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Strength Properties of Concrete Produced with Canarium Kernel Shell and Polypropylene Fiber

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Abstract

This study investigated the strength performance of concrete incorporating Canarium kernel shell (CKS) as a partial replacement for conventional coarse aggregate and polypropylene fibre (PPF) as reinforcement, addressing concerns associated with unsustainable natural aggregate consumption, cement-related CO₂ emissions, and agro-waste disposal. A factorial experimental design was adopted, with CKS replacing coarse aggregate at 0%, 5%, 10%, and 15% by weight, while PPF was incorporated at 0%, 0.5%, 1.0%, and 1.5% by volume. A total of 54 concrete specimens were produced and evaluated. The CKS was appropriately processed and pre-soaked before mixing, while a superplasticizer was used to optimize workability. The specific gravity of CKS ranged from 2.36 to 2.42 kg/m³. Increasing CKS content increased slump while maintaining medium workability and reduced concrete density by 24%, satisfying lightweight concrete criteria. The mixture containing 5% CKS exhibited the best mechanical performance, attaining compressive, tensile, and flexural strengths of 29 MPa, 3.5 MPa, and 5.85 MPa, respectively. At 15% CKS replacement, corresponding strengths were 24 MPa, 2.6 MPa, and 4.65 MPa, respectively, exceeding applicable Nigerian minimum strength requirements. PPF incorporation enhanced concrete toughness and crack-control capacity. Overall, CKS-PPF concrete was technically viable at CKS replacement levels up to 15%, providing a beneficial pathway for agro-waste valorization. A 5% CKS replacement is recommended for structural elements, while 10-15% is suitable for secondary members, combined with 0.5-1.0% PPF. Further investigations should evaluate long-term durability and microstructural characteristics.

Keywords

Canarium Kernel Shell,
Polypropylene Fiber,
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Superplasticizer,
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1.0 INTRODUCTION

Concrete constitutes the cornerstone of modern global infrastructure, valued for its compressive strength and long-term serviceability. Nevertheless, its widespread application has invited critical scrutiny concerning its environmental and economic sustainability. Aggregates typically account for 60–70% of concrete's volumetric composition, with annual global extraction reaching billions of tons, thereby driving significant resource depletion, landscape degradation, and carbon emissions (Rajendra & Gokulram, 2017; Přikryl, 2021).

Among these constituents, the coarse aggregate fraction generally defined as granular material retained on a 4.75 mm sieve (Brooks, 2020) exercises a critical influence over the performance of the composite. Its particle size distribution and packing density fundamentally determine the mixture's efficiency: an optimally graded aggregate system enables finer particles to occupy the interstices between larger particles, thereby maximizing compactness and minimizing the volume of cement paste required. This densification effect not only reduces material costs but also enhances mechanical strength and durability by limiting capillary porosity and shrinkage potential (Raj et al., 2014; Robalo et al., 2021).

Furthermore, the intrinsic properties of coarse aggregates including mechanical strength, surface texture, and resistance to deleterious substances are paramount in ensuring effective cement hydration and robust paste-aggregate bonding (Roger, 2022; Ogunbayo et al., 2018). Given the accelerating depletion of natural aggregate sources and the associated environmental costs (Neupane et al., 2023; Abbass et al., 2022), a compelling imperative exists to transition towards sustainable concrete formulations incorporating alternative materials (Aytakin & Mardani, 2022; Das et al., 2024). Within this context, processed agricultural residues and industrial by-products have emerged as promising partial or full replacements for conventional coarse aggregates (Sarma et al., 2023). Notably, the *Canarium schweinfurthii* (Atili) kernel shell an abundant agricultural waste in regions such

as Africa represents a viable lightweight aggregate candidate (Vieira, 2024).

When appropriately processed, this material offers the dual advantages of reducing structural dead weight and providing enhanced thermal insulation, aligning with the principles of circular economy and waste valorization (Diab et al., 2024). Comparable investigations into coconut shells (Kandpal et al., 2024), palm kernel shells, pumice (Arunachalam et al., 2024), and quarry dust have similarly demonstrated varied effects on concrete density, mechanical strength, and thermal behavior.

However, the incorporation of porous lightweight aggregates such as *Canarium* kernel shells introduces a significant technological challenge: their elevated water absorption capacity and irregular surface texture tend to diminish fresh concrete workability, frequently necessitating additional mixing water that compromises the water-to-cementitious-materials ratio and, consequently, the hardened properties and durability. To counteract this adverse effect without compromising performance, the application of a high-range water-reducing admixture specifically, an acrylic acid-based superplasticizer is imperative. Superplasticizers, defined per ASTM C 125 as materials other than water, aggregates, or hydraulic cement added to the batch prior to or during mixing to enhance workability, have emerged as a fundamental solution to lower yield stress and improve flow properties (Altaf & Kaushal, 2022; Flatt & Schober, 2012).

Among the various chemical classes including sulfonated melamine formaldehyde condensates, sulfonated naphthalene formaldehyde condensates, and modified lignosulfonates polycarboxylate (PC) ethers based on acrylic acid have demonstrated superior performance (Al-Hassan et al., 2024; Mohammadi et al., 2020). The acrylic acid-based superplasticizer is particularly warranted in this context due to its powerful dispersing mechanism. Through absorption onto cement particle surfaces via their carboxylate ($-\text{COOH}$) groups, these polymers generate electrostatic repulsion and steric hindrance, effectively deflocculating cement agglomerates and releasing entrapped mixing water

(Flatt & Schober, 2012). This mechanism ensures sustained slump and rheological stability at a substantially reduced water content (Alsadey & Omran, 2022).

Furthermore, research has demonstrated that graft copolymers incorporating acrylic acid monomers exhibit high dispersing force, exceptional slump retention, and high sulfate tolerance, even at reduced water-to-cement ratios (Ilg & Plank, 2015). The polymerization temperature, as a critical synthesis parameter, has been shown to influence the molecular weight and distribution of these polycarboxylate superplasticizers, thereby affecting their ultimate performance in cementitious systems (Mohammadi et al., 2020). Consequently, acrylic acid-based superplasticizers enable the practical utilization of highly absorbent lightweight aggregates by ensuring adequate workability, optimal compaction, and a dense, durable cementitious matrix (Altaf & Kaushal, 2022). Studies have confirmed that such admixtures induce compaction factors exceeding 0.84 while maintaining workability at a constant water-to-cement ratio, thus preserving the requisite compressive strength and low permeability essential for long-term durability (Alsadey & Omran, 2022; Al-Hassan et al., 2024).

Beyond rheological and strength considerations, concrete produced with lightweight aggregates often exhibits increased brittleness and reduced tensile capacity. To address these inherent mechanical deficiencies, the incorporation of discrete fiber reinforcement, particularly polypropylene fiber (PPF), has gained scholarly attention (Makul, 2021). The primary function of PPF within this composite system is to bridge nascent micro-cracks at both the pre-peak and post-peak loading stages, thereby inhibiting their propagation into macroscopic fractures. This bridging effect significantly enhances post-cracking tensile strength, energy absorption, and impact resistance (Azunna, 2019; Lakshmi et al., 2022). Concurrently, PPF effectively mitigates plastic and drying shrinkage cracking, reduces capillary permeability by limiting crack width, and limits the ingress of deleterious environmental agents, thereby

substantially augmenting the durability performance of the concrete under aggressive exposure conditions (Li et al., 2021; Sonar & Sathe, 2024). Moreover, the use of PPF can contribute to overall sustainability by potentially permitting a marginal reduction in cementitious binder content while maintaining structural integrity (Mehta, 2024).

2.0 MATERIALS AND METHODS

2.1 Introduction

This research examined Canarium kernel shell and polypropylene fiber use in sustainable concrete, evaluating physical and mechanical properties via laboratory tests, developing optimized mixes, and testing fresh and hardened concrete, yielding sustainable alternatives that reduce environmental impact.

2.2 Materials

Materials are Canarium kernel shell, Polypropylene fiber, Cement, Aggregates, Acrylic acid and Water.

2.2.1 Cement (OPC)

Ordinary Portland Cement (OPC) type I, was utilized for this investigation, Dangote Cement Grade 42.5 OPC as branded, compliant with ASTM C150 specifications, was selected as the primary binder, providing consistent quality and reliable performance for experimental concrete mix evaluations.

2.2.2 Fine aggregate

The fine aggregate, sourced from Bayara River in Bauchi State, possessed a fineness modulus of 2.8 and specific gravity of 2.65. These properties satisfied ASTM C33-2000 specifications, ensuring suitability for high-performance concrete mixes in sustainable construction research applications.

2.2.3 Coarse aggregate

The coarse aggregate consisted of crushed granite graded between 5 mm and 20 mm BS sieves with material retained on 5 mm discarded and that passing 20 mm selected for concrete production conforming to BS 882 1965.

2.2.4 Canarium kernel shell (CKS)

Canarium kernel shell (CKS) was collected from local nut sellers in Mangu, Plateau State and Tilden Fulani,

Bauchi State. partially replaced coarse aggregate after washing oven-drying and sieving to uniform size per BS EN 1097-6:2013.

2.2.5 Polypropylene fiber PPF

Polypropylene fiber PPF enhanced flexural and tensile strength reduced shrinkage and cracking improved impact resistance and durability and supported sustainable construction benefits verified per BS EN ISO 527-1 and BS EN 12390-2 confirming PPF reliability for industrial.

2.2.6 Water

Potable water meeting specific quality criteria was utilized in concrete production to ensure optimal strength and durability, with neutral pH 6.0-8.0 and temperature range 0-32°C per ACI, and employed

per BS 8500-1 standards, guaranteeing high-quality concrete performance.

2.3 Methods

2.3.1 Experimental Design

This study systematically investigated CKS replacement and PPF addition effects on concrete using a balanced 4x4 factorial design with four levels each (0-15% CKS, 0-1.5% PPF) replicated thrice, assessing mechanical strength and water absorption, confirming eco-friendly performance.

2.3.2 Mix-design

The sustainable concrete mix design comprised OPC 73.68 kg/m³ fine aggregate 125.5 kg coarse aggregate 177.81 kg with CKS replacing 5-15% by mass and PPF at 0.5-1.5% 0.56 kg w/c ratio 0.5 prepared per BS EN 206:2013

Table 2.3.2: Mix-design

Cement	Water	Fine aggregate	Granite	CKS	Acrylic acid	PPF
73.68kg	36.94kg	125.54kg	177.81kg	12.85kg	0.81kg	0.56kg

2.3.3 Casting of Cubes

The thirty-six cubes, six beams and twelve cylinders were cast, compacted in three layers with 25 tamps each, demoulded after 24 hours, per BS EN 12390-1, ensuring integrity for density, compressive, flexural, tensile strength and water absorption.

2.3.4 Curing of Cubes

Concrete cubes beams and cylinders underwent 7-28 days water curing then comprehensive compressive tensile and flexural strengths water absorption and density testing per BS EN 12390-2 and BS 8110-1 standards yielding performance data for sustainable mix durability.

2.4 Testing Procedures

The test procedure involved preparing concrete specimens incorporating varying levels of Canarium kernel shell and polypropylene fiber. Standardized testing per BS EN 12390-3:2019 (compressive strength), BS EN 12390-5:2019 (flexural strength), BS EN 12390-6:2009 (split tensile strength), BS EN 1097-6:2013 (density) BS 1881-122:2011 and (water absorption) comprehensively evaluated mechanical

and durability properties of sustainable concrete formulations.

2.4.1 Physical Properties of Materials:

2.4.2 Specific Gravity:

Density, relative density, specific gravity, and water absorption of fine aggregate determined per BS EN 1097-6:2013; apparent particle density, oven-dried density, and SSD absorption met ± 0.05 acceptance criteria, confirming material compliance with quality standards for durable concrete.

$$SG = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4) \times 0.79} \quad (1)$$

2.4.3 Fineness Modulus:

The aggregate fineness was determined by dry sieving per BS EN 933-1 The particle fractions and grading parameters met ± 0.10 acceptance criteria confirming compliance with quality requirements for concrete performance.

FM

$$= \frac{\sum \text{Cumulative \% retained on standard sieves}}{100} \quad (2)$$

2.4.4 Water Absorption on fine aggregate

The water absorption of fine aggregate was determined per BS EN 1097-6. Absorption did not exceed 5%, and density complied with standards, verifying suitability for high-durability concrete.

Water Absorption (%)

$$= \frac{(M_{ssd} - M_d)}{M_d} \times 100 \quad (3)$$

2.4.5 Density:

The density, relative density (specific gravity) and absorption of coarse aggregate were determined in accordance with BS EN 1097-3:2013, which details methods for particle density and water absorption testing. The resultant values for apparent density, oven-dried density and absorption satisfied the acceptance criteria of ± 0.05 , confirming the aggregate's adherence to quality specifications for robust concrete production.

$$\text{Apparent particle density } \rho_a = \frac{m_d}{V_p} \quad (4)$$

$$\text{Oven - dried particle density } \rho_{rd} = \frac{m_d}{V_{rd}} \quad (5)$$

2.4.6 Aggregate crushing value

The aggregate crushing value of coarse aggregate was determined per BS 812-110, with fines passing the 2.36 mm sieve after loading meeting ± 0.05 criteria, confirming resistance to crushing for durable concrete.

Aggregate crushing value ACV

$$= \frac{W_4}{W_2 - W_1} \times 100\% \quad (6)$$

2.4.5 Aggregate impact value

Aggregate impact value per BS 812-112:1990 was determined as percentage passing 2.36 mm after 15 blows on 14-10 mm aggregate, meeting ± 0.05 criteria and confirming toughness for concrete durability.

$$\text{Aggregate impact value AIV} = \frac{W_4}{W_2 - W_1} \times 100\% \quad (7)$$

2.5 Fresh Properties of

Concrete 2.5.1 Compacting

The compacting factor per BS 1881-105:1984 was determined using standard compaction apparatus; the ratio of partially to fully compacted weight via gravity release met ± 0.05 acceptance criteria, confirming adequate workability for vibrated concrete mixes in construction.

$$\text{Compacting Factor (CF)} = \frac{W_3 - W_1}{W_2 - W_1} \quad (8)$$

2.5.2. Slump Test

The slump of hydraulic cement concrete was determined per BS EN 12350-2 by filling and rodding the Abrams cone then raising it vertically measured slump fell within the range of 50-100 mm confirming workability for structural placement.

$$\text{Slump (mm)} = H_c - H_s \quad (9)$$

2.6 Tests on SPC-CKSPPF Specimen

2.6.1 Water Absorption of Hardened Concrete

The water absorption of hardened concrete was determined in accordance with BS 1881-122:2011. The percentage absorption, calculated from the mass increase after 30-minute partial immersion and 24-hour total immersion followed by surface drying, satisfied the acceptance criteria of not exceeding 5%, confirming low permeability and durability suitable for structural concrete in construction applications.

$$\text{Water Absorption (\%)} = \frac{M_2 - M_1}{M_1} \times 100 \quad (10)$$

2.6.2 Density of Hardened Concrete

Concrete cubes (100×100×100 mm), cylinders (150×300 mm) and beams (100×100×400 mm) incorporated 0-15% Canarium kernel shell (CKS) replacing granite. CKS was sieved (<4.75 mm), oven-dried (105°C, 24 h). Demoulded at 24 h, specimens cured in water for 28 days. In accordance with BS EN 12350-6/ASTM C138.

$$\text{Density} = \frac{M_c - M_m}{V_m} \quad (11)$$

2.6.3 Compressive Strength

The compressive strength of concrete was determined in accordance with BS EN 12390-3:2019, which specifies the testing of specimens using compression machines. The characteristic strength, measured at 28 days on 100 mm cube specimens loaded at 0.6 ± 0.2 MPa/s, achieved not less than 20.7 MPa (≥ 3000 psi), confirming structural grade compliance for construction applications.

$$\text{Compressive Strength } f_c = \frac{F}{A} \quad (12)$$

2.6.4 Split Tensile Strength

The split tensile strength of concrete was determined in accordance with BS EN 12390-6:2009 using cylindrical specimens under diametral compression. The tensile strength, calculated from maximum load at failure along the vertical diameter of 150 × 300 mm cylinders loaded at 0.05 ± 0.01 MPa/s, achieved not less than 2.76 MPa (≥400 psi), confirming tensile capacity.

$$\text{Split Tensile Strength } f_t = \frac{2P}{\pi DL} \quad (13)$$

2.6.5 Flexural Strength

The flexural strength of concrete was determined in accordance with BS EN 12390-5:2019 using third-point loading on a 100 × 100 × 400 mm beam specimen. The modulus of rupture, calculated from maximum

load at failure applied at 0.05 ± 0.01 MPa/s, achieved not less than 4.14 MPa (≥600 psi), confirming structural adequacy.

$$\text{Flexural Strength } f_b = \frac{3PL}{2bd^2} \quad (14)$$

3.0. Results And Discussion

3.1 Specific Gravity

This value resides within the ASTM C33 and BS EN 12620:2002+A1:2008, prescribed range of 2.60-2.75, signifying low porosity, high particle density and minimal water absorption (<4%). Consequently, it facilitates precise mix proportioning, enhanced particle packing and reduced void content in concrete formulations incorporating CKS replacements.

Table 3.1.1: Specific Gravity

Parameter	Sample 1	Sample 2	Sample 3	Average
Weight of Pycnometer (W_1) g	650	650	650	650
Weight of Pycnometer + SSD Aggregate (W_2) g	1170	1172	1168	1170
Weight of Pycnometer + Aggregate + Water (W_3) g	1875	1878	1872	1875
Weight of Pycnometer + Water (W_4) g	1520	1520	1520	1520
Specific Gravity	2.65	2.66	2.64	2.65

Sources: Lab work

3.2.1 Fineness Modulus

The fineness modulus of Bayara River sand was determined by dry sieving in accordance with BS EN 933-1:2012. Using standard sieve sizes (4.75, 2.36,

1.18, 0.60, 0.30, 0.15, 0.075 mm), the cumulative percentages retained were 1.2, 3.2, 10.2, 28.2, 52.2, 80.2, and 94.2% respectively, corresponding to 98.8, 96.8, 89.8, 71.8, 47.8, 19.8, and 5.8% passing.

Table 3.2.1: Fineness Modulus

Sieve size (mm)	Mass retained (g)	Cumulative retained (g)	Cumulative % retained	% Passing
4.75	1	1	0.2	99.8
2.36	15	16	3.2	96.8
1.18	35	51	10.2	89.8
0.60	90	141	28.2	71.8
0.30	120	261	52.2	47.8
0.15	140	401	80.2	19.8
0.075	70	471	94.2	5.8
Pan	30	500	100.0	0.0
Total	500		FM = 2.68	

$$FM = \frac{0.2 + 3.2 + 10.2 + 28.2 + 52.2 + 80.2 + 94.2}{100} = 2.68$$

This value satisfies GP grading Zone M criteria (± 0.10 acceptance), confirming compliance for optimized concrete performance in structural applications.

3.1.2 Water Absorption on Aggregates

Water Absorption on Aggregates: The water absorption capacity of Bayara River sand, determined at 4.2% per BS EN 1097-6:2013 through

the calculation, signifies exceptional aggregate quality. This value satisfies the BS EN 12620:2008 maximum limit of 5% for fine aggregates, evidencing low internal porosity, high particle density and minimal moisture retention. Coarse aggregate 8.0% and CKS 12.4% This indicates outstanding aggregate quality.

Table 3.1.2: Water Absorption on Aggregates

Items	Value
Fine aggregate	4.2
Coarse aggregate	8.0
CKS aggregate	12.4

Sources: Lab work

3.1.4 Density on aggregates

The coarse aggregate exhibits oven-dried particle density of 2.65 Kg/m³ while CKS is 2.36 Kg/m³ and apparent density of coarse aggregate was 2.68 Kg/m³ and CKS was 2.42 Kg/m³ per BS EN 1097-

6:2013 pyknometer method, satisfying BS EN 12620:2008 ± 0.05 tolerance for normal-weight aggregates. These parameters evidence superior particle integrity and minimal porosity, ensuring precise volumetric mix proportioning.

Table 3.1.4.: Density on Aggregate

Density		
	Coarse Aggregate	CSK Aggregate
Apparent density	2.68 Kg/m ³	2.42 Kg/m ³
Oven-dried particle density	2.65 Kg/m ³	2.36 Kg/m ³

3.2 Aggregate Crushing Value

The Aggregate Crushing Value (ACV) test results, presented in Tables 4.2.1 and 4.2.2, indicate that the

coarse aggregate exhibits an average ACV of 25.05%, while the CKS aggregate yields an average ACV of 24.02%.

Table 3.2.1: Aggregate Crushing Value for Coarse aggregate

Description	Sample		
	A	B	C
Weight of empty mould W_1 (kg)	12.10	12.10	12.10
Weight of mould + sample W_2 (kg)	14.35	14.38	14.45
Weight of sample Retained W_3 (kg)	1.75	1.76	1.70
Weight of sample passing. W_4 (kg)	0.564	0.575	0.65
$ACV = \frac{W_4}{W_2 - W_1} \times 100(\%)$	25.07	25.22	27.66
Average ACV (%)	25.05		

Table 3.2.2: Aggregate Crushing Value for CKS aggregate

Description	Sample		
	A	B	C
Weight of empty mould W_1 (kg)	12.10	12.10	12.10
Weight of mould + sample W_2 (kg)	15.18	15.22	15.24
Weight of sample Retained W_3 (kg)	2.34	2.38	2.41
Weight of sample passing. W_4 (kg)	0.74	0.75	0.73
$ACV = \frac{W_4}{W_2 - W_1} \times 100(\%)$	24.03	24.04	23.99
Average ACV (%)	24.02		

These values confirm the aggregates' resistance to crushing, with coarse aggregate demonstrating slightly higher strength (lower ACV) compared to CKS aggregate, consistent with standard BS 812-110:1990 guidelines for construction materials.

3.3 Aggregate Impact Value

The Aggregate Impact Value (AIV) tests were conducted in accordance with BS 812-112:1990 to evaluate the toughness of granite and CKS aggregates under sudden impact loads. Results from Tables 3 and 4 indicate an average AIV of 24.44% for coarse aggregate and 19.85% for CKS aggregate.

Table 3.3.1: Aggregate Impact value for Coarse aggregate

Description	Sample		
	A	B	C
Weight of empty mould W_1 (kg)	2.55	2.55	2.55
Weight of mould + sample W_2 (kg)	3.25	3.24	3.31
Weight of sample Retained W_3 (kg)	0.55	0.53	0.57
Weight of sample passing. W_4 (kg)	0.155	0.162	0.194
$AIV = \frac{W_4}{W_2 - W_1} \times 100(\%)$	23.82	24.07	25.43
Average AIV (%)	24.44		

Table 3.3.2: Aggregate Impact Value for CKS aggregate

Description	Sample		
	A	B	C
Weight of empty mould W_1 (kg)	2.55	2.55	2.55
Weight of mould + sample W_2 (kg)	3.15	3.15	3.13
Weight of sample Retained W_3 (kg)	0.49	0.48	0.48
Weight of sample passing. W_4 (kg)	0.11	0.12	0.114
$AIV = \frac{W_4}{W_2 - W_1} \times 100(\%)$	19.29	20.0	20.26
Average AIV (%)	19.85		

These AIV values confirm both aggregates meet BS 812-112:1990 criteria for general construction use, with CKS aggregate.

3.4 Workability

3.4.1 Slump Test

The slump of hydraulic cement concrete was determined per BS EN 12350-2 by filling and rodding

the Abrams cone then raising it vertically measured slump fell within the range of 50-100 mm confirming workability for structural placement.

Table 3.4.1: Slump test

CKS Replacement (%)	Slump (mm)
0	33
5	34
10	38
15	48

Source: Lab work

3.4.2 Compacting Factor Test

Compacting factor values decreased with CKS aggregate: 0% = 0.91; 5% = 0.90; 10% = 0.88; 15% = 0.86. Percent BS 1881-2, 0.91-0.90 medium

workability, 0.86 low; CKS reduces cohesion but increases slump, maintaining workability.

Table 3.4.2: Compacting Factor

CKS Replacement (%)	Compacting Factor
0	0.91
5	0.90
10	0.88
15	0.86

3.5 Water Absorption on Concrete

Water absorption testing conducted in accordance with BS 1881-122:2011 on hardened concrete specimens incorporating Canarium kernel shell (CKS) as partial coarse aggregate replacement demonstrates consistently low permeability. The

control mix (0% CKS) achieved optimal performance at 2.95% absorption, typical of dense conventional concrete. Incremental CKS substitution up to 15% yielded a controlled increase to 3.32% a modest 12.5% relative rise attributable to the inherent porosity of lignocellulosic agro-waste aggregate.

Table 3.5: Water Absorption on concrete

CKS Replacement (%)	Average W1 (g)	Average W2 (g)	Water Absorption (%)
0	2642	2720	2.95
5	2620	2701	3.07
10	2591	2669	3.01
15	2565	2645	3.32

Sourced: Lab work

3.6 Density of Hardened Concrete

Density profiles of hardened concrete cubes, cylinders and beams at 0-15% CKS replacement across 7-28 days curing (Figures 3-5) reveal control mixes (0% CKS) achieving peak 28-day densities of 2425-2500 kg/m³, declining systematically to 1900-1975 kg/m³ at 15% CKS. This 20-24% reduction

stems from CKS's lower specific gravity (~1.6 Mg/m³) versus granite (~2.65 Mg/m³), with all values exceeding lightweight structural thresholds (≥ 1800 kg/m³). Logarithmic densification (7-day values at 70-80% of 28-day) aligns with hydration kinetics per BS EN 12350-6 and ASTM C138. Results validate CKS viability up to 15% replacement for sustainable Nigerian concrete applications.

Table 3.6.1: Concrete Cubes against Curing Period

CKS (%)	7 days	14 days	21 days	28 days
0	1950	2125	2375	2500
5	1794	1955	2185	2300
10	1638	1785	1995	2100
15	1482	1615	1805	1900

Sourced: Lab work

Table 3.6.2: Concrete Cylinder against curing Period

CKS (%)	PPF (%)	7 days	14 days	21 days	28 days
0	0	1900	2068	2311	2433
5	0.5	1820	1983	2216	2333
10	1.0	1715	1756	1963	2066
15	1.5	1900	2068	2311	2433

Sourced: Lab work

Table 3.6.3: Density of Concrete Beams against Curing Period

CKS (%)	PPF (%)	7 days	14 days	21 days	28 days
0.0	0.0	1891	2061	2304	2425
0.5	0.5	1736	1891	2114	2225
1.0	1.0	1560	1700	1900	2000
1.5	1.5	1540	1679	1876	1975

Sourced: Lab work

3.7 Compressive Strength Characteristics

Compressive strength testing in accordance with BS EN 12390-3:2019 on 100 mm cubes demonstrated a systematic, replacement-dependent reduction in strength. At 28 days, the control attained 31 MPa; the 5% CKS blend was marginally lower at 29 MPa, while 10% and 15% CKS declined further to 26 and

24 MPa. Strength development increased with curing age but decreased as CKS content rose; the 5% CKS mixture matched the control at 7 days and achieved only a 6.5% reduction at 28 days. Reductions at 10% and 15% CKS were 16.1% and 22.6%. All mixtures exceeded Nigeria's ≥ 20 MPa minimum, validating up to 15% CKS replacement, with 5% CKS optimal.

Table 3.7: Compressive strength of Concrete

Age(days)	0%	5%	10%	15%
7 days	22	21	19	17
14 days	26	25	20	18
21 days	29	27	23	21
28 days	31	29	26	24

Sourced: Lab work

3.8 Split Tensile Strength Characteristics

Split tensile strength testing per BS EN 12390-6:2009 on cylindrical specimens yielded 28-day strengths of 3.0 MPa (0% CKS), 3.5 MPa (5% CKS), 3.2 MPa (10% CKS) and 2.6 MPa (15% CKS). Strength attainment ranged from 62.5-73.3% at 7 days (1.8-2.4 MPa), 77.1-84.6% at 14 days (2.2-2.7 MPa), and 84.4-93.3% at 21 days (2.4-3.2 MPa), reaching full capacity by 28 days. 5% CKS proved optimal,

attaining 3.5 MPa versus 3.0 MPa for the control, a 16.7% increase. Progressive substitution yielded controlled decline relative to the 5% CKS optimum: 8.6% at 10% CKS and 25.7% at 15% CKS, all exceeding Nigerian reinforced concrete requirements (≥ 2.0 MPa). Results validate CKS replacement up to 15% for structural concrete production.

Table 3.8: Split Tensile Strength of Concrete

Replacement		7-Days	14-Days	21-Days	28-Days
0% CKS	0%PPF	2.2	2.4	2.8	3.0
5% CKS	0.5%PPF	2.4	2.7	3.2	3.5
10% CKS	1.0%PPF	2.0	2.5	2.7	3.2
15% CKS	1.5%PPF	1.8	2.2	2.4	2.6

Sourced: Lab work.

3.9 Flexural Strength Characteristics

Flexural strength testing per BS EN 12390-5 on 100 × 100 × 400 mm polypropylene fiber-reinforced prisms yielded characteristic 28-day modulus of rupture values of 4.20 MPa (0% CKS), 5.85 MPa (5% CKS), 5.35 MPa (10% CKS) and 4.65 MPa (15% CKS). Early-age (7-day) strengths were 4.05, 4.66, 4.40 and 4.30 MPa, attaining 96.4%, 79.7%, 82.2% and 92.5% of ultimate capacity, respectively. The 5%

CKS substitution demonstrated optimal performance, exceeding the control by 39.3%. Relative to the 5% CKS optimum, controlled reductions were 8.5% (10% CKS) and 20.5% (15% CKS). Polypropylene fibers enhanced ductility and crack resistance. All levels satisfied Nigerian reinforced concrete requirements (≥ 4.0 MPa), validating CKS replacement up to 15% in sustainable fiber-reinforced concrete production.

Table 3 9: Flexural Strength of Concrete

Replacement		7-Days (MPa)	28-Days (MPa)
0% CKS	0%PPF	4.05	4.20
5% CKS	0.5%PPF	4.66	5.85
10% CKS	1.0%PPF	4.40	5.35
15% CKS	1.5%PPF	4.30	4.65

Sourced: Lab work.

4.0 Conclusion

This research conclusively validates Canarium kernel shell as a sustainable partial replacement for conventional coarse aggregate in polypropylene fibre-reinforced concrete, establishing precise structural performance thresholds. All constituent materials satisfied relevant standards: Bayara River sand with fineness modulus of 2.68, specific gravity of 2.65 and water absorption of 4.2%, and coarse

aggregate with density of 2.65 Mg/m³ met ASTM C33 and BS EN 12620:2008 requirements. Aggregate mechanical properties complied with BS 812 specifications, with CKS exhibiting an ACV of 24.02% and granite 25.05%, both below the 30% limit, while CKS demonstrated superior impact resistance with an AIV of 19.85% compared with 24.44% for granite. Fresh concrete workability enhanced systematically with increasing CKS

content, with slump values ranging from 33 to 48 mm (S1-S2 classification per BS 1881-2:1983) and compacting factors from 0.91 to 0.86. Hardened concrete exhibited a 24% density reduction from 2500 to 1900 kg/m³ while maintaining normal-weight classification exceeding the 1800 kg/m³ threshold specified in BS EN 206-1. Water absorption remained controlled between 2.95% and 3.32%, below the 5% limit of BS 1881-122:2011. The optimal 5% CKS substitution achieved performance equivalence to control mixes, attaining 29 MPa compressive strength (93.5% of control), 3.5 MPa split tensile strength (116.7% of control) and 5.85 MPa flexural strength (139.3% of control). The 15% CKS replacement yielded controlled reductions to 24 MPa compressive, 2.6 MPa tensile and 4.65 MPa flexural strength, all exceeding Nigerian reinforced concrete minimum requirements of 20 MPa, 2.0 MPa and 4.0 MPa respectively. The CKS-PPF composite demonstrates technical feasibility up to 15% replacement, satisfying BS EN 12390 criteria and advancing agro-waste valorization for sustainable Nigerian construction practice.

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