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Performance Assessment of Rice Husk Ash and Cassava Peel Ash Blended Concrete in Obajana, Nigeria

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ABSTRACT

The increasing demand for environmentally friendly building materials has led to the investigation of pozzolanic admixtures as partial substitutes for conventional Portland cement. This study investigates the performance assessment of rice husk ash (RHA) and cassava peel ash (CPA) blended concrete. The experimental methodology involved the production of concrete specimens using 100 cm3 cubical moulds and 150*300 mm cylindrical moulds. A consistent mix proportion of 1:1:2 and a water-cement ratio of 0.55 were maintained. Chemical, physical, and mechanical evaluations were conducted to determine the suitability of the ashes as pozzolans, with the compressive strength, and split tensile strength assessments at varying replacement levels (3.5–14%). The results show that both RHA and CPA possess high silica and alumina contents, and satisfactory pozzolanic indices. The optimum compressive strength was attained at a 7% replacement level, yielding 35.45 N/mm² for RHA and 34.77 N/mm² for CPA. Concurrently, the corresponding split tensile strengths after a 28-day curing period were recorded as 4.02 N/mm² and 3.97 N/mm². These findings suggest that RHA and CPA can substantially enhance performance of concrete in demanding environments, thereby offering a sustainable alternative for the construction sector and facilitating progress towards a more ecologically sound built infrastructure.

Keywords— **Cassava peel ash, Portland cement, Rice husk ash, Strength, Sustainable materials**

I. INTRODUCTION

The widespread use of concrete as a construction material is attributed to its adaptability, durability, and cost-effectiveness. Cement has long been fundamental to the development of modern infrastructure and remains the principal binding component in concrete production. It is employed across a wide range of structural systems, including buildings, dams, bridges, tunnels, offshore platforms, and other specialized infrastructure [1]. However, rising construction costs present significant economic challenges, and efforts to reduce these costs have sometimes compromised structural integrity.

According to the International Energy Agency (IEA), global energy consumption in 2021 resulted in a substantial increase in carbon dioxide (CO_2) emissions, marking the second-highest annual increase on record [2]. The production of ordinary Portland cement (OPC), the dominant binder in concrete, is highly energy-intensive and contributes approximately 7–8% of total anthropogenic CO_2 emissions [3]. Although the construction industry is a major contributor to environmental pollution, other sectors, particularly power generation and agriculture also play significant roles. These developments highlight the pressing need for sustainable binders or materials that can lower the amount of clinker in low-carbon concrete while preserving or improving its durability and mechanical performance.

The production of industrial waste is a major problem, especially in emerging nations such as Nigeria [4]. Despite being necessary for infrastructure development, cement production generates large quantities of waste, including clinker residue, kiln ash, cement dust, and quarry overburden [5]. The Obajana Cement Factory in Kogi State, one of the largest cement plants in Africa, has contributed to national development but also poses challenges to agriculture and the environment [6]. Improper waste management can negatively affect farmlands and ecosystems by altering soil pH, reducing nutrient availability, and introducing trace amounts of heavy metals [7].

In addition, wastewater and runoff from quarrying activities may contaminate nearby water bodies, thereby affecting aquatic life and irrigation quality [8]. These challenges underscore the need for sustainable agricultural practices, effective industrial waste management strategies, and environmental protection within host communities. Meanwhile, Nigeria remains one of the world’s leading producers of cassava, particularly across the southern and middle-belt regions, with an annual output exceeding 38 million tons and projected to double by 2025 [9],[10]. The country also generates considerable agricultural residues from key crops such as rice, sugarcane, maize, palm kernels, and others (see Table 1), which hold significant potential for renewable energy applications.

Despite the abundance of agro-wastes in Nigeria, many communities continue to face challenges in their sustainable management [13]. The country produces approximately 3.2 million tons of paddy rice annually, yielding about 2.0 million tons of milled rice [14], while domestic demand has risen to 4.1 million tons [15]. Improper disposal of agricultural residues is particularly evident in Obajana, where waste accumulation near industrial zones more than doubled over a specific period [11]. Such accumulation generates unpleasant odors, heat, greenhouse gases, and provides breeding grounds for pests, highlighting the need for sustainable waste recycling and disposal strategies.

Rice husk ash (RHA) and cassava peel ash (CPA) are derived from the burning of rice husk and cassava peel by-products generated during the processing of these essential crops [16]. Large quantities of cassava peel are produced during processing, and improper disposal poses environmental and public health risks [17]. Although a small proportion of rice husks and cassava peels is currently utilized, the majority is openly burned or left to decompose, contributing to pollution. Converting these materials into ash yields valuable supplementary cementitious materials (SCMs).

Previous studies demonstrate that incorporating RHA and CPA into blended cement influences both fresh and hardened concrete properties [16], [18], [19], [20], for instance, found that replacing 10–20% of OPC with RHA enhanced both durability and cost-effectiveness. Similarly, Zaid et al. [21] observed that mixtures containing 10% RHA and steel fibers achieved compressive strengths comparable to control samples, whereas higher replacement levels (>15%) reduced overall strength. Abdulwahab [22] further reported that concrete incorporating 5% metakaolin and 2% treated RHA outperformed control mixes in compressive strength.

The use of SCMs offers notable performance benefits, including improved workability, reduced heat of hydration, lower permeability, increased compressive strength, and enhanced long-term durability [23], [24]. As pozzolanic materials, RHA and CPA provide sustainable alternatives to OPC while simultaneously valorizing agricultural by-products. Pozzolans, whether naturally occurring or industrially derived, react with calcium hydroxide during cement hydration to form additional calcium silicate hydrate (C–S–H), thereby densifying the microstructure and improving mechanical performance [25], [27].

Although extensive research has examined RHA and CPA separately, limited studies have evaluated higher low-level replacements under the specific conditions. This study investigates the effects of RHA and CPA as partial replacements for OPC at levels of 3.5–14% on key engineering properties, including consistency, setting time, workability, compressive strength, and split tensile strength. The overarching objective is to assess the suitability of locally available agro-waste pozzolans for producing sustainable, low-carbon concrete. The findings are expected to provide empirical evidence that supports environmentally responsible and high-performance construction practices.

Table 1: Selected Agro-Waste Products in Nigeria (Sources: [11], [12])

Agro-Product	Type of Agro –Waste	Estimated Annual Production (Million Tons)
Rice	Rice husk, Rice straw.	2.5 – 3.0
Cassava	Cassava peels, Cassava bagasse.	10 – 12
Maize	Maize cob, Maize husk.	5 – 6
Sorghum/Millet	Stalks, husks.	1 – 2
Groundnut	Shells, haulms.	0.5 – 1
Cocoa	Pod husk, shells.	1 – 1.5
Oil palm	Fronds, empty fruit bunches, shell.	4 – 5
Yam	Peels, tuber waste.	1 – 1.2
Sugarcane	Bagasse, leaves.	1 – 1.5
Vegetable & Fruit	Peels, leaves, stalks.	2 – 3

II. MATERIALS AND METHODS

A. Materials

Materials included in the study were rice husk ash (RHA), cassava peel ash (CPA), Rice husk and cassava peel waste materials were sourced from the Agricultural Centre in Obajana, Kogi State, Nigeria, and calcined in a controlled gas furnace to produce ash. The resulting ashes were finely ground and sieved through a 75 µm sieve, as shown in Fig. 1. Others are sand, crushed granite, and potable water. Ordinary Portland cement (OPC) was obtained from retail outlets in Ado-Ekiti and delivered to the Civil Engineering Laboratory at the Federal Polytechnic, Ado-Ekiti.

B. Concrete Mix Design

The process of selecting suitable concrete materials and calculating their proper proportions to create concrete with the required strength and workability at the lowest cost is known as mix design. A nominal mix ratio of 1:1:2 was adopted, with a constant water-to-cement (w/c) ratio of 0.55 applied to all mixtures. Table 2 presents the details of five specimens was cast for each material (RHA and CPA) at each replacement level to optimize the concrete mix. For each trial, the constituents were accurately measured using a weighing scale, and water was measured with a graduated beaker. All mixtures were manually blended until a uniform paste was obtained.

C. Specimens Preparation

The study aimed to evaluate the strength characteristics of concrete incorporating rice husk ash (RHA) and cassava peel ash (CPA) as partial replacements for cement at varying proportions of 0%, 3.5%, 7%, 10.5%, and 14%. Concrete batching was conducted by weight, and the constituent materials were measured accurately using a digital balance. The dry materials, comprising cement blended with RHA or CPA, sand, and coarse aggregates, were thoroughly mixed in a clean tray mixer. Water was then added gradually during mixing to ensure a homogeneous and workable concrete mass.

The mixing process was maintained for a minimum of 3 minutes. For specimen preparation, the fresh concrete was placed into moulds in three equal layers, with each layer compacted using a tamping rod or mechanical vibrator to eliminate entrapped air. The top surface was leveled and appropriately labeled. A total of 100 concrete specimens were cast, comprising 50 cube specimens (100 × 100 × 100 mm) and cylindrical specimens (150 × 300 mm) designated for compressive strength and split tensile strength testing, respectively. Following casting, all specimens were left to set for 24 hours before demolding and subsequently transferred to a curing tank maintained at 26°C ± 2°C. The specimens were water-cured for 7 and 28 days before testing. This is illustrated in Fig. 2.

D. Testing Procedures

The testing procedures followed international standards to ensure that the experimental results were reliable and reproducible. Systematic evaluations were performed on the materials and mechanical properties of concrete specimens that incorporated rice husk ash (RHA) and cassava peel ash (CPA). These evaluations included specimen preparation, curing methods, and standardized tests for both fresh and hardened concrete.

E. Oxide Composition

A comprehensive chemical characterization of Rice Husk Ash (RHA), Cassava Peel Ash (CPA), and cement powder was performed using X-ray fluorescence spectroscopy. This analysis was conducted with a Total Cement Analyzer, model ARL 9900 XP, at the research laboratory of Obajana Cement Factory.

F. Sieve Analysis Test

The particle size distribution of a granular material is evaluated using this procedure. This assessment is essential for ensuring compliance with the design, production, control, and verification specifications required by ASTM C 136 [28] for engineering projects. The investigation included both fine and coarse aggregate materials used in concrete production. For this analysis, a series of sieves was utilized, with the coarsest sieve (20 mm) placed at the top and the finest sieve (0.075 mm) at the bottom, as illustrated in Fig. 3. This stack of sieves was then secured in a sieve shaker and operated for ten minutes. After the shaking, a graphical representation of the particle size distribution was created, along with the measurement of the mass of aggregates retained on each sieve.

Fig. 1: (a) Rice husk (b) Cassava peel (c) RHA (d) CPA

Fig. 2: Working Process

Table 2: The Details of Experimental Mix Design

% Additive Weight	Compressive Strength Mix Design					Split Tensile Strength Mix Design				
	Cement (Kg)	Aggregates		RHA (Kg)	CPA (Kg)	Cement (Kg)	Aggregates		RHA (Kg)	CPA (Kg)
		Fine (Kg)	Coarse (Kg)				Fine (Kg)	Coarse (Kg)		
0.0	4.62	4.62	9.24	0.00	0.00	7.26	7.26	14.52	0.00	0.00
3.5	4.46	4.62	9.24	0.16	0.16	7.00	7.26	14.52	0.26	0.26
7.0	4.30	4.62	9.24	0.32	0.32	6.75	7.26	14.52	0.51	0.51
10.5	4.14	4.62	9.24	0.48	0.48	6.50	7.26	14.52	0.76	0.76
14.0	3.97	4.62	9.24	0.65	0.65	6.24	7.26	14.52	1.02	1.02

G. *Consistency Test*

The Vicat apparatus is used to determine the optimal water content required to achieve a specified penetration depth during the consistency test of cement paste in accordance with ASTM C 187 [29]. This test serves as an essential preliminary step before other cement and concrete tests are conducted. In this procedure, a cement paste containing 3.5 –14% blended RHA/CPA by weight and an initially unknown water-cement ratio is prepared, placed into the Vicat mould, and tested using a standardized plunger, as shown in Fig. 4a. The water-to-cement ratio is then adjusted iteratively until the plunger reaches the required penetration depth of 5 –7 mm, thereby establishing the standard consistency.

H. Slump Test

The concrete slump test is a quick field technique used to evaluate the consistency and workability of fresh concrete that contains 3.5–14% blended RHA/CPA by weight of cement, in accordance with ASTM C143/C143M [30]. It involves filling a cone-shaped mould with concrete, removing the mould, and measuring the vertical distance that the concrete settles, as shown in Fig. 4a. This test helps engineers ensure that the concrete mix has adequate water content and maintains consistency between batches, making it suitable for placement. A greater slump value indicates a more fluid mix, while a lower slump value signifies a stiffer, less workable mix.

I. Compressive Strength Test

The maximum compressive force a specimen can endure defines its compressive strength, signifying a material or structural component's capacity to resist forces that diminish its dimensions. This metric indicates inherent resistance to compressive stress, and each cube was subjected to crushing using a compression machine with a 2000 KN capacity as per BS 1881: Part 116 [31]. The cube was positioned with its cast face oriented towards the applied force. The testing apparatus featured flat metallic platens at both the top and bottom, sufficiently sized to encompass the cube's total surface area, thereby ensuring uniform stress distribution across the specimen, as demonstrated in Fig. 5a. The compressive strength was calculated using a formula based on the gross surface area of the concrete. Equation 1 show how to compute this number by dividing the failure load by the specimen's cross-sectional area.

$$\text{Compressive strength} = \frac{\text{Load}}{\text{Area}}(\text{N/mm}^2) \qquad (1)$$

J. Split Tensile Strength Test

The split tensile strength test, also known as the Brazilian test, is an indirect method used to determine the tensile strength of materials such as concrete. In this test, each specimen was subjected to a compressive force was applied to a cylindrical specimen until it split along a vertical plane, as illustrated in Fig. 5b. The standard specimen typically has a diameter of 150 mm and a length of 300 mm and is placed horizontally. The compressive force is applied diametrically, and once the force reaches the point of failure, the split tensile strength is calculated using the specimen's diameter, length, and the load at which it failed. Equation 2 is applied to determine the splitting tensile stress of concrete conforming to:

Split tensile strength = $^{2F}/_{\pi DL}$ (2)

Where F is the applied force (N), D is the diameter of a specimen (mm) and L is the length of the specimen (mm), respectively.

Fig. 3: Sieve shaker machine

Fig. 4: Slump and Consistency Test

Fig. 5a and 5b: Compression and Split tensile machine

III. RESULTS AND DISCUSSION

The results of laboratory experiments conducted on the concrete and its constituent materials are hereby presented and discussed.

A. Sieve Analysis

Fig. 6 depicts that the fine aggregates in this study were primarily river sand, with 93.6% passing through the 4.75 mm sieve according to ASTM C136 [28], indicating their suitability for concrete production. The coarse aggregates were mainly sized between 5–10 mm, maintaining a consistent particle size distribution that meets typical specifications for structural concrete. The particle size distribution curves exhibited a well-graded profile, fitting within Zone II standards for fine aggregates. This grading signifies that most aggregate particles are roughly uniform in size or within a narrow range, which is crucial for concrete mix design, as it leads to denser concrete, minimizes voids, and improves both workability and strength.

B. Oxide Composition

Table 3 presents that rice husk ash (RHA) contains 68.22% silica, surpassing ordinary Portland cement (OPC) at 21.28% and cassava peel ash (CPA) at 54.75%, indicating RHA's significant pozzolanic potential. CPA, with higher alumina (12.65%) than OPC (5.60%) and RHA (2.28%), enhances reactivity in cement, alongside the highest iron oxide content (5.83%). These results are comparable with findings reported by Singh & Singh [32]. Overall, both RHA and CPA are suitable for partial cement replacement, with RHA excelling in silica content with excellent reactivity and CPA offering a balanced oxide profile for enhanced pozzolanic activity in concrete.

C. The Consistency

The consistency of cement pastes with varying percentages of Cassava Peel Ash (CPA) and Rice Husk Ash (RHA) used as partial cement substitutes, ranging from 0% to 14%. At 0% replacement, both types have a consistency of 29%. As the percentage of pozzolan increases, a slight decline in consistency is noted, but not significantly enough to affect the workability of the paste. This trend is consistent with the findings reported by Sreeranjini [33]. The CPA blends demonstrate slightly higher fluidity and water demand compared to RHA blends. Overall, both RHA and CPA are identified as suitable supplemental cementitious materials, as they do not majorly alter paste consistency.

D. Setting Time

The result illustrated in Fig. 8 demonstrates that increasing Rice Husk Ash (RHA) and Cassava Peel Ash (CPA) as partial cement replacements extends both initial and final setting times of cement paste.

Particularly, CPA has a greater retarding effect. For a 14% replacement, initial setting times increase significantly from 53 to 121 minutes for RHA and to 126 minutes for CPA, while final setting times extend from 150 to 290 minutes for RHA and to 297 minutes for CPA. Indicating that its hydration rate is slower than that of the RHA based paste. These findings are consistent with observations reported by Zhang et al. [34]. Higher replacement levels (10.5–14%) require longer mixing, placing, and curing periods, while lower levels (3.5–7%) have minimal effects, allowing for typical concrete practices. RHA and CPA are effective cement substitutes, but CPA has a marginally higher retarding capacity due to slower pozzolanic reactivity.

E. Slum Results

Fig. 9 shows that the slump values of concrete containing different percentages of rice husk ash (RHA) and cassava peel ash (CPA) decrease as the pozzolan content increases from 0% to 14%. This reduction is attributed to the high surface area and porous nature of the ashes, which increase water demand. Consequently, additional water may be required to maintain the desired consistency. These findings highlight the significant influence of pozzolan content on the workability and overall engineering properties of concrete [35].

F. Compressive Strength

The compressive strength data for mixes with varying weight percentages of rice husk ash (RHA) and cassava peel ash (CPA) indicate that both pozzolanic materials achieve maximum strength at 7% cement replacement. At this level, RHA yields 24.67 N/mm² at 7 days and 35.45 N/mm² at 28 days, outperforming CPA (22.95 and 34.77 N/mm², respectively). Compared to the control (0%, 29.13 N/mm² at 28 days), RHA provides a 21.7% increase, while CPA gives a 19.4% increase. This trend aligns with the findings of Nduka et al. [36] and Konduru [37], who reported enhanced compressive strength at moderate pozzolan replacement levels. Beyond 7%, strengths decline, with 14% replacement resulting in lower strength than the control for both materials. Thus, 7% is the optimal replacement level, with RHA being more effective. Furthermore, CPA-blended concrete exhibited lower strength compared to RHA-blended concrete, likely due to its comparatively lower pozzolanic activity.

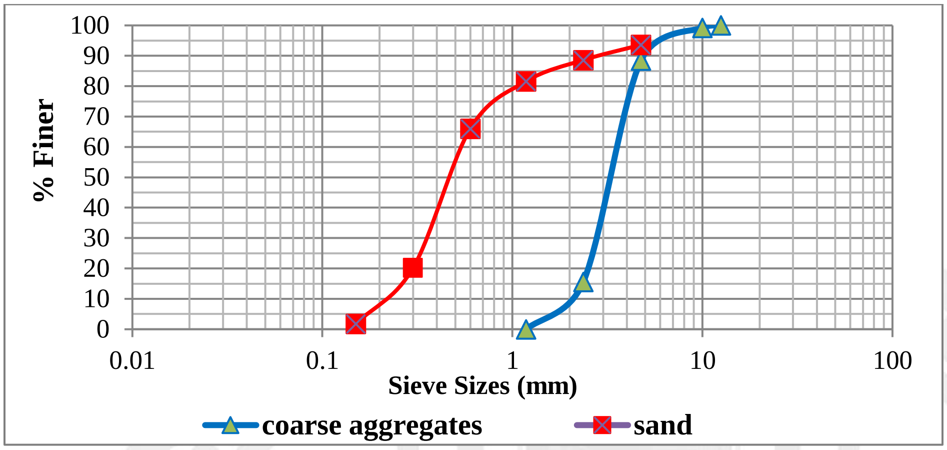

Fig. 6: Sieve analysis grading curve

Table 3: The essential components of oxides.

Materials	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Lol
Cement	21.28	5.60	3.36	64.64	2.06	2.14	0.72	0.05	0.64
RHA	68.22	2.28	0.54	0.37	3.59	0.61	3.14	3.78	13.33
CPA	54.75	12.65	5.83	10.41	0.15	0.44	12.09	0.07	2.81

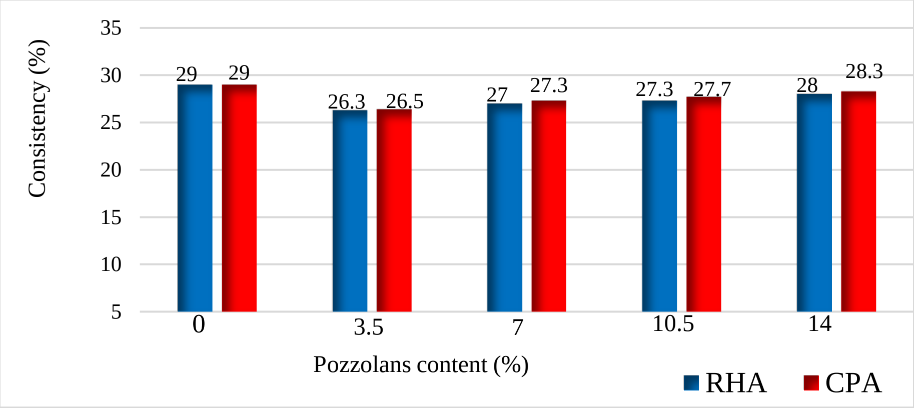

Fig. 7: Normal Consistency

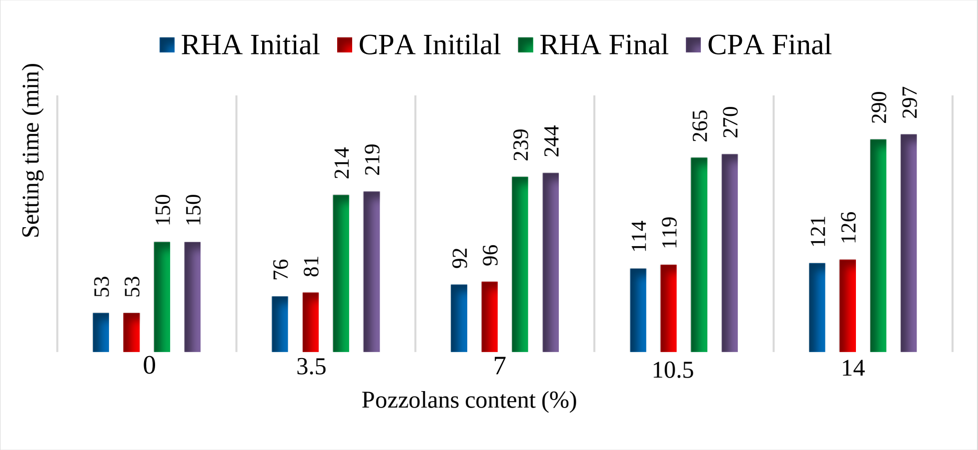

Fig. 8: The Setting Time Results

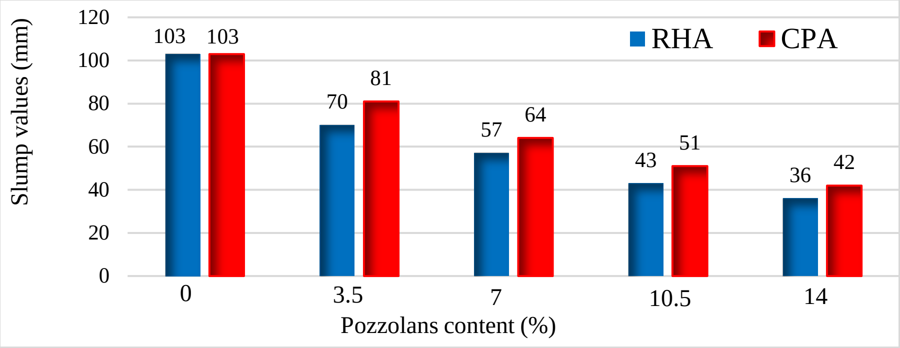

Fig. 9: The Slum Values

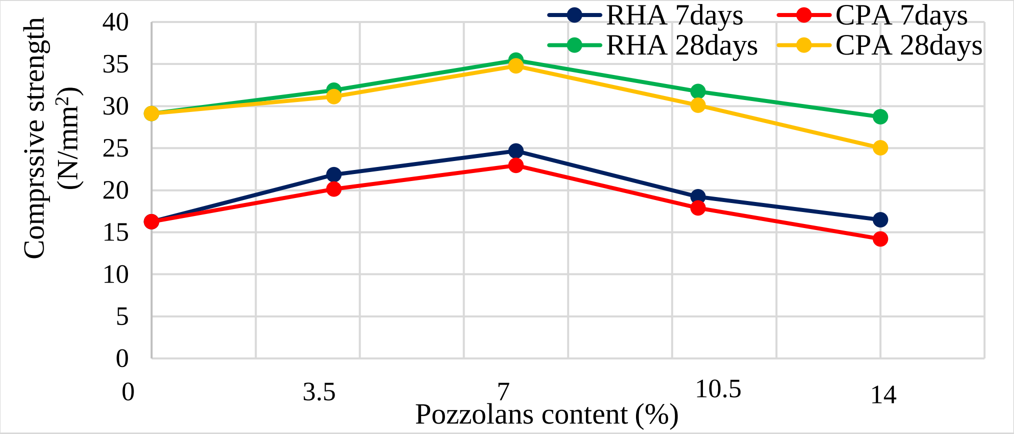

Fig. 10: Compressive Strength

G. *Split Tensile Strength*

Fig. 11 shows that the split tensile strength of concrete with RHA and CPA first increases with ash content up to 7%, then decreases at 14%. Compressive strength declines notably with increased ash content, especially at 7 and 28 days of curing. At 28 days, the split tensile strengths for concrete with 0%, 3.5%, 7%, 10.5%, and 14% RHA are 3.06, 3.88, 4.02, 2.63, and 1.82 N/mm², respectively; for CPA, they are 3.64, 3.97, 2.75, and 1.96 N/mm². These results are consistent with the findings of Odeyemi et al. [38], who reported that moderate replacement levels of agricultural pozzolans enhance the tensile performance of concrete. The optimum split tensile strength of 4.02 N/mm² for RHA and 3.97 N/mm² for CPA occurs at 7% pozzolan content, both exceeding the control strength of 3.06 N/mm², while CPA's contribution is hindered by lower pozzolanic properties relative to RHA.

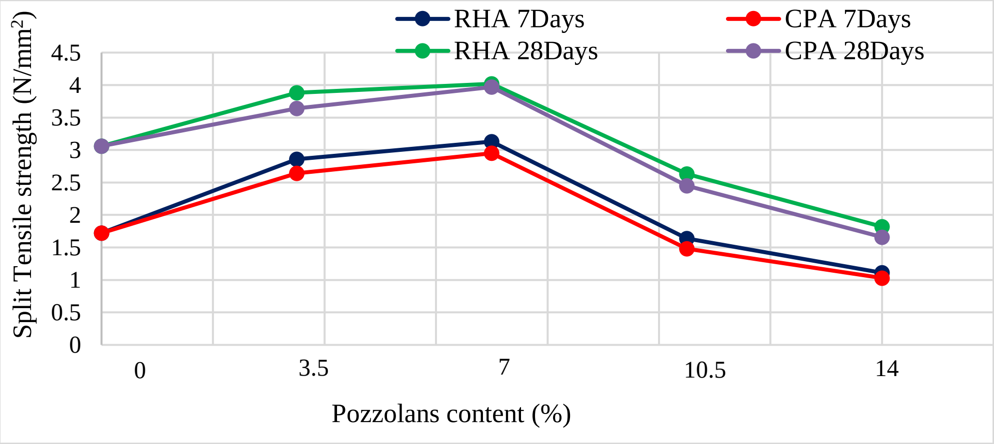

Fig. 11: Splite Tensile Strength

IV. CONCLUSION

Based on the experimental work performed in this study, the following conclusions are drawn: The results indicate that the aggregates are well-graded, suggesting that most particles are of similar size or fall within a narrow size range (Zone II). The ashes contain a total of SiO2, Al2O3, and Fe2O3, accounting for over 70% of the oxides, complies with ASTM C 618 standards for effective pozzolanas. A consistent decline in slump values was observed with the increased incorporation of RHA and CPA, signifying a reduction in workability attributable to the fine particle size and elevated water absorption characteristics of these pozzolanic materials.

The partial replacement of Ordinary Portland Cement (OPC) with Rice Husk Ash (RHA) and Cassava Peel Ash (CPA) up to 7% enhances concrete's mechanical properties. Compressive strengths reached 35.45 N/mm² for RHA and 34.77 N/mm² for CPA. While split tensile strengths were 4.02 N/mm² for RHA and 3.97 N/mm² for CPA, both strengths surpassed the control strength. CPA's contribution is somewhat limited due to lower pozzolanic reactivity.

In conclusion, a 7% replacement level is optimal for both ashes, maximizing mechanical properties. RHA is more effective than CPA in enhancing compressive and split tensile strengths, making it the preferred pozzolanic material for partially replacing OPC in structural concrete.

V. RECOMMENDATION

Due to the outcome of the laboratory tests conducted, the following are recommended: To address reduced slump values, the use of plasticizers or other water-reducing admixtures should be explored to improve the workability of RHA- and CPA-modified mixes. Proper burning between 500 –700°C, grinding, and sieving procedures for RHA and CPA should be standardized to ensure consistent quality, pozzolanic reactivity, and performance in concrete production. While laboratory-derived findings are encouraging, the execution of prolonged in-situ trials is advocated to substantiate the long-term performance characteristics. Government agencies, research institutions, and construction sectors should promote the use of RHA and CPA by supporting local production and integrating these materials into sustainable building policies.

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