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An Experimental Investigation into the Effects of Using Partially Substituted Cassava Peel Ash for Cement in Concrete

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Abstract:
When placed in landfills, agricultural wastes have been a significant source of contamination to the environment. The rate of consumption of cement being an essential part of concrete cannot be overemphasized. There is need to explore alternative supplementary binding material which is eco-friendly and sustainable towards the production of green concrete. The purpose of this study is to explore the possibility of using cassava peel ash (CPA) as a partial cement substitute in concrete. The partial replacement was achieved in differing percentages of 0%, 1%, 2%, 3%, 4% and 5% by weight of cement in the M20 concrete mix, making use of mix ratio 1:1.5:3. The batched concrete mix samples were cast in cube and cylinder moulds of 100 x 100 x 100mm and 100 by 200 mm respectively and cured for 7, 14, 28, 56 and 90 days. On the fresh concrete mixtures, slump tests were carried out and the split tensile and compressive strengths of the cured concrete cylinders and cubes were evaluated respectively. In the findings derived from the slump test, it is evident that with the incremental augmentation of the percentage replacement of (CPA) within the concrete mixture, there is a discernible augmentation in the workability of the resultant mixture. The results indicated that at 1% cassava peel ash (CPA) replacement, the optimal compressive strength and split tensile strength values were 32.9 N/mm² and 3.9 N/mm², respectively. These values are comparable to those of the control mix with compressive and tensile strength values of 33.1 N/mm² and 4.1 N/mm², respectively. This research investigation unveils the potential suitability of (CPA) as a prospective partial substitute for cement within the composition of a concrete mixture.

Keywords: Cassava peel ash, cement, compressive strength, concrete, split tensile strength

1. Introduction

Concrete an essential construction composite composed of cement, fine aggregate (sand), coarse aggregate (crushed stone), and water, supports global infrastructure development [1]. However, the production of ordinary Portland cement presents substantial environmental challenges. The manufacturing process of clinker, a fundamental cement constituent, emits carbon dioxide during the calcination of calcium carbonate ($CaCO_3$) into lime (CaO) [2-3]. Moreover, the combustion of fossil fuels in this process exacerbates carbon dioxide emissions, significantly contributing to global warming [4].

The environmental impact of the cement industry is profound on both local and global scales [5], [6], necessitating urgent research into sustainable and eco-friendly alternatives without compromising structural performance [7].

Extensive investigations have identified several supplementary cementitious materials (SCMs) such as fly ash (FA) [8–13], rice husk ash (RHA) [14–19], ground granulated blast furnace slag (GGBS) [20–24], silica fume (SF) [25–27], bamboo leaf ash [28–30] and sugar cane bagasse ash (SCBA) [31–33]. These materials have been evaluated for their pozzolanic reactivity and potential to enhance concrete properties.

Sustainability in construction requires context-specific solutions, influenced by regional availability of raw materials. Nigeria, the predominant global producer of cassava, generates over 34 million tonnes of tuberous roots annually [34], [35], and the potential to utilize cassava by-products in construction is significant. Studies have shown that calcined cassava peel ash, processed at approximately 700°C for 90 minutes, demonstrates high pozzolanic activity due to its alumina, silica, and ferric oxide content exceeding 70% [36]. Despite the promise of cassava peel ash as a pozzolanic material, research on its use as a partial replacement for Portland Limestone Cement (PLC) in concrete is sparse.

Olatokunbo et al. [37] investigated replacements ranging from 5% to 25%, but there is a need to identify the optimal replacement level at lower percentages. This research addresses this gap. The primary objective of this study is to evaluate the performance of concrete incorporating varying proportions of cassava peel ash as a partial cement replacement, focusing on parameters such as slump, split tensile strength, and compressive strength. This investigation aims to highlight the feasibility of cassava peel ash as a sustainable and environmentally friendly cementitious material

For this study, M20 grade concrete was designed with a mix ratio of 1:1.5:3. Cassava peel ash was incrementally introduced by weight of cement, from 0% to 5%. Following the curing process, comprehensive mechanical testing was conducted to determine the impact of cassava peel ash on the structural integrity of the concrete compositions.

II METHODOLOGY

A *Materials used*

The purpose of this study is to investigate the compressive strength of concrete using cassava peel ash (CPA) as a partial cement substitute. The following are the materials utilized in the experiment;

1) Cement: The cement type that was utilized in this study was Portland Limestone Cement (PLC) of grade 42.5R (Dangote Cement 3x) conforming to [38] and strength classes. Figure 1 shows the cement used;

Fig. 1. Cement

2) Fine aggregate: Naturally occurring river sand with no dirt in accordance with [39] which was obtained from Malate. The river sand has an aggregate size of 4.75mm. Figure 2 shows the sand used.

Fig. 2. Fine aggregate

3) Coarse aggregate: Gap-graded coarse aggregate was employed in this study. The size that passed through the 20mm sieve and retained on the 10mm sieve size was employed for this research. Figure 3 shows the granite used;

Fig. 3. Coarse aggregate

4) Water: The water used was tested with a physical inspection, smell, and color and was free from visible impurities.

4) Cassava Peel Ash: For this research, the cassava peel was acquired from farmers in Malete village, Moro local

government area LGA, Kwara state. They were collected after it has been peeled from the harvested cassava in four (4) different sacks, cleaned and then air-dried for 72 hours to get rid of moisture. The peels were subjected to open-air burning for 90 minutes in a dogged ground surrounded by a roofing sheet to prevent contact with sand particles before being subjected to control burning in a kiln at a temperature of 700ºC for 90 minutes. The burnt particles were collected, left to cool for 12 hours, and then sieved in a 90-micron sieve to obtain a fine cement-like particle. The cassava peel ash had a bulk density of 852 kg/m^3, a specific gravity of 1.92, and a fineness modulus of 2.13. It was examined for appropriateness as a pozzolana according to ASTM C618 as the cassava peel ash CPA was characterized using the XRF test. The characterization was completed at Central Laboratory, Umaru Musa Yar-adua University and the results are detailed in the third section of this study.

B *Laboratory Batching and Mixing*

Batching of the concrete was carried out by weight, targeting Grade M20 with a 1:1.5:3 mix ratio and a water-to-cement ratio of 0.45 for regular wetting and drying conditions. Materials were weighed on a balance before mixing. To achieve a consistent and homogeneous concrete mix, manual mixing was performed in a laboratory. Fine aggregate, cement, and cassava peel ash were carefully measured and mixed on a watertight, nonabsorbent platform. Coarse aggregate was then added until evenly distributed. The concrete mix included varying percentages of cassava peel ash as a cement substitute.

C *Slump Test*

The interior of the mould was cleaned, and oil was applied. The actions that were taken comprised placing the mould on a smooth horizontal non-porous base plate, tamping each layer of the concrete mix with 25 strokes of the tapping rod's rounded end in a uniform manner over the cross-section of the mould (in accordance with the specifications in BS 12390 Part 2 [40]). For subsequent layers, it was ensured that the tamping rod penetrated the underlying layer, removing excess concrete, levelling the surface using a trowel, cleaning the leaked-out mortar and water between the mould and the base plate, raising the mould immediately and slowly in a vertical direction, and measuring the slump as the difference between the height of the mould and of the sample being tested.

D *Preparation of Test Specimen*

Cassava peel ash CPA was utilized as a supplement for cement in differing percentages of 0%, 1%, 2%, 3%, 4% and 5% as previous research has only looked into higher percentages, with a recommendation for further research to be done to look at lower percentages to obtain an optimum value. The cube mould of dimensions 100 x 100 x 100 mm and the cylinder mould of dimensions 100mm by 200mm was applied in this research. Each mould was carefully greased with oil before the mixed concrete was placed in them. The mixed concrete was placed in three different layers in the mould, each layer of placement was compacted manually using a compaction rod, 25 strokes each to minimize the number of voids as specified in the British Standard codes BS 12390 Part 2 [40] . Immediately after compaction, the concrete surface was levelled to ensure a very smooth surface. Each set of specimens, comprising three (3) cubes and three (3) cylinders was identified by using a label of percentages of cassava peel ash content. A mix ratio of 1:1.5:3 was adopted for the concrete mix. 36 cubes and 36 cylinders of specimens were prepared. A total of 36 cubes and 36 cylinders were cast and tested.

E *Curing of Concrete Cubes and Cylinders*

After casting, the specimen was allowed to set for 24 hours before it was de-moulded and totally submerged in water at an average temperature of 21°C in a curing tank to ensure complete hydration as recommended in [41].The curing of the concrete cube and cylinder samples was done for a duration of 7, 14, 28, 56 and 90 days. Before testing the specimen, excessive water was retracted from the cube and cylinder and allowed to dry for about 30 minutes before crushing the samples. Figure 7 depicts the curing of the concrete cubes and cylinders.

F *Compressive Strength Test*

This mechanical test determines the maximum axial load that a material can support before breaking, or the amount of axial load that concrete can support before failing. A material under compression tends to reduce in size, while in tension, size elongates. For regular construction, the range of compressive strength for concrete is 15 MPa (2200 psi) to 30 MPa (4400 psi) for ordinary concrete and greater for commercial and industrial constructions. British standard was applied in preparing and testing the specimens with various mixtures. The cube mould with dimensions 100mm by 100mm by 100mm was usedfor the different concrete mixtures. On the day of testing, the cubes were exhumed from water and allowed to air dry at ambient temperature.. The geometrical dimensions and weight of each sample cube were measured before being positioned on the hydraulic testing machine. The machine applied an increasing load with a constant rate over a calibration of 0.2-0.4 N/mm^2. Concrete cube specimens that had been cured in water for 7, 14, 28, 56, and 90 days were used in the testing. Using (1), the compressive strength was determined;

$$\mathit{Compressive\ strength}\ \left(\frac{N}{mm^2}\right) = \frac{\mathit{Crushing\ load}\ P\ (KN)}{\mathit{Area}\ A\ (mm^2)} \quad (1)$$

Where P denotes the load from the machine when the cube was ruptured.

A denotes the area of the surface that the machine compressed.

G *Split Tensile Strength Test*

The test was conducted in conformity with BS EN 12390-6:2009 [41]. The Split Tensile strength test was carried out following the determination of the density of the concrete cylinder. The weighted cylinder was carefully placed in a universal testing machine UTM of 50 kN at the Mechanical Engineering department, University of Ilorin, Ilorin. The UTM was powered by an inverter, the machine was switched on from the power source and the crushing load at which the failure occurred was recorded. Concrete cylinder specimens that had been cured in water for 7, 14, 28, 56, and 90 days were used for the tests. Using Equation (2), the split tensile strength was determined.

$$f_{spl} = \frac{2P}{\pi LD} \qquad (2)$$

Where D is the diameter of the cylinder in (mm), L is the length of the concrete cylinder in (mm), P is the maximum applied load/ crushing load in (kN) and f_{spl} is the splitting tensile strength in ($\frac{N}{mm^2}$).

III RESULTS AND DISCUSSION

A *Chemical composition*

The chemical makeup of the cassava peel ash is presented in Table 1. In the ash, the oxide composition of silicon, aluminium, and iron is 76.32%, with silicon dioxide (SiO_2) making up the largest portion of the oxide composition. This satisfies the minimum 70% specified by ASTM C618 [42] standards for supplementary cementitious materials. This result agrees with Ogbonna et al. [37]'s findings.

Table 1. Oxide composition of cassava peel ash

S/N	Chemical Composition	Percentage (%)
1	SiO_2	42.26
2	Al_2O_3	19.79
3	Fe_2O_3	14.57
4	CaO	0.43
5	MgO	0.4
6	Na_2O	0.38
7	K_2O	1.31
8	SO_3	0.33
9	MnO	2.50
10	LOI	0.03

B *Slump Test Result*

Figure 4 shows the slump result of concrete samples with cassava peel ash content. As the proportion of cassava peel ash increases from 0% to 5%, the slump height of the concrete mix also increases, demonstrating that the introduction of cassava peel ash enhances the workability of the concrete. When no cassava peel ash is added (0%), the slump height is 33 mm, indicating relatively low workability or a stiffer concrete mix. At 5% cassava peel ash, the slump height reaches 87 mm, suggesting a highly workable and more fluid concrete mix. This relationship indicates that cassava peel ash improves the workability of the concrete mix, making it easier to handle and place. This result aligns with the research conducted by Raheem et al. [43].

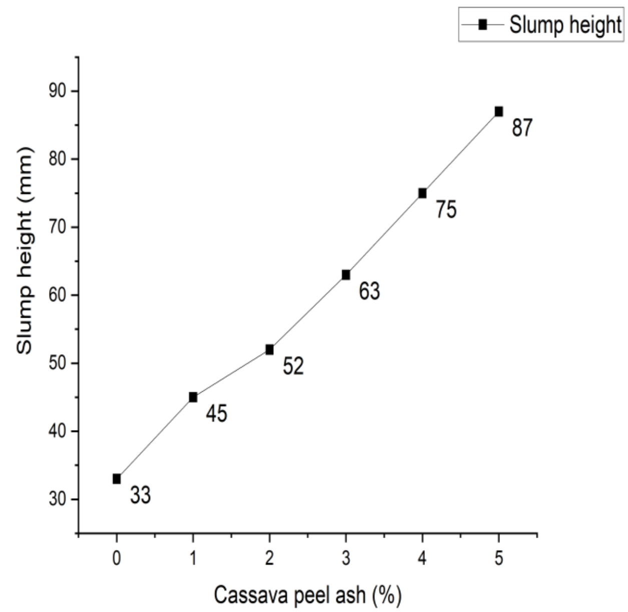

Fig. 4. Slump test results

C *Compressive Strength results*

The compressive strength of concrete with cassava peel ash is displayed in Figure 5. The analysis of the data reveals that as the percentage of cassava peel ash increases, concrete's compressive strength decreases at all curing ages. Specifically, at 7 days, the strength decreases from 16.5 N/mm² for the 0% ash mix to 13.5 N/mm² for the 5% ash mix. At 14 days, the strength decreases from 21.2 N/mm² for the 0% ash mix to 16.8 N/mm² for the 5% ash mix. At 28 days, the strength decreases from 25.3 N/mm² for the 0% ash mix to 17.7 N/mm² for the 5% ash mix. At 56 days, the strength decreases from 30.4 N/mm² for the 0% ash mix to 20.4 N/mm² for the 5% ash mix. Finally, at 90 days, the strength decreases from 33.1 N/mm² for the 0% ash mix to 24.5 N/mm² for the 5% ash mix. The optimum percentage of cassava peel ash was 1%. This reduction in strength with higher cassava peel ash content is likely consequential to slower pozzolanic reaction, which takes time to enhance the concrete's compressive strength as suggested by Raheem [43].

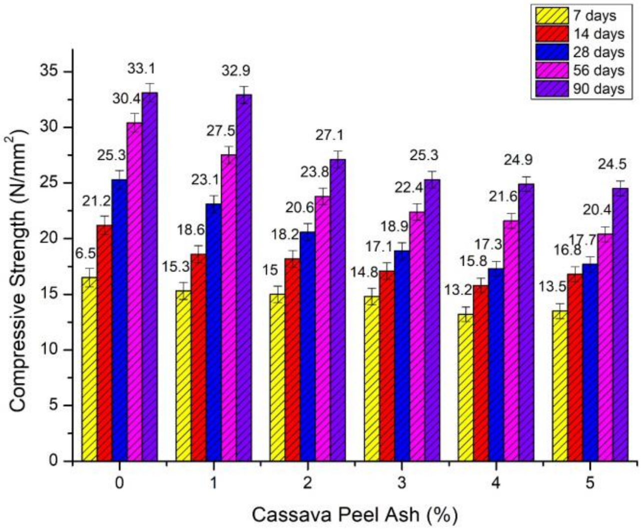

Fig. 5. Compressive strength results

D *Split Tensile Strength Results*

Figure 6 depicts the split tensile strength results of concrete samples with cassava peel ash (CPA). Generally, as the curing duration increases from 7 days to 90 days, there is an increase in split tensile strength for all CPA percentages. At 0% CPA content, the split tensile strength increases from 7 days (1.8 N/mm²) to 28 days (3.5 N/mm²), and it further increases at 90 days (4.1 N/mm²). As the CPA content increases from 0% to 5%, there is a decrease in tensile strength. Specifically, 1%, 2%, 3%, 4%, and 5% ash content in concrete produced strengths of 3.9 N/mm², 3.8 N/mm², 3.6 N/mm², 3.6 N/mm², and 3.2 N/mm², respectively. The optimum strength came from concrete with 1% CPA content. This suggests that the addition of Cassava peel ash negatively impacts the strength of the concrete, especially at higher percentages and longer curing times. This results agree with research conducted by Olatokunbo et al. [37].

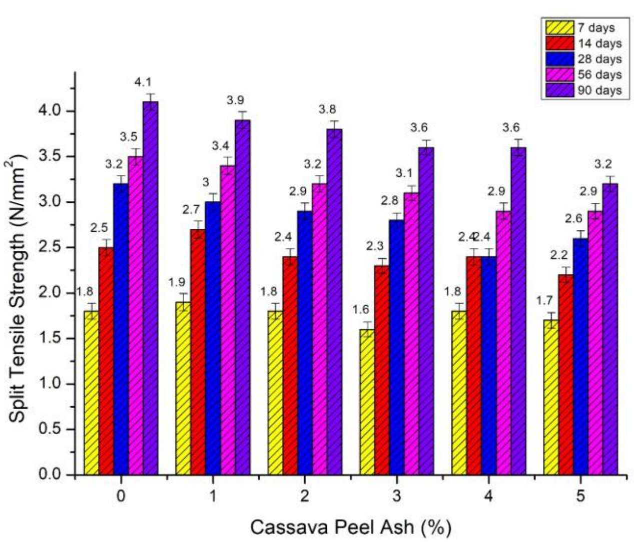

Fig. 6. Split tensile strength results

IV Conclusion

The following conclusion was made:

1) Cassava peel ash demonstrates its suitability as a highly effective supplementary cementitious material.

2) A larger percentage of cassava peel ash considerably improves concrete's workability.

3) The strength of concrete noticeably decreases as the quantity of cassava peel ash increases.

4) The ideal proportion of cassava peel ash for optimal performance was determined to be 1%.

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