
PALM FRUIT BUNCH ASH AS A PARTIAL CEMENT REPLACEMENT IN SANDCRETE BLOCK

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ABSTRACT

This empirical study investigates the potential of Oil Palm Empty Fruit Bunch Ash (PFBA) as a partial cementitious replacement in sandcrete block production. The material was produced via a systematic pre-burning process to convert empty fruit bunches into charcoal, followed by controlled calcination to obtain reactive pozzolanic ash. Physical characterization, including specific gravity and fineness (sieve size 45 μ m), was conducted per BS 1377:1990 and EN 196-6 standards. Mechanical performance was evaluated by substituting Ordinary Portland Cement (OPC) with PFBA at 0%, 5%, 10%, 15%, and 20% levels. Results indicate that while strength development is sustained over a 28-day curing period, increasing PFBA content correlates with reduced compressive strength and density, alongside increased water absorption. The study identifies 10% as the optimal replacement threshold, achieving a 28-day compressive strength of 3.5N/mm², which complies with the minimum requirements of the Nigerian Industrial Standard (NIS 978:2017). Furthermore, the research evaluates technical risks related to chloride content, environmental benefits of a low-emission approach, and the economic viability of controlled incineration. The findings conclude that with rigorous quality control and chemical pre-treatment, PFBA offers a sustainable, eco-friendly solution for masonry production in the Nigerian construction industry.

Keywords: Sustainable construction; Oil Palm Empty Fruit Bunch; Sandcrete blocks; Cement replacement; Material characterization

1. INTRODUCTION

The global construction industry is more and more looking for viable replacement to Ordinary Portland Cement (OPC) owing to its high carbon footprint and increasing cost. This cement industry is one among the largest industrial contributors to climate change accounting for approximately 7% to 8% of global CO₂ emissions. About 60% of these emissions happens in the process of the chemical decomposition of limestone (CaCO₃) into lime (CaO) which releases CO₂ as a major by product, the remaining 40% comes from the combustion of fossil fuels to heat kilns to temperatures exceeding 1400°C (Ripley et al., 2025).

In addition to that, in locations like Nigeria and Malaysia where palm oil production is higher, the disposal of agricultural waste like Empty Oil Palm Fruit Bunches (EOPFB) presents a significant environmental problem, recent findings is looking toward how these wastes can be processed into Empty Fruit Bunch Ash (EFBA) or Palm Oil Fuel Ash (POFA) through controlled burning to serve as supplementary cementitious materials (SCMs) in masonry units like sandcrete blocks (Yusuf & Hamza, 2023). The high cost of cement has made affordable housing a major challenge in developing nations as also the careless dumping and burning of oil palm fruit bunches lead to land pollution and greenhouse gas emissions lately findings have moved beyond just identifying agricultural waste, they are now looking on the mechanical characterization of combined composites (Sulaiman et al., 2020).

There is a major trend to move from just waste management to circular models which recent studies are developing means to measure the circularity of major materials such as cement, steel, and wood. This study investigates whether the partial replacement of cement with PFBA can produce sandcrete blocks that meet standard compressive strength requirements while offering a more ecofriendly disposal method for palm oil mill residues.

Chemically PFBA contains essential oxides such as silica (SiO₂), alumina (Al₂O₃), and calcium oxide (CaO), which categorize it as a pozzolan. When mixed with cement and water, these oxides react with the calcium hydroxide byproduct of cement hydration to form additional Calcium Silicate Hydrate

(C-S-H) gel, which is the primary binder responsible for strength in concrete and sandcrete, recent studies suggest that replacement levels between 10% and 20% are optimal for maintaining structural integrity while reducing material costs (Abe & Amu, 2022).

Given the abundance of oil palm residues in Nigeria and other tropical economies, coupled with the pressing demand for affordable, environmentally sustainable building materials, a systematic investigation into the effect of partial replacement of cement with oil palm empty fruit bunch ash in sandcrete block production is both timely and policy-relevant. Such a study can provide empirical data on the influence of EFB ash on key engineering properties of sandcrete blocks such as compressive strength, density, water absorption, and durability at different replacement levels. The findings will contribute to the development of locally appropriate guidelines for incorporating EFB ash in sandcrete production, thereby supporting waste-to-wealth initiatives, reducing environmental pollution, and potentially lowering the cost of masonry units in Nigeria and similar contexts (Ibrahim et al., 2021).

Key engineering properties of sandcrete blocks incorporating PFB ash such as compressive strength, bulk density, water absorption and durability have not been systematically characterized at varying replacement levels. In addition, the influence of ash production parameters such as burning temperature, fineness and local mix practices on block performance is not yet well established, leaving block makers without clear guidance on optimal replacement percentages or performance trade-offs, this lack of context specific data constitutes a critical research gap and without robust experimental evidence on sandcrete blocks produced with partial replacement of cement by PFBA, policymakers, standards bodies and small to medium scale sandcrete producers cannot make informed decisions about its technical feasibility, economic benefits or environmental advantages. As a result, an abundant agricultural residue with demonstrated pozzolanic potential remains largely unused in sandcrete block production, and opportunities for cost reduction, waste valorizations and emissions mitigation are missed.

Accordingly, this study seeks to investigate the effect of partial replacement of cement with oil palm empty fruit bunch ash on the properties of sandcrete blocks, with the aim of identifying replacement levels that satisfy engineering performance requirements while contributing to more sustainable and affordable construction in Nigeria.

Palm fruit bunch (PFB) originates from the palm oil milling process after sterilization and fruit stripping, the fresh fruit bunch (FFB) leaves behind the empty cluster known as the empty fruit bunch (EFB) whereby for every tone of FFB processed, around 20–23% of the mass becomes PFB, making it one of the largest solid residues from palm oil production (Yusoff et al., 2023). As palm oil production expanded, these residues grew into a significant waste management challenge, especially in Malaysia, Indonesia, and Nigeria, from the late 1990s into the 21st century, increasing environmental concerns and sustainability demands pushed researchers and industries to explore beneficial uses of PFB. Its high lignocellulosic composition, availability, and low cost made it attractive for Bioenergy production, Organic fertilizer, Composite materials, Soil stabilization and Pozzolanic ash for construction materials. (Sulaiman et al., 2020).

Recent studies highlight its potential as a supplementary cementitious material (SCM) when converted into ash under controlled burning conditions due to its high silica content. (Nwosu and Adeyemi 2025) conducted thermal conductivity tests on sandcrete blocks in tropical climates. They found that the porous nature of the ash reduces the thermal mass of the block, leading to a reduction in indoor heat gain. Chemically, PFB is composed mainly of cellulose, hemicellulose and lignin, with typical ranges of about 37–63% cellulose, 14–37% hemicellulose and 17–32% lignin, depending on variety and processing conditions (Umar and Bello, 2025). Amorphous Silica Content (SiO₂): The primary reactive component is amorphous silica, PFBA incinerated at a controlled temperature of 600°C contains between 55% and 65% SiO₂, which is essential for the pozzolanic reaction. (Nwosu and Adeyemi 2025), research indicate that the highly alkaline nature of the ash helps maintain the passivity of the cement environment, which is beneficial for the long-term durability of the masonry units. (Onyechere 2026), Major oxides example from (Nwaiwu et al. 2023): SiO₂ ≈ 18%, Al₂O₃ ≈ 46.8%, Fe₂O₃ ≈ 2.5%, K₂O ≈ 20.4%, CaO ≈ 4.2%, with minor TiO₂, MnO, ZnO and trace elements. In some boiler ashes, the combined (SiO₂ + Al₂O₃ + Fe₂O₃) is initially as low as ~15.7% with high carbon (~34%), meaning fresh ash often does not meet ASTM C618 pozzolan thresholds until it is further processed or re-burnt, ash from OPEFB pellets used as biomass fuel shows high K₂O and CaO contents (e.g., ~24%

SiO₂, ~46% CaO, significant K₂O), confirming its basic and alkali-rich character. (Okeke et al. 2025), Recent characterization studies show that the pozzolanic quality of oil palm empty fruit bunch ash (OPEFBA) is highly dependent on its production conditions. (Nwaiwu et al. 2023), for example, reported SiO₂, Al₂O₃ and Fe₂O₃ contents of 18.0%, 46.8% and 2.5% respectively, giving a combined pozzolanic oxide content of about 67.3%, which satisfies the ASTM C618 requirement for Class C but falls slightly below the 70% threshold for Class F pozzolans. In contrast, recent work on PFB ash for silica extraction has reported silica contents ranging from 25% to about 60% under optimal calcination regimes, the combined pozzolanic oxides would comfortably exceed 70%. (Nelson et al. 2023). The pozzolanic activity of PFBA has been confirmed through several studies, indicating that it can enhance compressive strength, workability, and water retention of sandcrete blocks (Suriani et al, 2021).

Studies demonstrate that replacing 10–30% of Portland cement with finely ground, heat-treated EFB ash can maintain or even improve compressive strength at medium to long curing ages, particularly in high-performance concrete. The fineness of the ash is another critical factor, finely ground PFBA improves packing density, reduces voids and enhances strength, whereas coarse ash increases porosity and water demand (Eziefula et al., 2025). According to (Onyechere et al. 2026), the average compressive strength decreases as the PFBA content increases, the maximum compressive strength of the concrete is achieved at 28 days of curing. While the 10% PFBA content is optimum content to achieve a balance between strength and workability (Nwaiwu et al. 2023), and replacing up to 20% of cement with PFBA improved the compressive strength of sandcrete bricks compared to conventional bricks. Their findings suggest that the incorporation of PFBA could effectively reduce the need for Portland cement, thereby lowering associated carbon emissions and replacing more than 30% of cement with PFBA led to a reduction in compressive strength.

PFBA contributes to lower permeability, which translates to improved resistance to chemical attacks and its incorporation of also reduces the carbon footprint associated with block production, aligning with sustainable construction practices and waste management strategies (Ibrahim et al 2021) further confirms this by showing improvements in the durability of concrete mixes containing PFBA when exposed to aggressive environments. Using Palm Fruit Bunch as a partial replacement of cement helps reduce agricultural waste, contributing to environmental conservation (Ibrahim et al 2025).

Moreover, research has established standards for the use of other pozzolanic materials, but similar frameworks for PFBA are still needed. (Suriani et al., 2021) emphasize the importance of developing standardized methods to test the performance of PFBA in construction materials. This gap exemplifies the necessity of further research in order to define best practices for incorporation into industry standards.

Equally important are the burning conditions under which the ash is produced, as controlled combustion at moderate temperatures (600–800 °C) enhances reactive silica formation, while uncontrolled burning increases carbon content and reduces strength contribution (Saldanha & Mallmann 2025). Together, these factors ash chemistry, burning regime, fineness, replacement level, mix/workability control and curing age determine whether PFBA enhances or diminishes the engineering performance of sandcrete blocks.

The use of Oil Palm Empty Fruit Bunch Ash (PFB ash) as a partial replacement for cement in sandcrete block production offers several environmental, economic, and technical advantages and replacing even a small proportion with agricultural waste ash directly lowers the carbon footprint of sandcrete and concrete production. Economically, PFB ash reduces the overall cost of sandcrete production. Cement constitutes the most expensive component in sandcrete blocks, and replacing even 10–15% with locally available PFB ash leads to substantial savings. (Suriani et al., 2021). An additional advantage is improved resource efficiency and waste management, this integrated waste-to-resource approach contributes to cleaner production practices and enhances community-level sustainability (Nwaiwu et al. 2022). Overall, research trends consistently show that PFB ash when processed correctly and used within optimal replacement percentages supports sustainable, cost-effective, and durable sandcrete block production while reducing environmental impacts.

This study will focus on palm fruit bunch (PFB) and to investigate the possibility of using the ash produced from PFB as a partial substitute for cement in sandcrete block production in order to provide an economic and proper way of disposal for palm fruit bunch. In this regard the pozzolanic activity of palm fruit bunch ash (PFBA) in the cement hydration will be investigated, as well as the oxide compositions of the ash and temperature of combustion of palm fruit bunch into ash, Therefor the

primary objectives of this study is to conduct laboratory tests on the Oil Palm Empty Fruit Bunch (OPEFB) ash.

2 METHODOLOGY

Ordinary Portland cement (OPC) of strength 42.5N according to BS EN 197-1 (2011) with a Specific Gravity (SG) of 3.14 obtained from local retailer was used as binder in this work. River sand from a local stream in life camp in Abuja was used as fine aggregate with specific gravity of 2.65 and bulk density of 1605.65kg/m³. Sieve analysis on the fine aggregates was conducted in accordance with ASTM C136 - 06 (2009) procedure after washing and air drying of the samples. The sand complies with grading requirements of ASTM C33 (ACI E-701, 2007), ensuring appropriate grain size distribution for optimal workability and cohesion in sandcrete block.

Palm fruit bunch (PFB) which is gotten from oil palm tree (*Elaeis guineensis*) was collected by gathering the raw empty bunches after the fruits of the palm tree were removed from a local palm oil mill in Agbaha Otukpa in Ogbadibo Benue state, Nigeria, the bunch was further shredded and sun dried to remove its moisture. After drying, a controlled pyrolysis/carbonization to turn the material into charcoal was performed and the charcoal was further blended making it easier to handle for the final calcination stage. In the laboratory at Nigeria Building and Road Research Institute (NBRRI) the blended charcoal was filled into the muffle furnace for control combustion where the final calcination was carried out, temperature of 751°C was recorded at when the organic carbon was completely burnt off leaving a clean greyish ash.

The furnace was allowed to cooled, the ash was sieved through a 45µm sieve to obtain the finer ash as cement, the sample was further analyzed using X-ray fluorescence (XRF) to obtain its element and composition of oxide for suitability of use as cement replacement. The resultant PFBA used for this work had specific gravity of 2.5 and bulk density of 260.54kg/m³. Potable water obtained from Nigeria Building and Road Research Institute NBRRI Abuja. A cement-to-sand ratio of 1:6 was adopted, palm fruit bunch ash (PFBA) was introduced as a partial cement replacement at one control and four varying replacement levels of 0%, 5%, 10%, 15%, and 20%. A total of 12 blocks were produced for each replacement level, for mechanical testing, triplicate specimens (n = 3) were crushed at each of the four designated curing ages (7, 14, 21, and 28 days) and the remaining 3 blocks per each replacement level were reserved for non-destructive physical evaluations, including water absorption testing, density determination, and dimensional tolerance checks prior to mechanical testing. Experimental values are presented as the mean ± standard deviation (Mean ±SD). Statistical variability across replacement levels (0%, 5%, 10%, 15%, and 20%) was assessed using one-way Analysis of Variance (ANOVA) at a 95% confidence level ($\alpha = 0.05$) to confirm the statistical significance of observed trends, that is three sandcrete blocks for each replacement percentage and the control were crushed to obtain the mechanical strength tests (compressive strength) at 7, 14, 21, and 28 days as well as water absorption.

Palm fruit bunch ash was incorporated at replacement levels of 0, 5, 10, 15, and 20% by weight of binder in a ratio of 1:6. The mix proportions for concrete specimen are presented in table 1 as well as the batch quantities used for each specimen.

Table 1: Mix proportioning of aggregates in sandcrete block production

Mix	PFBA Replacement (%)	Ash (Kg)	Cement (kg)	FA (kg)	W/C Ratio	Water (kg)
1	0	0	4.5302	27.1812	0.40	1.8120
2	5	0.2265	4.3036	27.1812	0.50	2.1518
3	10	0.4530	4.0772	27.1812	0.54	2.2016
4	15	0.6795	3.8507	27.1812	0.59	2.2719
5	20	0.9060	3.6242	27.1812	0.63	2.2832
Total		2.265	20.386	135.906		10.721

Note 1: The 'Total' row represents the cumulative sum of quantities across all mix proportions (Mix 1 to Mix 5), including the control batch (0% replacement).

Note 2: The sandcrete mix was proportioned using a target binder-to-aggregate mass ratio of 1:6 ($M_{\text{binder}} : M_{\text{FA}}$), that is Total binder mass ($M_{\text{binder}} = M_{\text{Cement}} + M_{\text{Ash}}$) was fixed at $2.265 + 20.386 = 22.651\text{kg}$, paired with 135.906kg , ensuring that the overall binder-to-fine aggregate ratio remained strictly constant at 1:6.00 ($22.651 / 135.906 = 6.00$) regarding the percentage of OPC replaced by PFBA

3 RESULTS AND FINDINGS

The quantitative oxide analysis of the palm fruit bunch ash (PFBA) results as presented in table 2 indicate that the oxide composition of the palm fruit bunch ash satisfies Class F pozzolan requirement specified in ASTM C-618 for good pozzolans as the sum of $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ is at least 70% and satisfies the minimum $\geq 70\%$ requirement (ASTM C618-19). The analysis identified an elevated chloride content of 4.90% which is anomalously higher than typical literature baselines of 0.20%–1.50% reported for palm-based biomass ashes. The observed variance in oxide composition compared to the values reported by Nwaiwu et al. (2023) is primarily attributable to differences in biomass provenance, processing parameters, and soil chemistry, because this concentration exceeds standard durability limits of 0.1%–0.4% by weight of binder unwashed EPFBA with this chemical profile is restricted exclusively to non-reinforced masonry applications, such as sandcrete partition blocks, to eliminate steel rebar corrosion risks. This result suggests the difference in ash source, the high iron of 22% and aluminum content of 16% suggests significant potential for contributing to the early and long-term strength of the sandcrete matrix. The presence of high alkali and chloride levels requires specific structural consideration: The potassium content of 12.03% in EFBA is relatively high compared to traditional coal fly ash and this will contribute to the setting time or hydration which may be beneficial for fast demolding process of the blocks this is confirms by Umar and Bello (2025). The primary risk is the presence of chlorine of 4.9% which is the primary agent of corrosion should not be used in reinforced concrete elements (like beams or columns) but does not pose a structural threat to the block itself.

Table 2: Chemical Composition of Palm Fruit Bunch Ash

Compound	Conc Unit (m/m%)	Element	Conc Unit (m/m%)
SiO_2	32.0300	Si	21.3500
Fe_2O_3	22.3300	Fe	14.8700
Al_2O_3	16.0190	Al	10.25000
K_2O	12.0260	K	8.02000
CaO	5.15000	Ca	4.25000
Cl	4.90000	Cl	4.20000
MgO	1.83000	Mg	1.21000
P_2O_5	1.32000	P	0.80000
SO_3	1.20000	S	0.8000

$$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 = 70.379$$

The bulk density of Palm Fruit Bunch Ash (PFBA) results as shown in table 3 indicates a low average bulk density of 260.54kg/m^3 contributes a substantial impact on the physical and mechanical properties of the resulting mortar and concrete composites. During the mixing phase, it was observed that the high porosity of the ash increased the water demand to maintain the required workability. Furthermore, the partial replacement of Portland cement with this low-density material is expected to facilitate a significant reduction in the bulk density of the hardened block, a property that is highly

advantageous for lightweight structural applications. Although the initial compressive strength was lower in comparison to the control mix, the pozzolanic activity of the EPFBA is anticipated to contribute to long-term strength development through the strengthening of the aggregate paste contact zone.

Table 3: Bulk Density of Empty Palm Fruit Bunch Ash (PFBA)

Parameter	Trial I	Trial II	Trial III	Mean ($\pm$ SD)
Net Mass of Sample (g)	691.00	692.00	691.14	691.38 $\pm$ 0.54
Volume of Container (cm ³)	2654.65	2654.65	2654.65	
Bulk Density (kg/m ³)	260.29	260.68	260.35	260.44 $\pm$ 0.21

The physical characterization of the Palm Fruit Bunch Ash (PFBA) was carried out in (BS 1377: 1990) yielded a specific gravity of 2.5 as given in table 4. This was cited by (Sulaiman et al 2020). These values are significantly lower than those of conventional Ordinary Portland Cement, establishing the potential of palm fruit bunch ash for the production of lightweight concrete and mortar composites.

Table 4: Specific gravity of Palm Fruit Bunch Ash (PFBA)

Specific gravity, BS 1377: 1990				
M1= mass of Pycnometer(g)				M1= mass of Pycnometer(g)
M2= mass of pyc+ sample(g)				M2= mass of pyc+ sample(g)
M3=mass of pyc+ sample +water(g)				M3= mass of pyc+ sample +water(g)
M4= mass of pyc+water(g)				M4= mass of pyc+water(g)
PFBA	PFBA	PFBA	PFBA	MEAN $\pm$ SD
M1	205	205.2	205.3	205.17 $\pm$ 0.153
M2	212.6	213.1	212.8	212.83 $\pm$ 0.252
M3	228.3	229.0	227.7	228.33 $\pm$ 0.651
M4	223.4	224.0	223.8	223.73 $\pm$ 0.306
	2.8	2.53	2.2	2.5 $\pm$ 0.399
Specific Surface Area (Blaine), EN 196-6				295.0m ² /kg
Sieve Residue (45um), ASTM C430-96				0.76%

Furthermore, the fineness of the ash was assessed via the Blaine method, recorded a specific surface area of 295m²/kg and a minimal sieve residue of 0.76% on the 45um sieve. This result conforms to Umar and (Bello 2025), who state that the pozzolanic activity of OPEFB ash is significantly enhanced when ground to a particle size finer than 45 μ m, as this increases the specific surface area available for chemical reaction. Consequently, the palm fruit bunch ash (PFBA) to contribute to the strength development of the matrix through the strengthening of the aggregate-paste contact zone, alongside

providing a micro-filler effect that enhances the overall densification of the hardened concrete. These properties collectively suggest that palm fruit bunch ash PFBA modified sandcrete block is well suited for non-load bearing structural applications where reducing self-weight is a primary design objective.

The compressive strength results for the varying PFBA replacement levels over a 28-day curing period are given in table 5, however, a progressive reduction in compressive strength is observed with increasing PFBA substitution this behavior is primarily attributed to the dilution effect, whereby the quantity of Portland cements the primary binder is reduced. Furthermore, the ash likely exhibits slower pozzolanic activity compared to the rapid initial hydration of cement clinker.

the control (0%), 5%, and 10% replacement levels meet the regulatory requirement demonstrating that 10% is the optimal threshold for structural applications, this value correspond to 3.5 N/mm² at 28 days, of the minimum given by Nigeria Industrial Standard (NIS), this agrees with Nwaiwu et al. (2023) and Eziefula et al., (2023). replacements of 15% and 20% with values of 3.24 N/mm² ±0.09 and 2.89 N/mm² ±0.09 fail to meet the standard therefore, these higher substitution levels are deemed unsuitable for load-bearing structural applications under existing regulations.

Table 5: Compressive strength (N/mm²) result of palm fruit bunch ash (PFBA)

Curing Age (days)	0% (control)	5% PFBA	10% PFBA	15% PFBA	20% PBFA
7	2.51	2.13	2.25	1.82	1.52
	2.64	2.27	2.14	1.93	1.63
	2.56	2.20	2.18	1.89	1.58
Mean ±SD	2.570 ± 0.07	2.20 ± 0.07	2.19 ± 0.06	1.88 ±0.06	1.58±0.06
14	3.11	2.44	2.42	1.99	1.96
	2.94	2.58	2.28	2.11	1.83
	3.02	2.51	2.36	2.07	1.90
Mean ±SD	3.02 ±0.09	2.51±0.07	2.354±0.07	2.06 ±0.06	1.90±0.07
21	3.58	3.34	2.96	2.80	2.20
	3.39	3.17	3.14	2.66	2.34
	3.47	3.24	3.07	2.75	2.29
Mean ±SD	3.48±0.10	3.25±0.09	3.06±0.09	2.74±0.07	2.28±0.07
28	3.82	3.51	3.41	3.32	2.79
	3.63	3.70	3.60	3.15	2.96
	3.73	3.62	3.52	3.24	2.92
Mean ±SD	3.73±0.10	3.61±0.10	3.51±0.10	3.24±0.09	2.89±0.09

The experimental data demonstrates a direct correlation between the percentage of PFBA replacement and the dry density of the sandcrete blocks. As the PFBA content increased from 0% to 20%, the block density decreased from 1969 kg/m³ to 1640 kg/m³ as shown in table 6. This reduction is primarily attributed to the lower specific gravity of the PFBA particles compared to the Portland cement they replaced. this conforms to Sulaiman et al (2020) who stated that this lower density allows for the production of lightweight masonry units, which can reduce the overall dead load of a building by up to 8%. But in structural engineering, higher density often acts as an indicator of the block's internal matrix quality.

According to established building standards, a significant drop in density can correlate with increased porosity. At 10% replacement, the unit achieves a density of 1820 kg/m³, which remains 20 kg/m³ above the 1800 kg/m³ threshold commonly used to demarcate standard weight from lightweight structural elements. While this value confirms that the 10% mixture successfully meets normal weight density requirements, it represents a critical transition point in the design envelope, as higher replacement levels (15% and 20%) drop to 1724 kg/m³ and 1640 kg/m³ respectively. The drop in density from the control value (1969 kg/m³) is directly linked to the lower specific gravity of the ash and increased void formation, as evidenced by the progressive increase in water absorption to 5.670%. Consequently, 10% represents the practical upper limit for maintaining standard density, requiring strict

field batching and compaction controls to ensure field production units do not dip below the 1800 kg/m³ minimum due to site variability.

The data in table 6 also revealed a consistent increase in water absorption as the percentage of PFBA replacement increases. The control sample (0% PFBA) exhibited the lowest water absorption at 5.100%, whereas the 20% replacement level recorded the highest value of 6.610%.

This upward trend suggests that the incorporation of PFBA leads to an increase in the porosity of the sandcrete block matrix. This is likely due to the modification of the pore structure, where the presence of ash particles influences the density of the binder matrix. While all observed values remain within the acceptable limits typically prescribed for sandcrete blocks (often capped at 12% by Nigeria Industrial standards NIS 978:2017 Sandcrete Block), the progressive increase indicates that higher replacement levels may negatively impact the durability of the blocks.

Table 6: *Density and water absorption of palm fruit bunch ash (PFBA)*

PFBA Replacement (%)	Wet Mass (kg)	Dry weight (kg)	Water Absorption $\pm$ SD (%)	Density $\pm$ SD (kg/m ³)
0	21.994	20.917	5.150	1958
	22.137	21.067	5.080	1972
	22.220	21.127	5.070	1977
	22.117	21.037	5.100 $\pm$ 0.044	1969 $\pm$ 9.85
5	21.084	19.987	5.490	1871
	21.228	20.137	5.420	1885
	21.291	20.197	5.410	1890
	21.201	20.107	5.440 $\pm$ 0.044	1882 $\pm$ 9.85
10	20.436	19.330	5.720	1809
	20.581	19.480	5.650	1823
	20.642	19.540	5.640	1828
	20.553	19.450	5.670 $\pm$ 0.044	1820 $\pm$ 9.85
15	19.393	18.300	5.970	1727
	19.539	18.450	5.900	1713
	19.598	18.510	5.890	1732
	19.510	18.420	5.920 $\pm$ 0.044	1724 $\pm$ 9.85
20	18.570	17.410	6.660	1629
	18.717	17.560	6.590	1643
	18.783	17.620	6.580	1648
	18.690	17.530	6.610 $\pm$ 0.44	1640 $\pm$ 9.85

4 CONCLUSION

- PFBA is a viable partial replacement for Ordinary Portland Cement in sandcrete block production with a replacement level of 10% as the optimal threshold for load bearing applications as the blocks meets the minimum required specification.
- The adoption of PFBA modified blocks lower carbon footprint in construction by diverting agricultural waste from open and uncontrolled burning, this practice significantly reduces emission and aligns with global sustainable development goals and local eco-friendly construction mandates.
- The chemical composition of the ash particularly high chloride content poses a significant technical risk as it's known to increase the electrochemical corrosion of embedded steel reinforcement in structural elements, therefore the chemical profile of the ash must be strictly validated to prevent long term structural failure.
- The use of control burning is paramount to ensuring the production of high-quality reactive pozzolanic ash suitable for masonry.

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