

Utilizing Palm Kernel Fibre to Reinforce Cement-Based Composite Panels Blended with Bamboo Leaf Ash

Zainab Tolu Giwa^{1,a*}, Samson Olalekan Odeyemi^{1,b},
Uwemedimo Nyong Wilson^{2,c}, Abdullahi Ayodeji Adefila^{2,d}
and Emmanuel Olusegun Eyinade^{1,e}

¹Department of Civil and Environmental Engineering, Kwara State University, Malete, Nigeria

²Department of Civil Engineering, Nigerian Defence Academy, Kaduna, Nigeria.

^{a*}zainab.giwa@kwasu.edu.ng, ^bsamson.odeyemi@kwasu.edu.ng, ^cunwilson@nda.edu.ng,
^dadefila.abdullahi2022@nda.edu.ng, ^eemmanueleyinade73@gmail.com

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Abstract. Panel wall systems are increasingly preferred in modern construction due to their efficiency and sustainability. However, conventional cement-based materials are brittle, have limited tensile strength, and are prone to cracking, necessitating reinforced alternatives. This study investigates using palm kernel fiber (PKF) and bamboo leaf ash (BLA) in cement-based composite panels to improve mechanical properties and durability. A water-to-binder ratio of 0.55 and a cement-to-BLA ratio of 3:1 were used, with PKF added in varying proportions from 0% to 4% by binder weight. 165 specimens were cast and tested for density, water absorption, modulus of rupture (MOR), modulus of elasticity (MOE), and compressive strength at 7, 14, and 28 days of curing. The results showed water absorption between 2.5% and 7.5% and densities from 1375 to 1497 kg/m³. The compressive strength was found within the range of 7.6 -16.54N/mm² and generally decreases with the increasing percentage of fiber contents but increases with curing age. The bending strength (MOR) ranges from 3.03 to 7.24 N/mm², while the modulus of elasticity (MOE) ranges from 6.03 to 10.49 N/mm². Both MOE and MOR increased with curing age and showed a slight increase with fiber content. All results complied with American Concrete Institute (ACI) standards. The study concludes that PKF-reinforced, BLA-blended composite panels exhibit suitable strength and durability for wall construction, offering a sustainable alternative to conventional materials.

Introduction

Panel wall systems are rapidly becoming the preferred choice over traditional wall systems for institutional buildings [1]. Internal walls in residential buildings are typically built with clay bricks or blocks, which require plastering on both sides up to 20 mm thick. Because of its weight, work requirements, and handling of waste production, this approach requires skilled labor during construction [2, 3]. In comparison to conventional brick or block walls, a locally made, reinforced wall paneling system offers an alluring substitute that improves weight, ease of installation, waste management, and finishing. These panels can be produced using materials like bamboo leaf ash and palm kernel fiber [4].

Various producers create cement-based composite panels using natural resources like cement, aluminum, wood, plastic, and treated or untreated natural agro-based fibers (e.g., coconut fiber, oil palm shell fiber, palm kernel fiber), as well as cementitious materials like bamboo leaf ash and rice husk ash [5, 6].

Palm trees, which belong to the Arecaceae family, include over 2,600 species grouped into more than 200 genera. They are characterized by branchless stems and evergreen leaves [7]. Palm kernel fiber is an agricultural byproduct generated in large quantities worldwide. Separating fruits or nuts from bunches and discarding empty fruit bunches is part of the process of extracting seeds [8, 9]. To create fibers that save energy and resources and benefit the environment, the husk or empty bunch of palm kernels can be utilized. In the construction industry, they can be utilized as natural fiber reinforcement for panels due to their low cost and natural abundance [10].

Tropical climates are ideal for the natural growth of bamboo, a composite material. The Bambusoideae family comprises over 1,662 species in 121 genera, with some species introduced beyond their native ranges [11]. Bamboo has hollow, smooth, round stems with branches mostly on the upper part of the plant. Bamboo leaves, which fall off during the dry season, create waste that affects soil suitability for planting. When dried and burned, these leaves produce ash with pozzolanic properties [12].

Umoh and Jonah [13] examined the use of coconut fiber as reinforcement in composite panels made of cement mixed with bamboo leaf ash and the use of natural agricultural waste in cement-based wall composites. Portland cement and bamboo leaf ash were combined at a weight-to-weight ratio of 1:3. The water-to-cement ratio was maintained at 0.55 while different weight percentages of coconut fiber (0%, 1%, 2%, 3%, and 4% of the cementitious materials) were added. Several parameters were analyzed, including density, water absorption, moisture content, modulus of rupture (MOR), and compressive strength. The specimens underwent tests for compressive strength, MOR, and moisture content at 7, 14, and 28 days after casting, as well as tests for density and water absorption at the same time. Findings showed that while compressive strength and MOR increased with curing age and fiber concentration up to 2%, density decreased as fiber content increased. Increased moisture content and water absorption were also associated with higher fiber content. According to the results, composite panels made of bamboo leaf ash cement can be efficiently reinforced with coconut fiber.

Odeyemi et al. [14] investigated high-performance concrete's mechanical properties and microstructure with added bamboo leaf ash. It was emphasized how the exceptional strength, durability, and workability of high-performance concrete (HPC) have made it highly sought after. After being calcined at 700°C in an electric furnace, bamboo leaves were examined using Energy Dispersive X-ray Fluorescence (EDXRF), which showed that the ash had a high silica concentration and pozzolanic qualities. At 5%, 10%, 15%, and 20% by weight, BLA was used in place of cement, and the concrete's compressive and splitting tensile strengths were assessed after 7, 28, and 56 days. After 56 days of curing, 5% replacement yielded the maximum strength, and the concrete microstructure showed enhanced interlocking. According to the study's findings, 5% BLA could be used in place of cement in HPC.

Amambey et al. [15] studied the use of lateritic aggregates and palm kernel fibre (PKF) as alternatives to conventional concrete materials. Experimental tests were conducted to evaluate the compressive, tensile, and anchorage bond strengths of lateritic concrete mixed with PKF. Results showed that lateritic concrete without PKF achieved only 29.68% of the target 25N/mm² compressive strength, and the addition of PKF further reduced strength, with a 74.34% decrease at 20% PKF. Tensile strength followed a similar trend, while bond strength declined gradually with increasing PKF content. Based on these results, the study recommended limiting PKF addition to a maximum of 5% to prevent significant reductions in concrete strength.

Akinbile et al. [16] investigated the use of bamboo leaf ash (BLA) and palm fruit fibre ash (PFFA) as partial replacements for Portland cement (PC) in concrete. The research evaluates their physical, chemical, and microstructural characteristics using XRF, XRD, and SEM/EDX analyses, along with pozzolanic reactivity through the Modified Chapelle test. Concrete samples incorporating 0–25% BLA and PFFA were tested for compressive strength over 7, 28, 56, and 90 days. Findings indicate that both ashes meet pozzolanic standards, displaying high silica content and notable Ca(OH)₂ consumption. The optimal compressive strength of 46.58 MPa was recorded at 10% replacement after 90 days, demonstrating their suitability as eco-friendly alternatives to PC in concrete product

Onikeku et al. [17] examined the properties of concrete incorporating bamboo leaf ash (BLA) as a partial cement replacement. Their experimental findings revealed that BLA enhanced the concrete's split tensile, compressive, and flexural strengths, with 10% replacement identified as the optimal level. Additionally, the use of BLA led to a reduction in setting time, consistency, compacting factor, slump, water absorption, permeable voids, sorptivity, and density.

Amambey et al. [18] examined the mechanical properties of lateritic concrete with palm kernel fibre (PKF), focusing on compressive, tensile, and bond strengths. Plain lateritic concrete had a compressive strength of 7.42 N/mm², about 29.68% of conventional concrete (25 N/mm²). Increasing

PKF content led to a gradual decline in strength, reaching 1.90 N/mm² at 20% PKF, a 74.34% reduction. Tensile strength followed a similar trend, while bond strength decreased from 2.31 N/mm² (0% PKF) to 1.27 N/mm² (20% PKF). A pull-out bond failure mechanism was noted, with the modulus of rupture retaining 84.79% of bond strength at 0% PKF. The study indicates that PKF reduces lateritic concrete's strength, necessitating higher water-cement ratios for workability.

While a lot of research has been done on using agricultural waste, such as BLA, as concrete additives, not much has been done on combining different materials, one as an additive and the other as reinforcement in cement-based composite panels. The goal of this project is to investigate how palm kernel fiber and bamboo leaf ash can be used as reinforcement in cement-based composite panels.

Materials and Methods

Portland Limestone Cement (PLC) in line with the Nigerian Industrial Standard [19], PLC of grade 42.5R, was utilized for this study.

Palm kernel fibre (PKF) was sourced from the Palm Oil market in Onimia Area, Imia, Kajola Local Government, Oyo State. The fiber was treated by boiling it in water for fifteen minutes, pounding it to remove oil, rinsing it with lukewarm water, and drying it in the laboratory for three days to make sure it was both moisture- and oil-free. Fig. 1a shows the palm kernel fibers after it has been treated. Bamboo leave was sourced from Onimia Area, Imia, Kajola Local Government, Oyo State. The process for obtaining bamboo leaf ash (BLA) involved finely powdering the leaves, sieving them through a 45µm sieve, and then calcining them in a furnace at 700°C. Fig. 1b shows the calcined bamboo leaf ash.



a: Palm Kernel Fibre



b: Bamboo Leaf Ash

Fig. 1. Admixture added to panel wall samples

Mix Proportions and Sample Preparation

To create a cohesive and workable mixture, a ratio of 1:3 (BLA to cement) was adopted, based on recommendations from Umoh & Jonah [13]. The palm kernel fiber was cut into 30 mm lengths and incorporated in concrete at varying weight percentages of 0%, 1%, 2%, 3%, and 4%. All combinations were kept at a constant water-to-binder ratio of 0.55. The prepared mixes were poured into molds, left to set for 24 hours before demolding, and then cured in water for 7, 14, and 28 days.

To evaluate the mechanical and physical properties of the composite panels, specimens were cast in different dimensions: 300 × 150 × 25 mm for density and water absorption, 150 × 75 × 40 mm for modulus of rupture (MOR), 160 × 40 × 40 mm for modulus of elasticity (MOE), and 100 × 100 × 100 mm for compressive strength. The cube and panel wall samples are shown in Fig. 2.



Fig. 2. Panel Wall Samples

Testing Procedures

Density

The samples' density was carried out in accordance to BS EN 12390-7:2019[20] and was computed after 28 days. Weighing and computing the volumes of three specimens were done. The density was computed using Eq. 1.

$$\text{Density } \left(\frac{\text{kg}}{\text{m}^3} \right) = \frac{M}{V} \quad (1)$$

Where m is the Mass of the sample (kg), v is the volume of the sample (m^3).

Water Absorption

The water absorption test was carried out following ASTM C642-13:2013 [21]. During the 28-day curing period, the specimens' mass was measured both prior to and following a 24-hour immersion in water in order to ascertain their water absorption capacity. Eq. 2 was utilized to compute the water absorption.

$$\text{Water absorption, } (W_{ab}) = \frac{M_1 - M_2}{M_2} \times 100 \quad (2)$$

Where M_1 is the mass before absorption (kg), M_2 is the mass after absorption (kg).

Compressive Strength Test

Compressive strength tests were performed on 100x100x100 mm cube specimens in compliance with BS EN12390-4:2000 [22]. Using a 5000 kN capacity compression testing equipment, the specimens were subjected to increasing compressive loads until failure, at which point the maximum compressive load was recorded.

Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were conducted according to the procedure in BS EN 12390-5 [23] and BS EN 12390-13 [24], respectively. These tests were conducted using a modified Testometric apparatus (model FS 50AT with a 50 kN capacity) at the Mechanical Engineering Department of the University of Ilorin. The equipment provided the failure parameters for each sample.

Results and Discussion

Density

The density of the composite panels, which were reinforced with palm kernel fiber and contained bamboo leaf ash, was obtained following a 28-day curing period. The density of the panels decreased as the fiber content rose, as shown in Fig. 3. This decrease is explained by the fibers' lighter weight

in relation to the cement matrix, which creates more voids and a less dense structure. This result is consistent with a prior study by Odeyemi et al. [2], which found that adding more lighter components, like sawdust and groundnut shell ash, decreased density. The minimum density of cement-bonded particle board is set at 1250 kg/m³ by the Indian standard [25], however, the International Organization for Standardization (ISO) [26] stipulates a minimum density of 1000 kg/m³ for particle boards. The panels in this study, with fibre content up to 4%, meet these density requirements. It was also observed that there is a loss in the density by 1.5%, 2.0%, 2.3%, and 8.15% for 1%, 2%, 3%, and 4% incorporation of palm kernel fibre.

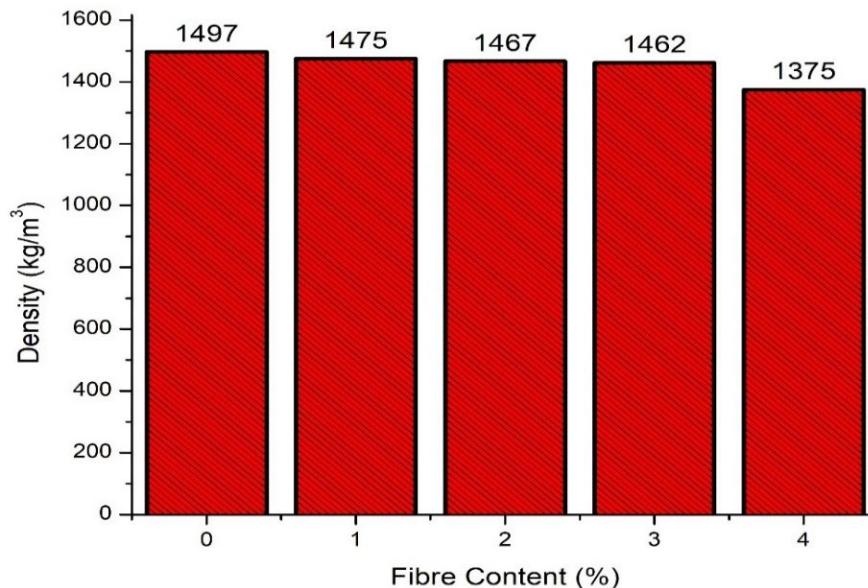


Fig. 3. Effect of Fibre Content on Density of BLA Blended Cement Wall Panels

Water Absorption

Fig. 4 presents the water absorption results of the composite panels. After 28 days of curing, water absorption increased from 2.5% for the control sample to 7.5% for the sample with 4% fibre content. Higher porosity and spaces created by the fibers are the major causes of the increase in water absorption. This result corroborates earlier research findings by Odeyemi et.al. (2020) [27] that showed increased water absorption with higher volumes of sawdust in cement composites. The results fall within the acceptable range of 2.5-7.5% for panel walls as stipulated by NIS 87 [28] for panel walls.

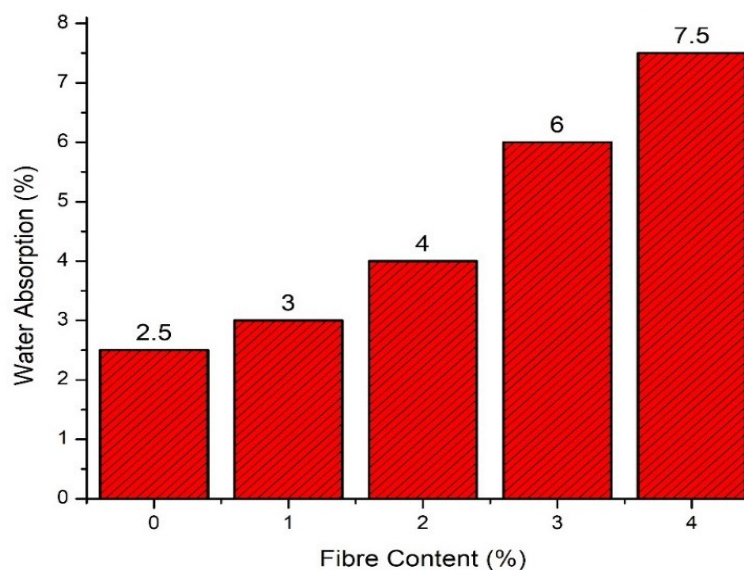


Fig. 4. Effect of Fibre Content on Water Absorption of BLA Blended Cement Wall Panels

Modulus of Rupture (MOR)

The Modulus of Rupture (MOR) results for the composite panels at 7, 14, and 28 days, respectively, are shown in Fig. 5. The MOR values increased with the curing period for both the control and fiber-reinforced samples. The highest MOR was observed at 28 days with 1% fibre content, reaching 7.2 N/mm², while the lowest was recorded with 4% fibre content at 7 days, at 3.0 N/mm². The modulus of rupture (MOR) initially increased with the addition of palm fiber up to 1%; however, further increases in fiber content led to a decline in MOR. Also, it was discovered that there is a loss in the MOR by 38.8%, 28.8%, 5.8%, and 28.8% for 1%, 2%, 3%, and 4% incorporation of palm kernel fibre. The superior distribution and crack-bridging action of the fibers inside the composite matrix are probably the cause of the improved MOR at 1% fiber content [5]. This provided additional evidence for the assertion made by [27] that a larger MOR was the consequence of sawdust and periwinkle shell quantities decreasing while cement quantity rose.

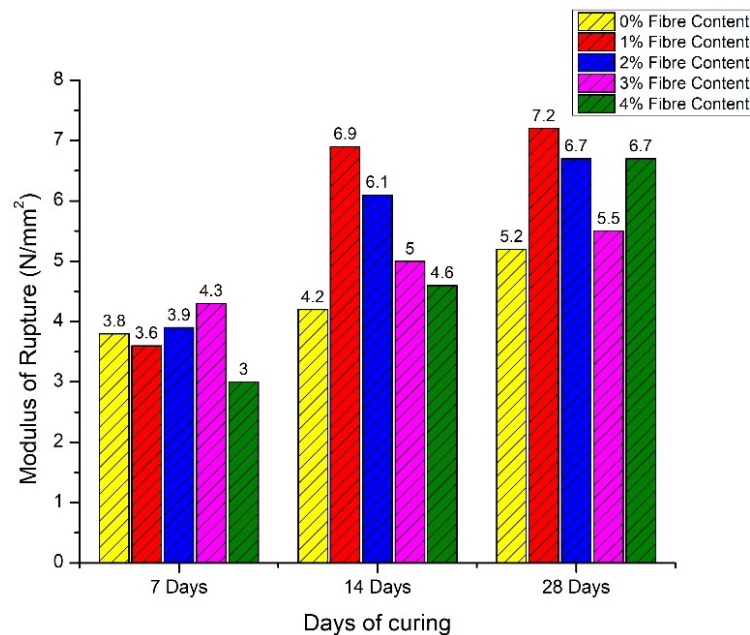


Fig. 5. Effect of Fibre Content on Modulus of Rupture of BLA Blended Cement Wall Panels (7, 14, and 28 days)

Modulus of Elasticity (MOE)

The Modulus of Elasticity (MOE) results for the 7, 14, and 28-day curing periods are presented in Fig. 6. Similar to the MOR trend, the MOE increased with curing time and peaked at 1% fiber content. Beyond this point, a decline in MOE was observed. Specifically, MOE increased by 10.53% and 9.47% for 1% and 2% fiber incorporation, respectively, before decreasing by 13.68% and 27.4% at 3% and 4% fiber content. The reduction in MOE at higher fiber concentrations can be attributed to increased porosity and weaker fiber-matrix bonding. These findings further support the claim that MOE tends to decrease as the proportion of agro-waste increases [27].

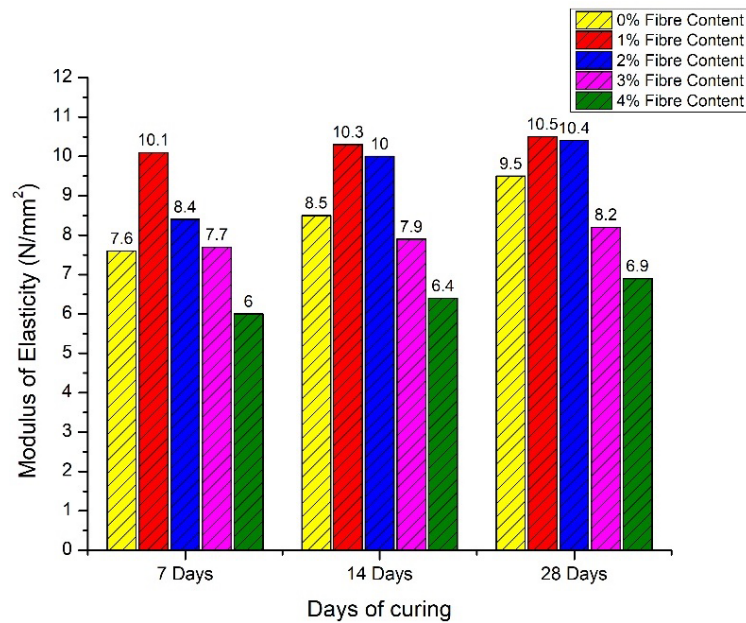


Fig. 6. Effect of Fibre Content on Modulus of Elasticity of BLA Blended Cement Wall Panels (7, 14, and 28 days)

Compressive Strength

Fig. 7 presents the compressive strength of the composite panels at 7, 14, and 28 days of curing. After seven days, compressive strength ranged from 7.6 to 10.73 N/mm², with the highest strength observed at 2% fiber content. This trend continued at 14 and 28 days, where the maximum compressive strengths of 15.0 N/mm² and 16.54 N/mm², respectively, were recorded at the same fiber level. Compressive strength increased by 11.4% and 25% with 1% and 2% fiber incorporation, respectively, before decreasing by 15.1% and 10.6% at 3% and 4% fiber content. These findings align with the conclusions of [4], which suggest that moderate fiber content enhances compressive strength, while excessive fiber addition leads to fiber congestion and weak points, reducing overall strength. Therefore, 2% fiber content appears to be the optimal level for maximizing compressive strength in these composite panels.

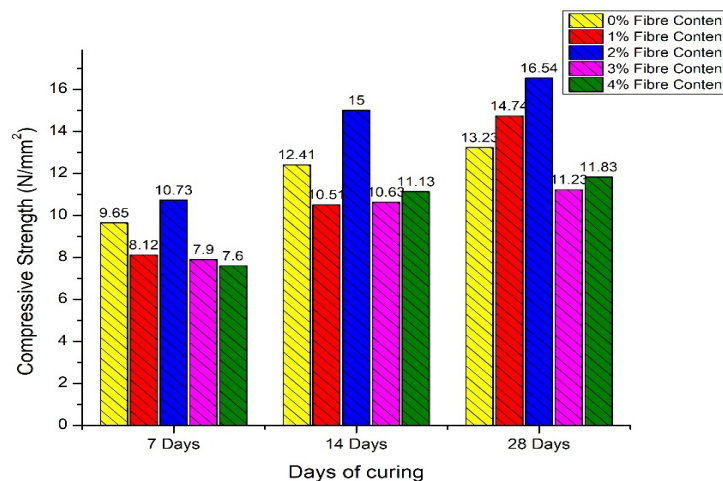


Fig. 7. Effect of Fibre Content on Compressive Strength of BLA Blended Cement Wall Panels (7, 14, and 28 days)

The findings from this study highlight the potential of utilizing palm kernel fiber (PKF) and bamboo leaf ash (BLA) in cement-based composite panels to enhance their mechanical properties while promoting sustainability in construction materials. The results indicate that while PKF incorporation reduces density and increases water absorption, it also enhances certain mechanical properties at optimal concentrations. The modulus of rupture (MOR) and modulus of elasticity (MOE) improved with curing time and exhibited the highest values at 1% PKF content, whereas compressive strength

was maximized at 2% PKF content. Beyond these levels, excessive fiber content resulted in strength reductions due to increased porosity and weaker bonding between the fibers and the cementitious matrix.

These results suggest that combining PKF and BLA offers a viable alternative to traditional cement-based materials, particularly for lightweight and eco-friendly wall panel applications. The study aligns with previous research findings, reinforcing the role of agro-waste materials in sustainable construction. However, Future studies should examine the long-term durability of these composite panels under different environmental conditions, optimize fiber treatment methods, enhance fiber-matrix adhesion, and explore additional durability aspects such as fire resistance, long-term creep behavior, and thermal insulation properties.

Conclusions

The experiment's outcomes led to the following deductions being made:

1. The density of the composite panels decreased with increasing fiber content, while water absorption increased due to fiber-induced porosity.
2. The modulus of rupture (MOR) and modulus of elasticity (MOE) reached peak values at 1% PKF content, indicating improved flexural strength and rigidity before declining at higher fiber concentrations.
3. Compressive strength followed a similar trend, with a maximum value of 16.54 N/mm² recorded at 2% PKF incorporation after 28 days of curing, suggesting that optimal reinforcement levels exist for maximizing strength and durability while maintaining the lightweight benefits of the material.

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