2025
September coou African Journal of Environmental Research *Vol 6, No. 2 2025. pp 212-219*

SELECTED PHYSICO-MECHANICAL PROPERTIES OF CEMENT-PLASTIC COMPOSITES OF BANANA PSEUDO STEMS FIBRES

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Abstract

This study investigates the viability of Banana Pseudo Stem (BPS) fibres as a reinforcement material in cement-plastic composites. BPS fibres, an abundant and lightweight lignocellulosic resource, offer promising potential due to their accessibility and eco-friendliness. However, like other natural fibers, BPS contains inhibitory substances, such as hemicelluloses and tannins, which can hinder cement setting. This research addresses these challenges through various pre-treatment methods, including water soaking and the addition of chemical accelerators. By examining untreated and treated BPS combined with plastic particles, the study evaluates the impact of BPS on composite strength, density, water absorption, and thickness swelling. Results indicate that chemical treatments and plastic additions enhance composite density and flexural strength, suggesting improved compatibility with cement. Based on these results, BPS-cement composites are recommended for indoor, non-structural applications such as insulation panels, ceiling boards, and partition walls, where the need for stability under fluctuating moisture conditions is minimized.

Keywords: Banana Pseudo Stem, cement-plastic composites, eco-friendly materials, lignocellulosic fibres, sustainable building components.

INTRODUCTION

One of the functions of a building is to provide the microclimate required for human habitation (Munonye, 2020). In many developing countries, housing shortages pose a significant challenge, limiting progress and quality of life. Traditional building materials are often costly and inaccessible, prompting the search for sustainable alternatives (Obakin, 2020). Through a comprehensive review of journals, books, websites, and publications, the potential of Banana Pseudo Stem (BPS) fibres as reinforcement in cement-plastic composites is explored. Highlighting the unique chemical and mechanical properties of BPS fibres, the review demonstrates their promise as affordable, energy-efficient building materials. These findings suggested that BPS fibres could offer a sustainable, practical solution to address housing needs in developing regions. Nigeria's housing situation is gradually becoming critically bad and could make Nigeria fail in the sustainable development plans and goals. Hence, there is need to cushion housing challenges in Nigeria towards the attainment of sustainable development. (Jiboye, et al 2020).

Wood and other lignocellulosic materials in the form of fibers or particles have been utilised as furnished in cement matrices to fabricate building components (Olorunnisola, 2007; Adefisan et al., 2016). The primary role of these lignocellulosics is to reinforce the cement matrix, thereby delaying and controlling tensile cracking to reduce stress and ensure a well-defined post-cracking behavior (Swamy, 1990). The resulting cement composites are commonly employed in the construction of sandwich panels, wall coverings, partition walls, pre-fabricated houses, false ceilings, and flooring due to their exceptional properties such as eco-friendliness, fire resistance, insect resistance, fungal resistance, low coefficient of thermal expansion, optimal structural performance, and ease of manufacturing (Goodell et al., 1997; Fabiyi, 2004; Pereira et al., 2006; Olorunnisola, 2007). To improve the smartness of its core components, a city should transform them into more effective, environmental and innovative ones. Therefore, a smarter land means cleaner territory, water and air, a reduced consumption of land for new buildings, environmental reclamation and so on. Smarter infrastructures should be cleaner, more effective in serving the citizens and answering to their needs, using high technology, ICT and mobile devices to spread e-services and information. Use of cement-plastic composites ensure cleaner environments (Oladunmoye & Obakin, 2023).

Various lignocellulosics have been examined, approved, and utilised in the production of Cement Bonded Composites (CBCs). Some examples of these lignocellulosics include sawdust from both hardwoods and softwoods, peeler cores, agricultural residues, and rattans (Olorunnisola & Adefisan, 2002). However, the selection of furnish for CBCs manufacturing depends on factors such as availability, transportation costs, and accessibility (Olorunnisola, 2006). In this context, Banana Pseudo Stem (BPS), an abundant natural resource in numerous states in southwest Nigeria, could be considered as a suitable furnish for CBCs production owing to its plentiful supply, accessibility, and lightweight nature. Nonetheless, many lignocellulosics like BPS, when utilised as furnish in composite production, contain inhibitory substances such as hemicelluloses, simple sugars, and tannins that impede cement setting and the formation of robust crystalline bonds, resulting in delayed demolding. Consequently, pre-treatment methods involving cold and/or hot water are sometimes employed to mitigate the retarding effects of water-soluble components of these substances on cement hardening (Olorunnisola, 2008). Additionally, chemical accelerators like diluted sodium hydroxide (NaOH), sodium silicate (Na_2SiO_3), calcium chloride ($CaCl_2$), and aluminum sulfate $Al_2(SO_4)_3$, among others, have been utilised to diminish or delay the inhibitory impacts of these components (Adefisan & Olorunnisola, 2009).

Moreover, CBCs are known to exhibit excessive water absorption, leading to dimensional instability (Adefisan et al., 2012). The undeniable reality of climate change in recent times, along with the majority of studies advocating for adaptation and green lifestyles as the primary means of mitigation, underscores the necessity for building design and construction to align with nature. The rise in tree planting and the adoption of biophilic design indicate significant efforts to reconnect with the natural environment. Incorporating impermeable materials like plastics (e.g. discarded water sachets) could assist in reducing moisture ingress in cement mixes, thereby promoting dimensional stability (Taiwo et al, 2025). The research aims to offer innovative insights into the development of sustainable construction materials, highlighting the critical interplay between environmentally-friendly additives and structural performance. This study contributes to the broader discourse on eco-conscious construction while addressing the need for stronger and more durable building materials (Obakin, 2023). However, the behavior of CBCs incorporated with discarded water materials is relatively underexplored in literature and warrants further investigation. Hence, this study aimed to evaluate the strength and sorption properties of cement composites fabricated with banana pseudo stems (*Musa acuminata*) combined with particles of discarded water sachets.

MATERIALS AND METHODS

Pseudo stems of banana trees (*Musa acuminata*) were obtained from the premises of the University of Ibadan, Oyo State. Portland limestone cement served as the binder, while granitic stone dusts and milled particles of discarded water sachets were sourced from a local depot in Ibadan, Nigeria. The harvested banana pseudo stems were cut into billets of approximately 0.9 meters, sliced into strands measuring about 1.5 mm in thickness, and air-dried for a period of three weeks until the moisture content reached about 10%. Subsequently, the dried strands were manually further reduced to 2 mm before undergoing bur milling (Plate 1).

Plate 1: a. Granitic Particles **b. Milled Plastic wastes**
Source: Field study (2024)

Bulk Density Determination

The loose bulk densities of the Banana particles were assessed using the modified BS standard as outlined by Olorunnisola (2008).

Board Production

The dried banana particles, stone dust, and plastic materials were sifted through a 4.75 mm sieve. Particles that passed through the sieve were gathered and utilised for board production. The sieved banana particles were divided into two categories: untreated and those that underwent a 30-minute soak in water and/or 3% chemical additives (Calcium Chloride-$CaCl_2$). The banana stem particles (50 and 100%) were manually blended with cement, granitic particles (1:3 based on cement weight), plastic particles (0 and 50%), at a water-cement ratio of 0.4 based on preliminary trials until uniform slurries were achieved. Cement composites were created using the following parameters:

i. Untreated BPS particles
ii. BPS particles soaked in water for 30 minutes
iii. Untreated BPS particles + Plastic particles (50:50)
iv. BPS particles + Plastic particles (50:50) with the addition of 3% $CaCl_2$
v. v. BPS particles soaked in water for 30 minutes + Plastic particles (50:50)
vi. BPS particles soaked in water for 30 minutes + Plastic particles (50:50) + 3% $CaCl_2$

The cement slurries were poured into a wooden mold measuring 40cm x 25cm x 5cm at room temperature, compacted manually to eliminate air bubbles, and demoulded after 24 hours. The fabricated composites were then wrapped in polythene bags for 14 days, unwrapped, and left to cure for an additional 14 days at room temperature before undergoing testing.

Composites Testing

The composites were subjected to testing for physical properties such as density and water absorption and flexural properties following the American standard test method (ASTM D1037).

RESULTS AND DISCUSSION

Bulk Density of Banana Pseudo Stem Particles

The bulk density of the particles from the Banana Pseudo Stem (BPS) was determined to be 0.09g/cm^3, which was notably lower than the values of 0.15, 1.15, and 1.45 g/cm^3 found for *Cissus populnea*, coir, and sisal fibers (Amoo et al., 2016). The decreased bulk density of the particles suggests a porous nature of the BPS, which may potentially impact the flexural and sorption properties of the cement composites.

Density

The densities of the BPS composites varied from 865.0 to 1292.8 kg/m^3 (Table 1). Notably, these composites exhibited densities ranging between moderate and high levels, possibly due to their low bulk density (ACI, 1987; Sradhi et al., 2005). Treatment of the particles with water, as well as treatment with water containing 3% calcium chloride, resulted in increased composite densities. Furthermore, composites incorporating plastic components and subjected to water and/or chemical treatments displayed higher densities compared to the control. These findings suggest that the pre-treatment methods and the inclusion of plastic components enhanced the cement compatibility of the BPS composites. It is plausible that the pre-treatment measures eliminated or reduced the inhibitory effects of sugars and other foreign substances present in the BPS particles, facilitating the formation of robust cohesive bonds.

Table 1: Physical and Mechanical Properties of Banana Pseudo Stem Composites

Pre-treatments	Density	MOR	MOE
Untreated (Control)	865.0 (55.2)b	0.3 (0.1))d	28.9 (8.2)b
Water Treatment (W)	956.8 (65.2)b	0.7 (0.1)cd	98.2 (10.3)b
Untreated + Plastic (50 : 50)	1210.8 (80.8)a	1.0 (0.1)c	97.7 (11.3)b
Untreated + Plastic (50 : 50) +3% CaCl2 (CHP)	1292.8 (70.6)a	4.7 (0.4)a	731.5 (25.1)a
Water Treatment + Plastic (50 :50) (WP)	1252.9 (44.1)a	3.9 (0.7)b	606.5 (30.7)a
WCHP	1188.1 (85.7)a	3.7 (0.3)b	672.3 (35.7)a

* Means with the same letter and columns are not statistically different
Standard deviation in parentheses
Source: (Fieldwork, 2025)

Overall, composites treated with chemical additives and incorporating plastic components exhibited elevated densities. This indicates that the chemical additives used during production mitigated the inhibitory effects of sugars and foreign materials that typically impede cement adhesion. Additionally, the plastic particles may have served as fillers, effectively sealing off pore spaces and thereby enhancing composite densities. Statistical analyses (Duncan's test) confirmed that the inclusion of plastic particles, chemical additives, and/or water significantly ($P < 0.05$) influenced the densities of the composites.

Flexural Strength

The results of the flexural test are summarized in Table 1. The Moduli of Rupture (MOR) ranged from 0.3 to 4.7 N/mm^2, while the respective Moduli of Elasticity (MOE) varied from 28.9 to 731.5 N/mm^2. The MORs and MOEs of the BPS composites were notably lower compared to the recommended values of 15 to 24 N/mm^2 (for MOR) by the forest products laboratory in Madison, USA (Cai and Ross, 2010) and 9 to 4000 N/mm^2 by the European Committee for Standardization (2007). These results suggest that BPS is not inherently compatible with cement. The low MORs and MOEs of the BPS composites may be attributed to the low bulk density of BPS, leading to the conclusion that these composites are unsuitable for structural applications but rather for insulating components like panels and ceiling boards.

The adoption of pre-treatment methods alongside the incorporation of plastic particles in composite production notably enhanced the flexural properties of BPS composites. This improvement may be linked to the elimination of cement inhibitors through pre-treatment and the sealing of pore spaces within cement mixtures by the plastic particles, which are known sites of structural weaknesses. Statistical analyses (Duncan's test) revealed that pre-treatment methods and the incorporation of plastic particles significantly ($P < 0.05$) influenced the MORs and MOEs of the BPS composites.

Water Absorption (WA) and Thickness Swelling (TS)

The results for WA and TS are detailed in Tables 2 and 3, with WA ranging from 14.7 to 66.9% and TS from 1.3 to 8.8%. The WA and TS values obtained in this study slightly exceeded the recommended thresholds (WA: 10% and TS: 1.5%), indicating that the BPS composites lacked dimensional stability and are therefore unsuitable for outdoor applications. The heightened sorption properties of the BPS composites can once again be linked to the low bulk density (i.e., high porosity) of the BPS particles resulting in increased porosity of the BPS particles. Furthermore, the introduction of water or chemical pre-treatment with plastic particles on the BPS particles augmented the sorption properties of the composites. This suggests a potential incompatibility between the BPS particles and cement. The water pre-treatment likely eliminated or reduced the cement inhibitors in the BPS particles, thereby enhancing cement compatibility. The inclusion of plastic particles may have effectively filled voids within the cement mixes, thereby enhancing the sorption properties of the composites. Statistical analyses utilising Duncan's test demonstrated that pre-treatment and the integration of plastic particles significantly (P <0.05) impacted the sorption properties of the BPS particles.

Table 2: Water Absorption of Banana Pseudo Stem Composites

	Water Absorption (%)		
Pre-treatments	**24h**	**48h**	**72h**
Untreated (Control)	53.4b (2.6)	59.2ab (2.5)	60.6ab (1.4)
Water Treatment (W)	57.5ab (2.3)	64.0ab (1.3)	66.9a (1.7)
Untreated + Plastic (50 : 50)	28.0d (1.4)	29.7d (1.6)	30.5cd (3.1)
Untreated + Plastic (50 : 50) +3% CaCl2 (CHP)	17.6e (1.1)	20.3e (1.3)	21.4e (1.4)
Water Treatment + Plastic (50 :50) (WP)	14.7e (1.5)	17.4e (1.7)	17.6e (1.0)
WCHP	21.6e (1.4)	22.6e (1.3)	23.0de (1.4)

* Means with the same letter and columns are not statistically different
Standard deviation in parentheses
Source: (Fieldwork, 2025)

Table 3: Thickness Swelling of Banana Pseudo Stem Composites

	Thickness Swelling (%)		
Pre-treatments	**24h**	**48h**	**72h**
Untreated (Control)	6.1c (1.6)	6.4c (1.4)	8.8b (1.0)
Water Treatment (W)	7.1bc (1.4)	8.1b (1.2)	10.0a (1.2)
Untreated + Plastic (50 : 50)	1.3g (0.2)	1.7f (0.5)	2.1ef (0.1)
Untreated + Plastic (50 : 50) +3% CaCl2 (CHP)	1.8f (0.5)	2.8e (1.8)	3.6d (1.7)
Water Treatment + Plastic (50 :50) (WP)	1.3g (0.1)	1.3g (0.1)	3.2e (1.6)
WCHP	2.7e (1.1)	2.8e (1.6)	4.0d ((1.0)

* Means with the same letter and columns are not statistically different
Standard deviation in parentheses
Source: (Fieldwork, 2025)

CONCLUSION

This study concludes that Banana Pseudo Stem fibers hold substantial potential as a reinforcement material for cement composites, particularly when used with treatments that mitigate natural setting inhibitors. Through a series of tests, including density, flexural strength, water absorption, and thickness swelling, the findings show that chemical treatments and plastic additives significantly enhance the structural characteristics of BPS composites. Treated composites demonstrated improved cement compatibility, with increased density and flexural properties. However, despite these enhancements, the composites exhibited notable water absorption and thickness swelling, indicating limitations in dimensional stability that may restrict their use in outdoor environments.

The inclusion of plastic particles and the application of pre-treatments have proven effective in addressing some inherent limitations of BPS fibers, though further research is needed to improve moisture resistance and dimensional stability. This study underscores the value of BPS as a sustainable and readily available material, while also highlighting the need for continued exploration to broaden its application potential in eco-friendly building materials because the attitude exhibited by most consumers of sachet water in developing countries such as Nigeria in terms of littering and proper disposal of used nylons (and water plastics) is most worrisome. This is because of the huge environmental nuisance created by the non-biodegradable nature of littered waste sachets/ water nylons/ plastics. A means of curtailing the nuisance of improper disposal of these items may be in the production of environmentally friendly cement based composites. This could serve not only as low-cost building components for rural communities in need of affordable shelter but also help in enhancing the quality of our environment.

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