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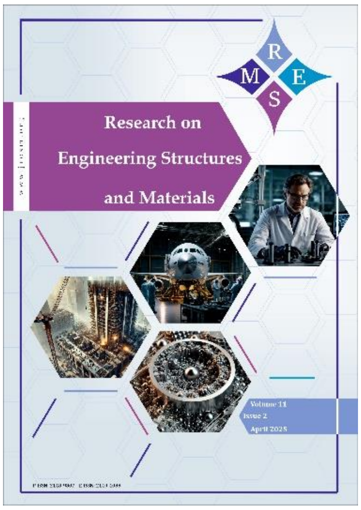

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Research Article

Enhancing the mechanical and durability quality of fibre-modified concrete using eco-sustainable wastes and lime powder

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Abstract

The use of agro-waste as reinforcement can enhance the mechanical and water absorption properties of concrete. The study investigates the use of agro-wastes, such as coconut fiber and plantain peel ash (PPA), combined with lime powder to enhance concrete properties and mitigate environmental harm. Coir fiber was added to the concrete at 0%, 5%, and 10% of the concrete's total density, while the cement was partially substituted with lime powder at 0%, 10%, and 20%, and with PPA at 1.5%. The concrete mix's qualities were evaluated at different ratios. A concrete mix containing 10% lime powder, 0.5% coconut fiber, and 1.5% plantain peel ash yielded higher flexural and split tensile strengths, while the highest compressive strength compared with the control (Mix 1) was achieved with fiber content ranging from 0.5% to 1%. The concrete with 0.5% coir fiber, 10% lime, and 1.5% PPA showed better water absorption than other mixes. The study reveals that alkali-treated coconut fiber enhances the tensile strength of concrete, while plantain peel ash, lime powder, and coconut fiber decrease workability and increase compressive, split tensile, and flexural strengths. Nigeria's sustainable management of agricultural waste, such as coconut fiber and plantain peels, can improve concrete workability, reduce Portland cement usage, and decrease CO_2 emissions.

1. Introduction

The growing population and modernization have led to increased waste production, raising environmental concerns [1]. This has necessitated a paramount drive for sustainable construction in the construction industry [2,3]. Recycling of agricultural and industrial waste into useful resources can significantly promote a sustainable environment [4]. Fibers are being incorporated into concrete to enhance its strength and toughness, and also reduce pollution [5]. Natural, synthetic, glass, and steel fibers are being utilized to reduce environmental pollution and enhance concrete strength. Utilizing locally available, sustainable non-abrasive materials such as coconut, bamboo, sugarcane, palm, hemp, banana, pineapple leaf, and cotton has been the focus of researchers lately. Concrete, a durable and cost-effective construction material, is widely used for its versatility, resulting in annual consumption of approximately 10 billion tons. Concrete strength is influenced by various factors, including curing, water-cement ratio, compaction, raw material

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quality, age, additives/admixtures, fiber content, and temperature, all of which are crucial for designing structures and selecting materials.

The use of reinforcement does not stop crack growth in cement-based materials. However, it has been reported that the addition of short and discrete fibers to the concrete matrix will significantly improve the concrete's toughness, ductility, and post-cracking strength of concrete due to the bridging mechanism fibers deplores when loaded [6,7]. Fibers, hair-like structures found in animals, plants, minerals, and synthetic materials, are used as reinforcements in cementitious composites. Concrete uses fibers to control shrinkage and drying shrinkage cracking. Steel reinforcement enhances strength, while short fibers provide uniform tensile properties and increased resistance to microcracking. Natural fibers are used in construction for environmental, waste-reduction, insulation, safety, and economic benefits [8]. Reinforced concrete, including steel, polyester, glass, and polypropylene fibers, improves impact strength, strain capacity, plastic shrinkage resistance, segregation, fire resistance, and durability. Fiber-reinforced concrete is popular due to its high tensile strength and low maintenance costs [9].

The incorporation of coconut fiber derived from recycled coconut residue into concrete offers an avenue for environmental sustainability in the construction sector. It is a natural fiber with high strength and scraping resistance. Coconut fiber is readily available in Nigeria due to the abundance of coconut trees, especially in the country's coastal regions [10]. In recent times, coconuts have been grown and used for commercial purposes in more than 90 countries, contributing to the 64 million tons of coconuts produced globally each year [11].

It offers a 25% improvement in flexural strength, making it a potential reinforcement material in concrete due to its ductility and affordability. Examining the strength properties of coir fiber in concrete, used to replace fine and coarse aggregate replacement of 0.5% and 1%. With a design strength of 20.59 MPa, cylinders with a 1% fiber addition performed better than those without fibers [12]. In another study by Ede and Agbede [10] the findings demonstrated that the compressive strength of coir fiber-reinforced concrete increased with curing age and increased with the coir fiber proportion up to 0.5%, before progressively declining from 0.75% to 1.0%. In comparison to the control sample, the percentage strength improvement at 28 days for fiber contents of 0.25%, 0.5%, 0.75%, and 1.0% is 4.58%, 38.13%, 8.56%, and -2.42%, respectively. According to the data, the concrete's flexural strength increased by 28.82%, 22.15%, and 0.42% at 28 days for 0.25%, 0.5%, and 1.0% of coir fiber, respectively. This proves that Coir fiber enhances concrete properties and reduces pollution by minimizing waste from coir-based manufacturing units, making it a sustainable waste management technique.

Several researchers have explored the incorporation of industrial by-products and agricultural residues into concrete to enhance its strength and durability [13]. Plantain peels, non-biodegradable by-products from plantain processing industries, are a significant contributor to environmental pollution. A study by David et al. [14] identified the PPA as a water-reducing admixture that prevents bleeding and segregation in freshly mixed concrete and found that adding 5% PPA to concrete boosts its compressive strength, which was 27.30 N/mm^2. Additionally, the concrete's standard workability is 45 mm for the control and 60 mm for the 5% PPA. The application of PPA as a concrete admixture has been shown to significantly enhance the compressive strength, workability, and durability of concrete structures. It was found that adding ripe and unripe plantain peel ash to concrete increased its workability and late strength development, such that concrete containing 1.5 and 2.5% ripe PPA has strengths of 22.77N/mm^2 (28.50% increase) and 20.64N/mm^2 (32.40% increase), respectively, while concrete containing 1.5 and 2.5% unripe PPA has strengths of 20.86N/mm2 (31.00% increase) and 19.02N/mm2 (35.70% increase) at 90 days, prompting the study to investigate the use of PPA as a partial replacement for cement [15]. Aderinola et al. [16] examined the impact of partial cement replacement with PPA and polystyrene (POL) on concrete compressive strength. Results showed that adding PPA and polystyrene to concrete improved workability but reduced compressive strength.

The effect of replacing Portland cement with fine limestone powder improves the compressive strength of high early-strength cement but decreases its compressive and flexural strengths [17]. Studies show that increasing the $CaCO_3$ content and fineness accelerates the hydration rate of C_3S

in Portland cement, while limestone powder enhances strength without affecting mortar workability. When working with lower-reactivity pozzolans, such as plantain ash, lime increases the availability of $Ca(OH)_2$, thereby accelerating and improving ash reactivity and concrete workability [18]. Hence, combining Portland cement with lime also increases early strength.

It has been established in the literature that coir fibres increase the strain capacity and toughness of concrete by acting as crack arresters, bridging microcracks before they spread and enhancing service life under dynamic conditions and lessening brittleness [19, 20]. Plantain peels contain silica (SiO_2), alumina (Al_2O_3), and other oxides, which are comparable to the conventional pozzolans used in concrete when burned to ash. Thus, by taking part in pozzolanic interactions with lime/cement hydration products, PPA strengthens the paste by forming additional binding gel (C-S-H) [21]. When working with lower-reactivity pozzolans, such as PPA, lime increases the availability of $Ca(OH)_2$, which speeds up and improves ash reactivity and concrete workability [18]. Therefore, the fibers prevent cracking, making the matrix more resilient to pressure without brittle failure. As lime/ash densifies the cementitious matrix, decreasing porosity, the matrix becomes more resilient to pressure. This is more beneficial than employing any single additive alone; this type of hybrid system (fibre + pozzolanic + activator) is more sophisticated, as it concurrently enhances mechanical performance, durability, and sustainability. In terms of pozzolanic Reactions, Calcium hydroxide is less significant, but calcium silicate hydrates produced during cement hydration are substantial. Reactive silica and alumina found in plantain ash react with Ca $(OH)_2$ from cement and lime to form additional C-S-H, increasing strength and decreasing free Ca $(OH)_2$ that could cause efflorescence [21].

Previous studies have focused more on mechanical characteristics, using separate SCMs or a combination of two, with little attention paid to the strength and durability of concrete blended with coir fiber and agro-based materials, such as plantain peel ash. Currently, to the best of the author’s knowledge, there are no published works on the combination of lime and PPA, indicating a grey area as far as the binary use of SCMs in concrete is concerned. This further demonstrates that there is still much to explore in the use of agro-waste materials for construction, especially in Nigeria, where an acute housing shortage persists. The dumping of agricultural wastes, such as coconut fiber and plantain peel, at landfills is a significant problem. Utilizing these eco-sustainable wastes can improve concrete strength and reduce environmental degradation [22]. The novelty of this study is shown in the synergistic application of low-energy, agro-based by products; plantain peels, lime, and coir fiber as either waste or requiring far less processing than cement, and also the sustainability of the product. A significant environmental problem is addressed by substituting some of the cement component with these materials, thereby lowering greenhouse gas emissions associated with cement manufacture. Therefore, the study evaluates the mechanical and water absorption properties of coconut fiber reinforced concrete incorporating plantain peel ash as an admixture and lime powder as a supplementary cementitious material.

2. Materials and Methods

2.1 Materials Preparation

The materials used included cement, fine aggregates, coarse aggregates, superplasticizer, water, coconut fiber, plantain peel ash, and lime powder, all of which were locally sourced. The study's findings determine the quality and features of the concrete. Dangote 3x cement, a crucial component of concrete, was procured. The concrete was then made from crushed granite stones, ranging in size from 10 to 20 mm, after thorough cleaning to remove dirt and dust. The fine aggregates were locally sourced in Ado-Ekiti, washed with potable water, and sieved to remove large particles and lumps, with a maximum particle size of 4.75 mm. Coconut fiber, an agricultural waste material obtained from the outer husk of coconuts, was used in the study. According to Adetayo and Jubril [15], unripe plantain peel ash contains a high content of silica oxide (54%) as well as other oxides such as aluminum oxide (3.080%), magnesium oxide (6.633%), calcium oxide (4.067%), ferric oxide (2.887%), and sulfur trioxide (0.583%). Plantain Peel Ash (PPA) is produced by sun-drying and burning plantain peels at 700°C in a furnace, as presented in Figures 1a and 1b.

The study used COSTAMIX 200 super plasticizer (SP), a high-range water-reducing admixture, according to ASTM C494 04 [23], and hydrated lime powder (LP), a hydrate-based product, to enhance the workability and water-retention properties of cement, as illustrated in Figures 1c and 1d. According to Awolusi et al. [24], lime powder contains silica oxide (5.69%), aluminum oxide (7.65%), magnesium oxide (4.69%), calcium oxide (80.71%), ferric oxide (0.24%), and sulfur trioxide (0.07%). The treatment process for coconut fiber (CF) began with washing in clean water, soaking for 30 minutes, and removing the coir dust. The fiber was then soaked in NaOH water for 45 minutes, washed with fresh water, and the color changed from light brown to dark brown, as shown in Figures 1e to 1h. Coconut fibers treated with sodium hydroxide exhibit improved cement performance, chemical stability, splitting tensile strength, and resistance to degradation in alkaline environments [25]. The untreated and treated are shown in Figure 1g and 1h, respectively.

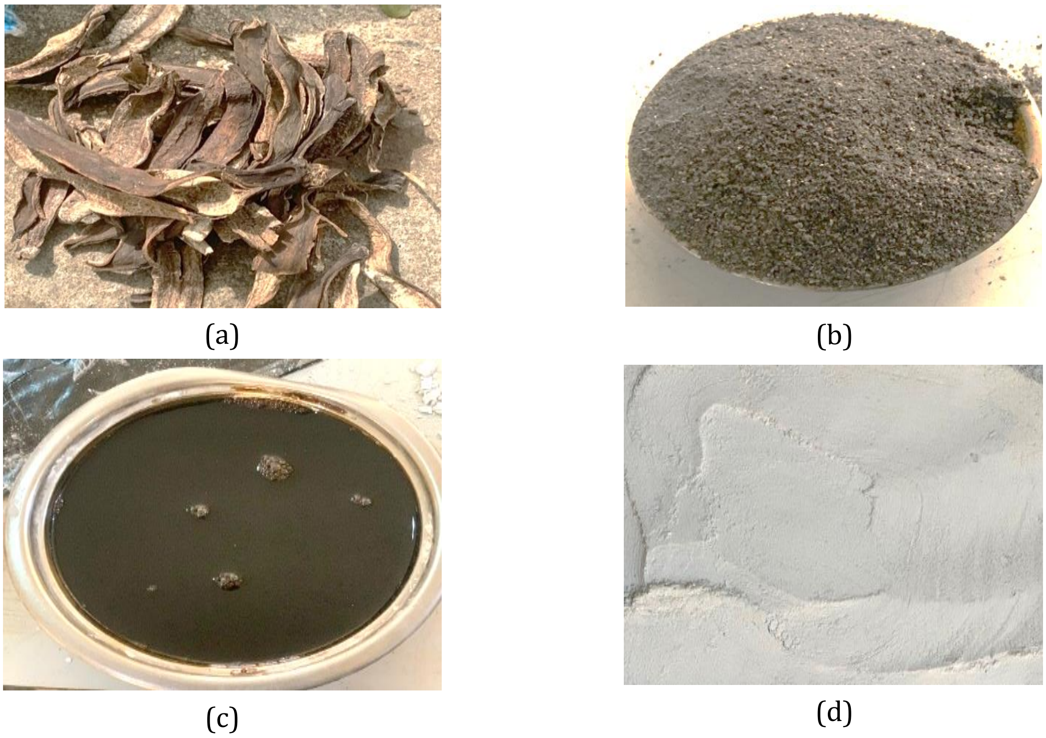

Fig. 1. Material preparation process (a) Sun-dried plantain peels (b) Plantain peel ash (c) Super plasticizer (d) lime Powder

2.2 Experimental Procedure

The coconut fiber-reinforced concrete was thoroughly mixed with various materials, including coarse aggregates, cement, fine aggregates, lime powder, and plantain peel ash, as shown in Table 1. The lime powder was incorporated as a percentage replacement for cement. The plantain peel ash was incorporated into the concrete mix as an admixture. To achieve a workable concrete and maintain a constant water-cement ratio of 0.3, the superplasticizer was mixed with water before adding it to the concrete mix. The fibers were cut into a length of 20 mm with an aspect ratio of 100. Half of the fibers were randomly dispersed in the concrete mix, which was then thoroughly mixed for 1 minute. The other half was randomly dispersed, ensuring a homogeneous concrete was achieved. Concrete was placed in moulds, cubes (100 mm), cylinders (200 mm x 100 mm), and beams (400 mm x 100 mm), compacted with 25 blows, demolded 24 hours after casting, and transferred into a water curing tank at a laboratory temperature of 29 °C ± 1. Figure 2 illustrates the flowchart of the experimental procedure and results analysis. The slump measurement and **c**oncrete cubes, cylinder, and beam casting are shown in Figures 3a and 3b, whereas the result of the concrete cube and failed samples after curing are presented in Figures 3c and 3d. The data were computed for each mix proportion as the average of three specimens. Three (3) samples of cube, cylinder, and prism for each mix were prepared, along with corresponding control samples (Mix 1). The quantity of lime powder required for each mix was incorporated into the concrete as a percentage replacement of the binder content by mass. The PPA used as admixture was also added to the concrete mix by mass of the binder content. The coir fibre content (0.5%, 1%, 1.5%) were incorporated into the mix as a percentage of the volume fraction of concrete.

Table 1. Mix proportion for constituent materials

Mix No.	Lime powder %	Coconut fibre (%)	PPA (%)	Super Plasticizer (%)	Binder content (kg/m^3)	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregates (kg/m^3)	Water (kg/m^3)
1	0	0.0	0	1.5	400	400	1200	597	120
2	0	0.5	1.5	1.5	400	400	1200	597	120
3	0	1.0	1.5	1.5	400	400	1200	597	120
4	0	1.5	1.5	1.5	400	400	1200	597	120
5	10	0.5	1.5	1.5	400	360	1200	597	120
6	10	1.0	1.5	1.5	400	360	1200	597	120
7	10	1.5	1.5	1.5	400	360	1200	597	120
8	20	0.5	1.5	1.5	400	320	1200	597	120
9	20	1.0	1.5	1.5	400	320	1200	597	120
10	20	1.5	1.5	1.5	400	320	1200	597	120

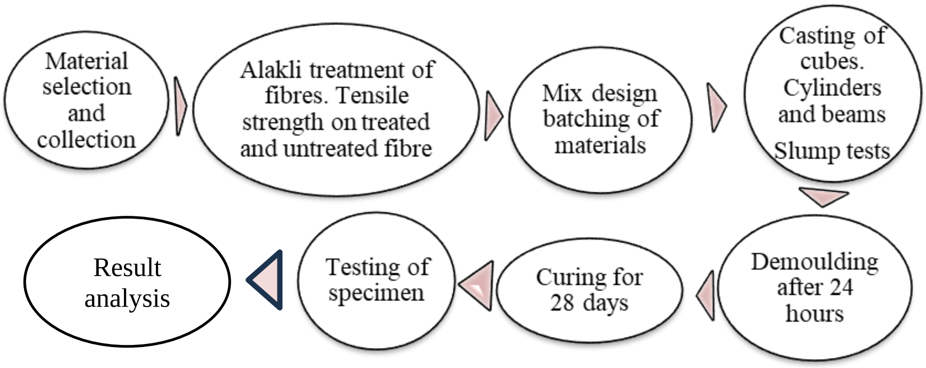

Fig. 2. Experimental design flow chart

(a)

(b)

(c)

(d)

Fig. 3. (a) Slump measurement (b) Concrete cubes, cylinder, and beams casting (c) Concrete cube after curing (d) Failed concrete

2.3.1 Specific Gravity Test (SGT) and Particle Size Distribution (PSD)

Sieve analysis was conducted on fine and coarse aggregates, PPA, and lime powder, focusing on the granular material through progressively smaller mesh sizes. The specific gravity was determined using equations 1, 2, 3, and 4:

$$S_g = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \tag{1}$$

$$R = \frac{W_{far}}{m} x\ 100 \tag{2}$$

$$P = 100 - \Sigma R \tag{3}$$

$$F_{mfa} = \frac{\Sigma R}{100} \tag{4}$$

2.3.2 Tests on Fresh Sample Properties (FSP)

The slump test is a control method used to assess the consistency and workability of the concrete, ensuring it meets the BS EN 12390 standard [26]. It involves filling a cone with three layers of concrete, tamping 25 times, and measuring the slump level.

2.3.3 Test on Hardened Concrete Samples

In this section, test procedures for cube, cylindrical, and prism samples were illustrated based on existing standard test methods for concrete samples.

2.3.3.1 Compressive Strength Test (CST)

Compressive strength measures the material's ability to withstand axial loads. Concrete cubes (100 mm x 100 mm), both plain and fiber-reinforced, were tested using an ELE machine at a loading rate of 0.6 kN/s, in accordance with BS EN 12390-3 [27]. The strength was calculated by dividing the maximum crushing load by the effective area as stated in Equation 5:

$$C_s = \frac{L}{A} \tag{5}$$

2.3.3.2 Split Tensile Strength Test (STS)

The tensile strength of concrete, measured on 200 mm by 100 mm concrete cylinders, containing coconut fiber, lime powder, and plantain peel ash, was obtained after 28 days of curing using an ELE compression testing machine at a loading rate of 0.940 kN/sec according to BS EN 12390-6 [28]. The split tensile strength (STS) was determined using Equation 6, and the result is presented in Figure 4a.

$$F_t = \frac{2P}{(\pi\, DL)} \tag{6}$$

2.3.3.3 Flexural Strength Test (FST)

The flexural strength of the concrete was determined using 400 mm by 100 mm beams under a central line load and a three-point test. The beams were subjected to a displacement control condition of 0.10 mm/min, as specified in BS EN 12390-5 [29], 28 days after casting, as per equation 7, and the result is presented in Figure 4b.

$$F_{St} = \frac{3PL}{2BD^2} \tag{7}$$

(a) (b)

Fig. 4. (a) Split tensile test on concrete cylinders (b) Flexural test on concrete beams

2.3.4 Water Absorption Test (WAT)

The water permeability of concrete was assessed using ASTM C642 [30], with water absorption tests on cubes conducted to determine initial surface absorption (ISA) and final water absorption (FWA) after 90 minutes and 24 hours, as shown in Equations 8 and 9.

$$I_{SA} = \frac{W_{@90\,mins} - W_{OD}}{W_{OD}} \times 100 \tag{8}$$

$$F_{WA} = \frac{W_{@24\,hours} - W_{OD}}{W_{OD}} \times 100 \tag{9}$$

3. Results and Discussion

This research involved ten runs of concrete with coconut fibre, PPA, and lime powder, cured in potable water for 28 days. The fresh and hardened properties were determined through compressive, flexural, and split tensile strength tests, as well as the Initial surface absorption and final water absorption.

3.1 Particle Size Distribution and Specific Gravity Test

The distribution of sieve analysis was conducted on fine aggregates, coarse aggregates, and lime powder, with results of 2.65, 2.50, and 2.62, respectively. The average fine moduli for the three samples considered are 2.20, 2.87, and 2.5, as presented in Tables 2, 3, and 4. The deflection outcomes for varying loads of untreated and treated alkali coconut fiber are presented in Figures 5 and 6.

Table 2. Sieve analysis of fine aggregate

Sieve Size (mm)	M_1 (g)	M_2 (g)	Fine aggregate Retained (g)	Retained (%)	Cumulative Retained (%)	Passing (%)
4.75	540	540	0	0.0	0.0	100.0
2.36	535	538	3	1.5	1.5	98.5
1.18	487	500	13	6.5	8.0	92.0
0.60	479	530	51	25.5	33.5	66.5
0.30	412	451	39	19.5	53.0	47.0
0.15	383	397	14	7.0	60.0	40.0
0.063	397	404	7	3.5	63.5	36.5
Fine modulus = 2.20						

Table 3. Sieve analysis of coarse aggregate

Sieve Size (mm)	M1 (g)	M2 (g)	Retained Coarse Aggregates	Retained (%)	Passing (%)
28	1500	1500	0	0	100
20	1510	1568	58	29	71
14	1270	1334	64	32	68
10	1270	1391	121	60.5	39.5
6.3	1198	1349	151	75.5	24.5
4.75	800	979	179	89.5	10.5
Fine modulus = 2.87					

Table 4. Sieve analysis of lime powder

Sieve Size (mm)	M1 (g)	M2 (g)	Lime Powder Retained	Percentage Retained (%)	Percentage Passing (%)
5.00	545	545	0	0	100
2.36	535	535	0	0	100
1.18	487	505	18	9	91
0.60	478	520	42	21	79
0.30	412	522	110	55	45
0.15	383	533	150	75	25
0.06	397	577	180	90	10
Fine modulus = 2.5					

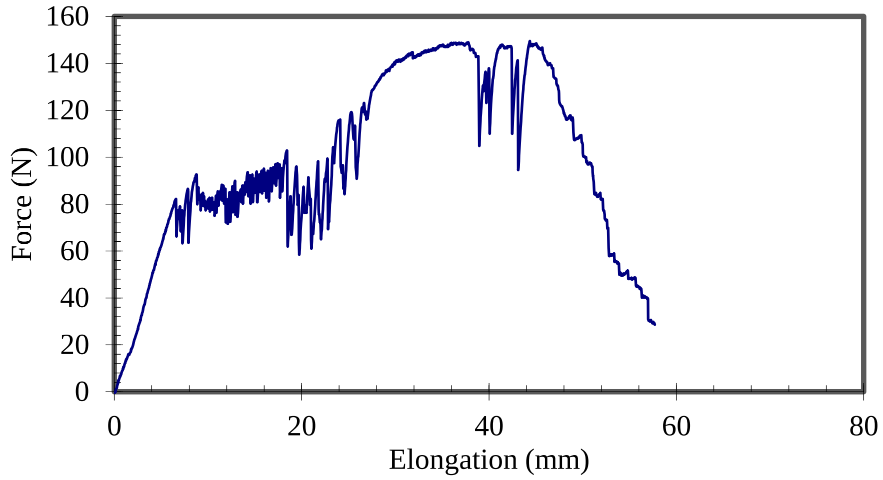

Fig. 5. Load deflection of untreated coconut fibre

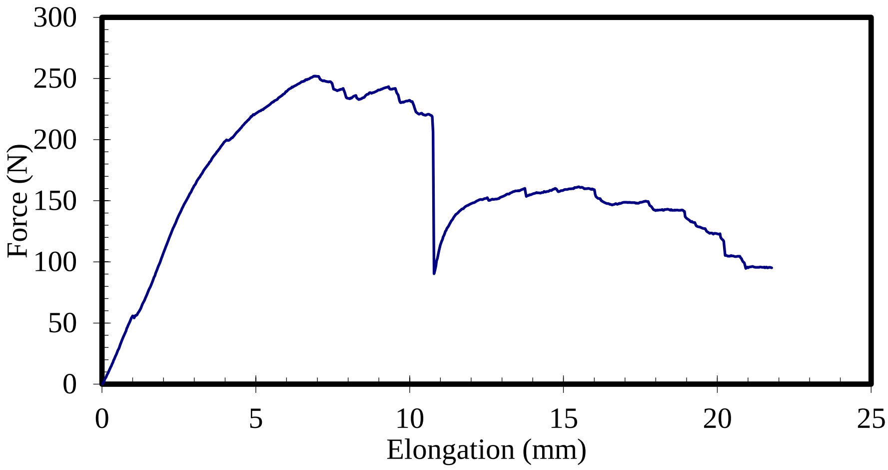

Fig. 6. Load deflection of treated coconut fibre

3.2 Tensile Strength of Untreated and Alkali-Treated Coconut Fibre

Table 5 presents the tensile strength and elongation of untreated and alkali-treated coconut fibers, tested at a rate of 50 mm/min with a sample length of 100 mm and a diameter of 0.2 mm. The tensile strength of untreated coconut fiber is 7.48 N/mm^2, while the tensile strength of alkali-treated coconut fiber is 12.6 N/mm^2. The tensile strength of alkali-treated coconut fiber significantly increases by 68% compared to that of untreated coconut fiber. According to Aluko et al. [31], treated natural fibers have been observed to exhibit higher tensile strength than untreated ones.

Table 5. Maximum force, tensile strength, and elongation

Treatment	Maximum Force (N)	Tensile Strength (N/mm^2)	Elongation
Untreated	149.50	7.48	57.70
Alkali treated	252.00	12.60	21.77

3.3 Tests on Fresh Properties of Coconut Fiber-Reinforced Concrete

Table 6 displays the mix proportions and slumps; the controlled concrete has the highest slump of 35 mm, excluding coconut fiber, plantain peel ash, and lime powder. Concrete with 0% lime powder, 0.5% coconut fiber, and 1.5% PPA had a slump of 38 mm, while concrete with 20% lime powder, 1.5% coconut fiber, and 1.5% PPA had a slump of 25 mm. The addition of increased coconut fiber content to the concrete mix decreases workability due to its high-water absorption during mixing [32,33]. Workability was observed to decrease in the presence of high fiber content combined with PPA and high lime powder content.

Table 6. Mix proportions and their varying slumps

Mix Number	Lime powder (%)	Coconut fibre (%)	PPA (%)	Slump (mm)
1	0	0.0	0.0	35±1.2
2	0	0.5	1.5	38±0.5
3	0	1.0	1.5	40±0.7
4	0	1.5	1.5	45±0.3
5	10	0.5	1.5	40±0.5
6	10	1.0	1.5	42±0.4
7	10	1.5	1.5	45±0.5
8	20	0.5	1.5	44±0.6
9	20	1.0	1.5	44±0.5
10	20	1.5	1.5	25±0.3

3.4 Mechanical Properties of Coconut Fibre Reinforced Concrete

The mechanical properties of concrete cubes, beams, and cylinders were tested. The compressive, flexural, and split tensile strengths result alongside the standard error is presented in Figure 7.

3.4.1 Compressive Strength (CS)

Based on Figure 7, the concrete's compressive strength ranged from 6.167 N/mm^2 to 13.171 N/mm^2. Mix 2, which contained 0% Lime Powder, 0.5% Coconut powder and 1.5% PPA gave a compressive strength surge of 12.1 N/mm^2, probably due to 1.5% PPA content, even with no lime powder added, the strength falls with Mix 3, however, the strength gradually rose and topped its strength with Mix 6 giving the highest value of average compressive strength at 13.171 N/mm^2, with 10% Lime Powder, 1% Coconut fiber and 1.5% PPA as compared to the control mix. This can be attributed to the synergistic effect of Lime Powder and PPA in improving the concrete performance. This is supported by a previous study on the effects of SCMs on concrete mechanical properties. The lowest compressive strength, mix 9, was 6.167 N/mm^2 and comprised 20% Lime Powder, 1% coconut fiber, and 1.5% PPA. The low compressive strength of the concrete specimens could be attributed to the coconut fiber's orientation, modulus, and specific gravity. Coir fiber is a low-modulus fiber, unlike steel fiber, which is a high-modulus fiber [7,34]. According to a previous study by Velez et al. [12], the presence of coir fibers tends to reduce the compressive strength of composite concrete. Based on the compressive strength results of this study, it can be inferred that concrete can be beneficial for non-structural applications.

3.4.2 Split Tensile Strength (STS)

According to Figure 7, the split tensile strength of the mix's ranges from 1.348 N/mm^2 to 2.604 N/mm^2. The split tensile strength of Mix 2 increased to 2.604 N/mm^2, as compared to the control sample (Mix 1) of 2.08 N/mm^2, which indicates that 0.5% is the optimum coir fiber content, as 1% and 1.5% of coir fiber did not improve the split tensile strength. The decline in strength could be attributed to the reduction in fiber-matrix affinity. As the fiber content increases, the surface area requiring bonding between the concrete mixture and the fibers increases. Mix 4 has the lowest split tensile strength of 1.348 N/mm^2, and the decline in split tensile strength may be attributed to both the high fiber content of 1.5%. The addition of 0.5% coir fiber and 0% Lime Powder with a PPA content of 1.5% to coconut fiber-reinforced concrete significantly enhances its tensile strength, thereby improving the material's behavior. The observation of the positive effect of coir fiber in enhancing the post-cracking tensile strength properties of concrete is corroborated by previous studies [12, 35].

3.4.3 Flexural Strength (FS)

Concrete Prisms with dimensions of 400 mm by 100 mm by 100 mm were tested for flexural strength, and the concrete's strength ranged from 3.24 N/mm^2 to 6.96 N/mm^2 as presented in Figure 7. A minimum strength of 3.24 N/mm^2 was attained with 0% lime powder, 1.5% coconut fiber, and 1.5% PPA while the flexural test yielded highest strength with Mix 5, which consisted of 10% Lime Powder, 0.5% coir fiber, and 1.5% PPA, as compared to the control sample (Mix 1). The flexural strength of 6.96 N/mm^2 indicates improved performance for coconut fiber reinforced concrete. From this result it could be inferred that a 0.5% coir fiber content is an optimum level for enhancing concrete flexural properties, as it improves concrete ductility and prevents fractures by quickly transferring and distributing stresses to the concrete matrix through the interfacial bonding between the fibers and the concrete components [36].

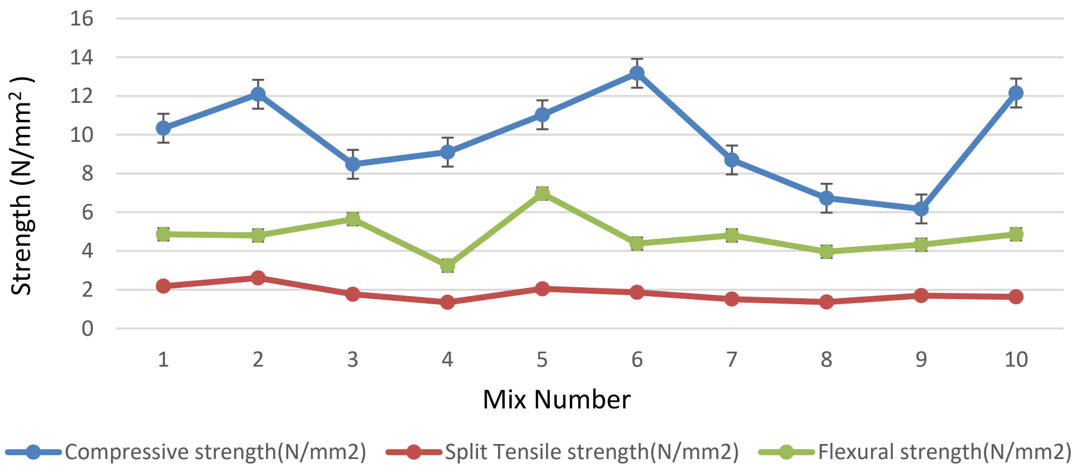

Fig. 7. Compressive, flexural, and split tensile strengths

3.5 Water Absorption Properties of Coconut Fibre Reinforced Concrete

The water absorption results alongside the standard errors is presented in Figure 8. This Figure presents the intial surface and final water absorption as a function of the mix proportions, and it is clear that both properties follow the same pattern. In controlled concrete without coir fiber, PPA, and lime powder, the absorption rates were 0.769% and 1.154%, respectively. The results of the analysis comparing the water absorption of concrete with different amounts of lime powder, coconut fiber, and PPA showed a range of 1.21% to 2.41% for the usual amount. In contrast, using

20% lime powder, 1.5% coconut fiber, and 1.5% PPA resulted in water absorption rates of 1.316% and 2.193%, respectively. Generally, plant-based fibers tend to absorb water due to their hydrophilicity and hygroscopic nature; however, alkaline treatment and chemical modifications have significantly reduced coconut fibers' tendency to absorb water. Therefore, Mix 5, with 10% Lime Powder, 1.5% PPA, and 0.5% Coir fiber among all the mixes, has a lower water absorption percentage at 0.8135% and 1.22% for ISA and FWA, respectively. Relating this to Figure 7, the mechanical characteristics, it is obvious that apart from Mix 1, Mix 5 has the lowest water absorption rate. Furthermore, the reason may not be far-fetched, since density could be related to strength, the compressive strength is 11.03 N/mm^2, above the control sample (Mix 1), indicating the 10% lime powder and 1.5% PPA has remakable impact on the Mix 5, thus, by taking part in pozzolanic interactions with lime/cement hydration products, PPA strengthens the paste by forming additional binding gel (C-S-H) [21]. Mix 5 has the highest flexural strength of 6.96 N/mm^2, and the split tensile strength is marginal and comparable to that of Mix 1. Low resistance to water could be linked to the combined effect of Cement, Lime, and PPA. This finding aligns with previous studies on the water-absorbing tendency of organic fibers [37].

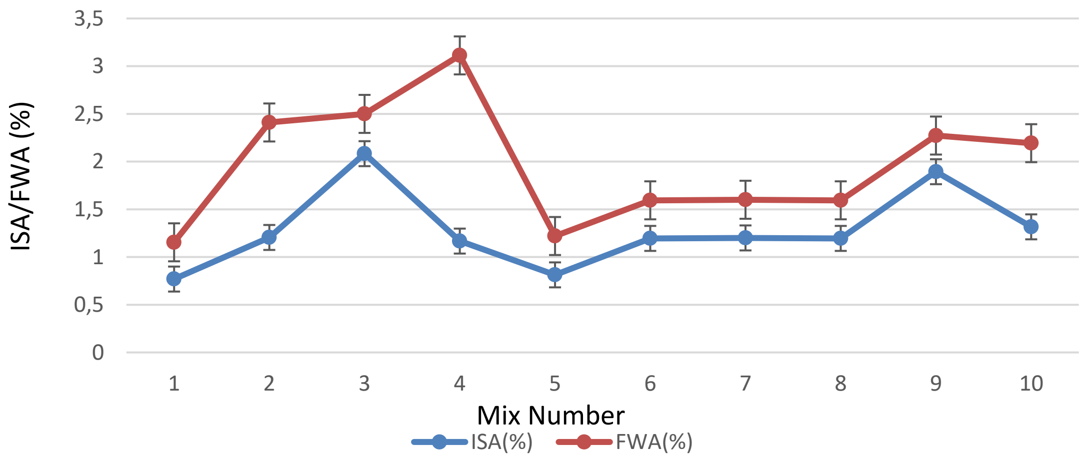

Fig. 8. Initial surface absorption and final water absorption

4. Conclusion

The ability of waste materials to either replace or supplement the conventional material in concrete requires that their performance in use is evaluated. The present and future performance of these alternative materials play a vital role in its acceptability hence the need for an experimental investigation on the mechanical and water absorption properties. The study examined the use of waste materials, including coconut fiber and plantain peel ash combined with lime powder in concrete. The study achieved improved flexural strength using the mechanical approach and demonstrated potential for improved resistance to water absorption with concrete mix containing 10% lime powder and 1.5% plantain peel ash. The maximum compressive, flexural and split tensile strengths was achieved with coconut fiber content of 0.5%. Based on maximum compressive strength of 13.17 N/mm^2 achieved in this study, this concrete can practically be applicable for non-structural or low-load purposes. The outcome reveals that alkali-treated coconut fiber enhances the tensile strength of concrete, while adding plantain peel ash, lime powder, and coconut fiber reduces workability. The study demonstrates that the combination of these aforementioned materials can enhance the concrete mechanical properties, minimize environmental impact, and reduce the water absorption rate in concrete. Agricultural waste, including coconut fiber and plantain peels, can be used to improve concrete performance, while reducing dependence on Portland cement and CO_2 emissions. The increasing generation of agricultural waste and the expansion of infrastructure in Nigeria necessitate sustainable management strategies to address growing waste and enhance the quality of construction materials. Further research is needed to examine the microstructural properties of coconut fiber reinforced concrete incorporating PPA and lime powder. This will provide detailed insight into the materials internal structure of the concrete.

In addition, a mechanism to enhance the separation of coconut fiber strands for easier mixing and compaction will promote the applicability of this natural fiber. Furthermore, a life-cycle cost analysis and sustainability metrics is required to promote the environmental benefits associated with sourcing and processing of waste materials.

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