board (4.87 ± 1.30 MPa).

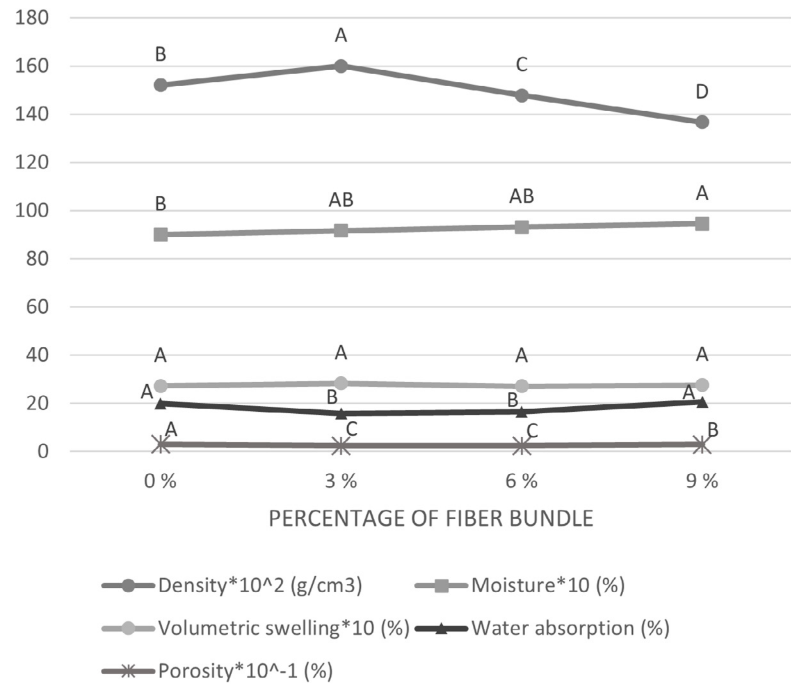

Figure 1. Physical properties of FCCs with different OPMF proportions

Bars with different letters mean that there is a significant difference at $p < 0.05$ (Tukey test)

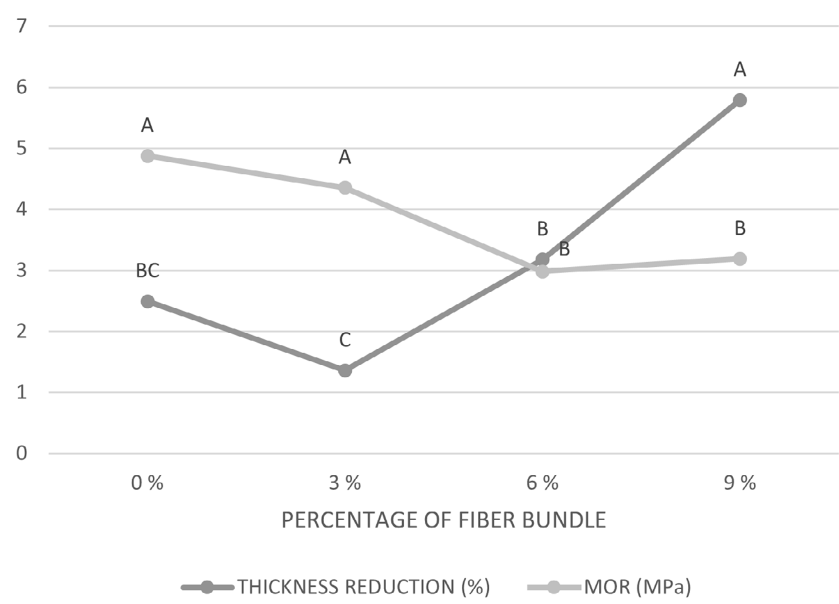

Figure 2. Mechanical properties of FCCs with different OPMF proportions

Bars with different letters mean that there is a significant difference at $p < 0.05$ (Tukey test)

Scanning electron microscopy

The OPMFs' random distribution in the cementitious matrix is shown in Figure 3.

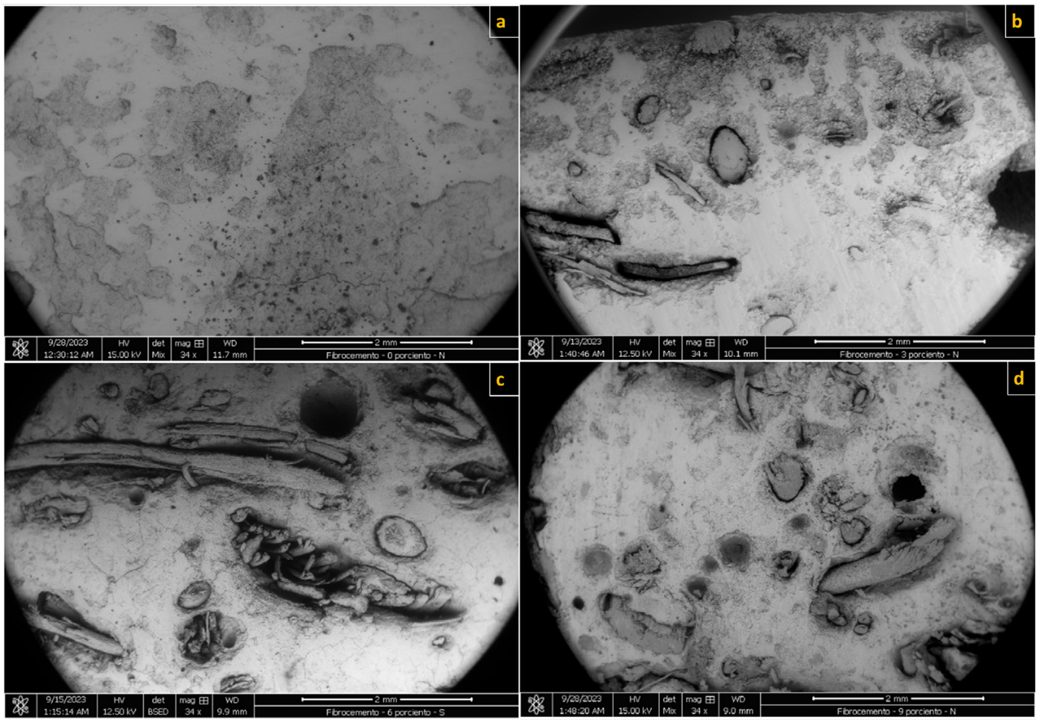

Figure 3. SEM images: a) control board (0% OPMF); b) FCC containing 3% OPMF; c) FCC containing 6% OPMF; d) FCC containing 9% OPMF

Individual fibers and bundles of fibers are easily distinguishable in Figures 3b, 3c, and 3d in comparison with the control board (Figure 3a).

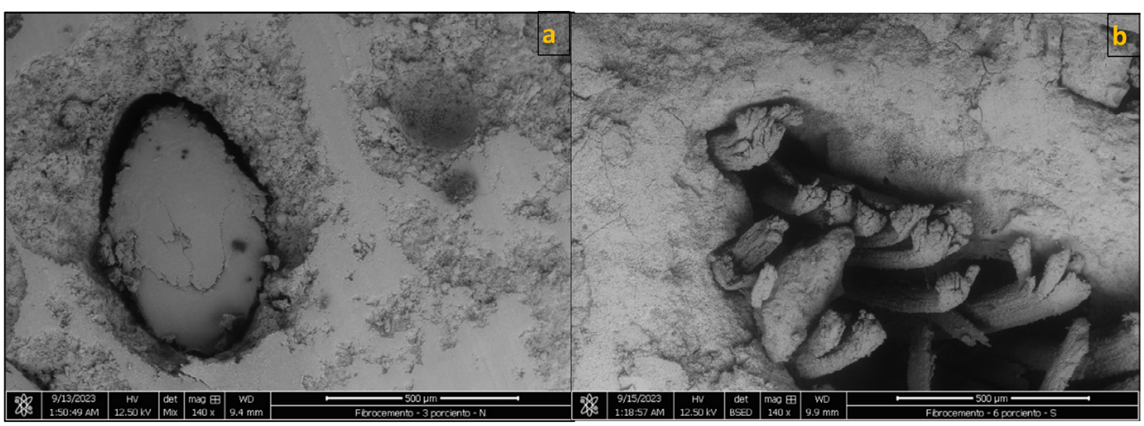

Figure 4. Internal structure of the FCC: a) an individual fiber and b) a bundle of fibers within the cementitious matrix

Figure 4 shows the internal structure of the FCC. A void distribution difference between an individual fiber (Figure 4a) and a bundle of fibers (Figure 4b) is observed.

Fourier-transform infrared spectroscopy

Figure 5 presents the FTIR spectra of the control board (0% OPMF), the FCCs containing 3, 6, and 9% OPMF, and the OPMF.

The FTIR graph shows vibrations in different band regions and similar patterns in the FTIR spectra.

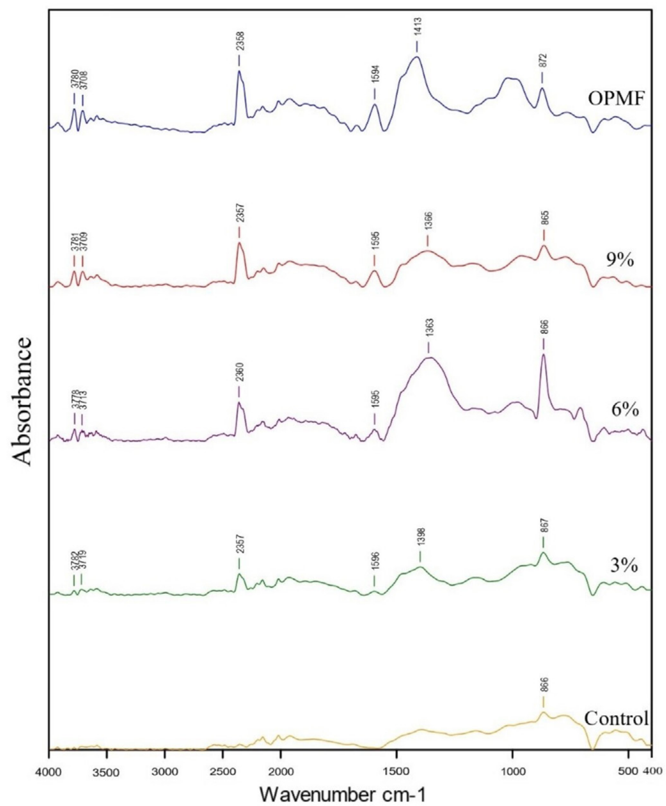

Figure 5. FTIR spectra of the control board (0% OPMF), the FCCs containing 3, 6, and 9% OPMF, and the OPMF

DISCUSSION

Physical properties

The FCCs densities are reduced when the fiber proportion is increased. This indicates that adding higher OPMF contents tends to reduce the board density (Lertwattanaruk & Suntijitto, 2015; Adamu *et al.*, 2022). The density of the composites is determined by the density and quantity of their components and their degree of compactness (voids/porosity) (Adamu *et al.*, 2022). In this work, the control board (1.52 ± 0.02 $g.cm^{-3}$) exhibited a lower density than the FCC with 3% OPMF (1.60 ± 0.05 $g.cm^{-3}$). This is due to the presence of cavities, which is a characteristic of cementitious materials (Alencar *et al.*, 2023), and to the increased number of voids resulting from the addition of fiber (Bellel & Bellel, 2023).

The similarity of the moisture contents in the FCCs can be explained by the fact that the fiber content was not enough to increase the samples' moisture due to the hydrophobic nature of lignin (31.03%), which was not removed during the mechanical pulping process. The lowest moisture content corresponded to the control board (9.00 ± 0.55%), indicating that the addition of fibers increased the permeability of concrete materials, mainly due to their relatively high moisture absorption and hydrophilic behavior, which is attributed to the presence of hemicellulose and the porous nature of the materials (Komuraiah *et al.*, 2014; Choi, 2022; Hamada *et al.*, 2023).

The comparability of the volumetric swellings of FCC is contrary to that expected (the addition of OPMF should increase the swelling of the composite) (Adamu *et al.*, 2022). This indicates that the FCC were not negatively affected by fiber with regard to swelling. The OPMFs' 15.8 mm length could reduce heterogeneity in the samples and prevent surface cracking, which can lead to excessive water absorption and, subsequently, volumetric swelling (Cárdenas-Oscanoa *et al.*, 2020; Córdova Contreras *et al.*, 2020; Momoh & Osofero, 2020).

Water absorption is a physical property that is related to porosity; a lower water absorption increases the durability and stability of concrete (Jamshaid *et al.*, 2022). The addition of 3% OPMF to cementitious composites has been generally found to reduce the water absorption of FCC (Jamshaid *et al.*, 2022). However, other studies have yielded contradictory results (Kareche *et al.*, 2020; Adamu *et al.*, 2022).

The porosity at the interface increased as the fiber loading increased (Jamshaid *et al.*, 2022; Bellel & Bellel, 2023). A possible explanation is that the interfacial transition zone (ITZ) of the FCC matrix, which is characterized by a high porosity, formed a gap (debonding) around the lignocellulosic fiber (Savastano *et al.*, 1999; Ali *et al.*, 2022). Furthermore, a higher porosity and a larger number of voids could influence strength properties, resulting in increased water absorption and reduced density (Cipra-Rodriguez *et al.*, 2022; Fernando *et al.*, 2023).

Mechanical properties

The increase in OPMF content tends to reduce the compressive strength of the materials, or to augment the thickness reduction (Lertwattanaruk & Suntijitto, 2015), as fibers typically exhibit a lower density than the matrix. The lowest value was achieved by the FCC with 3% OPMF, which agrees with other studies (Raut & Gómez, 2016; Alatshan *et al.*, 2017; Adamu *et al.*, 2022). The addition of 1 and 3% (by volume) of natural fibers in cement composites has been demonstrated to enhance the properties of cement mortars and concrete (Momoh & Osofero, 2020). Furthermore, an increased fiber loading fraction can deteriorate mechanical properties (Jamshaid *et al.*, 2022).

The flexural behavior of the FCC depends on the type, length, diameter, aspect ratio, and texture of the fibers (Khorami & Ganjian, 2011). Nevertheless, the failure of a FCC is highly influenced by size and the cross-section of the lignocellulosic fiber, which is not uniform (Ishak et al., 2013). The length-to-diameter ratio (*i.e.*, aspect ratio) of a fiber has significant effects on the properties of composites (Altez Basaldúa *et al.*, 2020). Short oil palm fibers can be used as additive fillers in polymer composites to enhance mechanical properties (Arao *et al.*, 2015). However, the aspect ratio of the fibers used in this study (48) was less than that observed in Asyraf *et al.* (2022) (155.5). Moreover, the addition of oil palm fiber has no effect on the chemical composition of the matrix, thus preventing any interference with the curing of the material (Bellel & Bellel, 2023).

Cement concrete without fiber is brittle and exhibits lower tensile strength, limited ductile properties, and limited resistance to cracking. The addition of fiber in concrete can arrest the propagation of microcracks while increasing its strength (Jamshaid et al., 2022). However, our results regarding mechanical properties showed equal or lower strength values when adding OPMF to FCC. The inferior performance of the FCCs containing 6 and 9% OPMF with respect to the control board may be attributed to the decomposition of the fibers' lignin within the alkaline matrix (Savastano *et al.*, 2005), promoting the presence of voids. It is worth highlighting that the hydroxyl groups available on the surface of the cellulose serve as the primary means through which fibers and cement bond together (Coutts, 2005). In addition, the homogeneous dispersion of fibers in the matrix is a crucial factor to develop FCC with well-balanced mechanical properties while incorporating plant fibers. Hence, the dispersion of fibers can be improved by increasing the water quantity to the optimal value (Fernando et al., 2023).

The physical and mechanical properties and the chemical components of OPMF may vary depending on factors such as the weather, soil conditions, fertilization, plant age, *etc.* (Bajuri *et al.*, 2017). In this vein, the findings of each research study may be unique and therefore cannot be extrapolated to other work (Khorami & Ganjian, 2011). FCC can be employed in roofing, internal or external walls, façades, internal or external pavements, and flooring slabs as a sustainable construction material for the future (Khorami & Ganjian, 2011; Jamshaid et al., 2022). In this study, the optimal performance was achieved by FCC with 3% OPMF, which aligns with the findings of Abdalla *et al.* (2023) and Khorami & Ganjian (2011), who found a maximum of 4% to be the optimal replacement of natural fibers to enhance the properties of FCC in laboratory settings.

Scanning electron microscopy

The fibers and fiber bundles in the FCCs (Figures 3b to 3d) are readily discernible in the analyzed micro-images, unlike the case of the control board (Figure 3a). The presence of fibers and fiber bundles increases FCC porosity (Bellel & Bellel, 2023). Conversely, the observed cavities are characteristic of porous materials such as cement. However, the presence of gaps in the transition zone or in fiber tunnels could potentially render some points fragile or negatively alter the structure of the FCC (Alencar *et al.*, 2023), which justifies the lower strength of the samples with 6 and 9% OPMF.

Figure 3 shows some fiber tunnels, which are the result of a rupture mechanism known as *fiber pulling*. Additionally, fiber breaking was observed in the majority of fibers (Khorami & Ganjian, 2011).

An adequate curing of the FCCs was observed, as indicated by the minimal number of microcracks in the internal structure (Figure 4). Furthermore, there were voids in the ITZ, which can be attributed to inadequate interfacial bonds, likely because of the heterogeneous fiber surface resulting from the mechanical pulping process (Feng et al., 2023). Fiber swelling tendencies and non-alkaline pre-treatments of OPMF have been found to attenuate interface efficiency in FCCs (De Souza Castoldi *et al.*, 2023). The dissimilar void distribution between an individual fiber (Figure 4a) and a bundle of them (Figure 4b) is due to the fibers' different diameters (Alatshan *et al.*, 2017). A homogeneous dispersion of fiber is required to manufacture FCC with well-balanced mechanical properties (Fernando et al., 2023).

Fourier transform infrared spectroscopy

The FTIR graph illustrates the spectra of the FCCs and the OPMF, which was reported in a study on bamboo fiber-reinforced cement composite (Alencar *et al.*, 2023). The differing vibration intensities (peaks) observed between spectra are dependent on the fiber content (Feng et al., 2023).

The 3708-3782 cm^{-1} band is a result of the stretching vibration of OH groups, which originate from the hydroxyls present in the cellulose molecules, the primary means by which fibers and cement bond together, and the vibration of the hydrogen bridge, characteristic of intermolecular bonds between cellulose chains (Coutts, 2005; Feng et al., 2023; Jiang et al., 2023; Liu *et al.*, 2023; Arango-Pérez *et al.*, 2024). This band also reveals the presence of functional groups such as phenols, alcohols, and water in hemicellulose polymers, lignin, and polyphenols (Alencar *et al.*, 2023).

The vibration in the 2357-2360 cm^{-1} band is related to the presence of CO_2, which can easily adhere to the surface of lignocellulosic materials through the adsorption phenomenon (Arango-Perez *et al.*, 2024).

The peaks in the 1594-1596 cm^{-1} band are associated with the vibration of the acetyl and uronic ester bonds of hemicellulose and with ester linkage in carboxylic groups of lignin and/or hemicellulose. Furthermore, these peaks indicate the C-H deformation of lignin and the C=C bonds originating from its aromatic rings (Alencar *et al.*, 2023; Ezugwu et al., 2023; Jiang et al., 2023; Arango-Pérez *et al.*, 2024). The 1450 cm^{-1} band indicates C-H deformation in cellulose/hemicellulose (Alencar *et al.*, 2023).

The 1000 cm^{-1} band can be attributed to deformations in the C-H and C-O couplings present in cellulose (Alencar *et al.*, 2023; Ezugwu et al., 2023). The 865-867 cm^{-1} region is associated with the stretching vibration of the Si-O bonds of the SiO4-4 tetrahedron of the C-S-H present in cementitious matrices (Alencar *et al.*, 2023). Conversely, the peaks observed in the 800-900 cm^{-1} band are attributed to C-OH deformation of the β-glucosidic bonds present in the hemicellulose of plant fibers (Alencar *et al.*, 2023).

CONCLUSIONS

Fiber cement composites containing 3, 6, and 9% of oil palm mesocarp fiber were produced. The addition of up to 9% OPMF reduced density by 10.17%, porosity by 6.60%, and the modulus of rupture by 34.62%. There was an increase in the short-term water uptake (3.41%), as well as in thickness reduction (132.53%). This was due to lower fiber density and moisture absorption capacity. In addition, there were no significant differences between the FCCs with regard to volumetric swelling and water absorption. The FCC containing 3% OPMF achieved the optimal physical and mechanical performance due to its higher density and its lower water absorption and porosity in comparison with the control board (0% OPMF).

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the research, authorship, and the publication of this paper.

AUTHOR CONTRIBUTIONS

L.F.G.-R.: Data curation, formal analysis, investigation, methodology, software, validation, visualization, writing (original draft, review & editing). H.E.G.M.: Conceptualization, funding acquisition, supervision, project administration, resources, methodology. J.A.C.-R.: Data curation, formal analysis, writing (original draft, review & editing). A.J.C.-O.: Conceptualization, supervision, methodology, project administration, writing (original draft, review & editing).

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Appendix 1. Physical and mechanical properties of FCC with different OPMF proportions

OPMF	Density ($g.cm^{-3}$)	Moisture content (%)	Volumetric swelling (%)	Water absorption (%)	Porosity (%)	Thickness reduction (%)	Module of rupture (MPa)
0%	$1.52^{b} \pm 0.02$	$9.00^{b} \pm 0.55$	$2.72^{a} \pm 1.13$	$20.00^{a} \pm 1.03$	$30.75^{a} \pm 1.12$	$2.49^{bc} \pm 0.99$	$4.87^{a} \pm 1.3$
3%	$1.60^{a} \pm 0.05$	$9.17^{ab} \pm 0.31$	$2.83^{a} \pm 0.69$	$15.86^{b} \pm 0.69$	$25.13^{c} \pm 1.08$	$1.36^{c} \pm 1.02$	$4.35^{a} \pm 0.65$
6%	$1.48^{c} \pm 0.02$	$9.32^{ab} \pm 0.61$	$2.72^{a} \pm 1.80$	$16.53^{b} \pm 0.45$	$24.47^{c} \pm 0.53$	$3.18^{b} \pm 2.00$	$2.98^{b} \pm 0.37$
9%	$1.37^{d} \pm 0.03$	$9.45^{a} \pm 0.41$	$2.77^{a} \pm 1.70$	$20.68^{a} \pm 0.56$	$28.72^{b} \pm 0.57$	$5.79^{a} \pm 1.19$	$3.19^{b} \pm 0.31$

An * within a column with different letters means that there is a significant difference at $p < 0.05$ (Tukey test). The standard deviation is also shown.