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Research Article

An Investigation on Durability Properties of Concrete From Selected Argo-Based Materials as Pozzolanas

Wilson Uwemedimo Nyong[1], Nuhu Abubakar Eneye[2], Adeyemi Festus Oluwasogo[3], Odeyemi Samson Olalekan[4], Nurudeen Yusuf[*,5]

[1,2]Department of Civil Engineering, Nigeria Defence Academy, Kaduna State, Nigeria
[3]Department of Civil Engineering, Ajayi Crowther University, Oyo, Oyo state, Nigeria.
[4]Department of Civil and Environmental Engineering, Kwara State University, Malete, Nigeria.
[5]Department of Civil Engineering, Usmanu Dan Fodiyo Univsersity Sokoto, Nigeria.

Keywords

Agricultural materials, Agro-based pozzolans, Concrete durability, Pozzolanic materials, Rice Husk Ash, Supplementary cementitious materials, Sustainable construction.

Abstract

This research examines the properties and durability of green and hardened concrete incorporating selected agro-based pozzolans: rice husk ash, locust bean pod ash, sugarcane bagasse, soya bean pod ash, and maize cob ash. These pozzolans were calcined and analyzed using X-ray fluorescence (XRF) to replace cement in concrete cubes, which were cured over 7, 14, 21, and 28 days. The findings indicate that all pozzolans meet ASTM C618 requirements. Specifically, rice husk ash, sugarcane bagasse, and maize cob ash qualify as Class C pozzolana, while locust bean ash and soya bean ash are classified as Class F. The inclusion of these pozzolans increased the consistency, initial, and final setting times of cement. Consistencies ranged from 33% to 39.5%, with initial setting times from 74 to 225 minutes and final setting times from 152 to 400 minutes. The selected pozzolans slightly reduced the workability of the concrete but enhanced its durability, significantly improving resistance against aggressive media, including H2SO4, NaCl, and wastewater, at a 10% replacement level. This study highlights the potential of agro-based pozzolans as sustainable alternatives to conventional cement, offering environmental benefits and improving concrete performance in harsh conditions.

1. Introduction

In the construction industry, concrete is one of the most crucial building materials. Given its many benefits, including excellent durability, outstanding mechanical properties, affordability, and setting appropriateness, concrete has been a crucial building material for infrastructure and industrial development [1]. A valuable building material, concrete is waterproof, fireproof, and reasonably priced to cast and handle. Concrete's surface continuity allows it to be used as a binder with other materials.

It is well recognized that the curing environment, together with the kind and amount of components, affects the concrete's compressive strength. [2]. According to [3], the ingredients of concrete include cement, water, and coarse and fine aggregate; these ingredients must be workable, chemically resistant, have low permeability, endure wear, and not freeze. Typically, cement serves as the "glue" that gives structures their strength.

On the other hand, concrete's durability performance is critical for a structure's serviceability life, especially when it comes to soil/water interaction at sub-structures; when harmful elements contained in soil or groundwater attack concrete, its strength and durability deteriorate; a drop in alkali-silica reactivity is observed. However, cement is considered a limiting factor due to its increasing cost, complex production process, and associated release of greenhouse gases—one of the main causes of global warming [1]. Efforts have been made to find alternatives, such as locally available materials that have the same or comparable qualities as partial replacements, with some success.

To withstand harmful elements like sulphate assault, acid attack, carbonation, and chloride ion penetration, among others, the concrete needs to be long-lasting. For low-income people who want to start building, the cost and availability of special cement appropriate for these aggressive media constitute a disadvantage. The level of attack by harmful substances and some aggressive media, particularly to conventional Portland cement during sub-structural work, results in the collapse of the building. However, a significant factor in concrete's resilience to hostile media is its durability, which can be linked to the interaction between soil and water: According to the code [4] aggressive mediums are harmful compounds that have a major effect on the durability of hardened concrete.

The pozzolanic reaction of the majority of the agro-base materials under investigation revealed their reaction with the release of carbon and hydrogen from the cement hydration process, which results in additional product that fills the cavity and lowers the average pore size, making the concrete denser and more resistant to corrosion-causing chloride ions [5]. Prior studies have unequivocally demonstrated that certain supplementary cementitious materials (SCMs) are effective in meeting the requirements of durable concrete, which promotes the use of blended cements in practically every region of the world today.

Rice husk ash (RHA), cowpea ash [1,6,7,8,9], locust bean ash [10], and [11] all have some pozzolanic qualities, according the following research. Rice husk ash, or RHA, has also been extensively studied for its effectiveness as an extra cementitious element in high-performance concrete applications, showing significant improvements in durability, reduced permeability, and enhanced resistance to chemical attacks [12].

Sugarcane bagasse's pozzolanic capabilities have recently been tested in various parts of the world and have been found to improve concrete's compressive strength and watertightness in some replacements [8]. Additionally, developments in the application of pozzolanic materials, including agro-waste ashes, demonstrate how they can enhance the mechanical qualities, longevity, and

*Corresponding Author: ny.kwami@yahoo.com
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environmental sustainability of concrete, especially in harsh locations [13].

This study aims to investigate the durability life (serviceability) properties of green and hardened concrete made with some selected agro-based prozzolans, such as rice husk ash, locust bean pod ash, sugarcane bagasse, soya bean pod ash, and maize cob ash, exposed to various aggressive media (Sewage, 0.5M H2SO4, and 0.5M NaCl). This is done considering the fluctuating and high price of Portland cement and, second, a method of reducing the threat of environmental pollution from the massive waste generated from rice mills, sugar cane bagasse, maize processing, and bean processing farms with due regard to animal feedings.

This will have a significant impact on lowering the price and accessibility of the specialty cement required to improve the durability of concrete in the known hostile media. Additionally, the application of these pozzolanic materials would contribute to lowering the environmental risk passed by constant disposal.

2. Materials and Methods

2.1. Materials

Portland Limestone Cement (CEM II/AL, 42.5N) was used in this research, manufactured by Dangote Cement Company. Crushed rock with maximum aggregate size of 20mm was used as coarse aggregate), while clean river sand was used as fine aggregate. Potable water obtained from Civil Engineering Laboratory, Nigerian Defence Academy, Kaduna was used to produce the concrete. White Cowpea (Beans) Husk was collected at a central location, Hayin damani junction, along Nnamdi Azikiwe express way, Kaduna. These cowpeas are sold in sampling bags at retail prices (bulk samples and grab samples). Rice Husk was collected from an existing small scale rice processing mills at Kakuri, Kaduna, while the Locust bean tree pod was collected from Tsami village in Zaria Local Government, Kaduna state Nigeria. The Soya bean pods waste was collected at the farmers harvesting point from an existing soya bean farm accessible and with permission, while Maize cob waste was collected from maize farm at the point of maize processing also with permission.

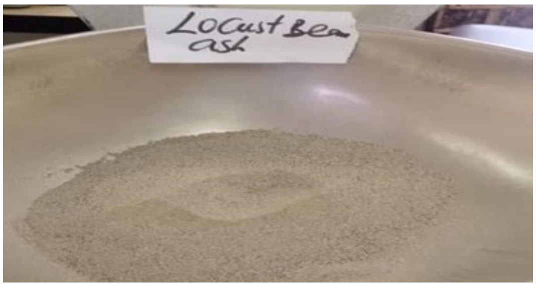
2.2. Methods

2.2.1. Production of Ash

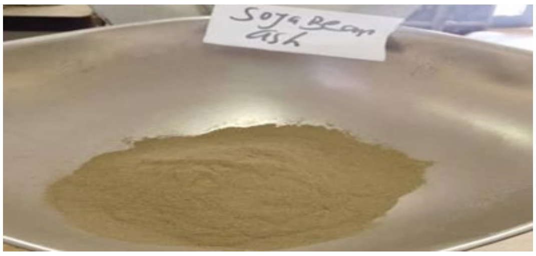
Cowpea (bean) husks, rice husks, maize cob debris, soy beans, and locust bean pods were all burned in an incinerator set to a regulated temperature of 500–7000C. The ashes were grounded and sieved using a standard sieve of 75 microns to produce finer ash as shown in figures 1a to 1d.

(a)

(b)



(c)



(d)

Figure 1. (a)Cowpea ash, (b)Rice husk ash, (c) Locust bean ash, (d)

2.3. Materials Properties and Characterization

2.3.1. X-ray fluorescence (XRF) on all the ash and cement

The oxide composition analysis of Rice husk ash, cowpea(beans) ash, locust bean pod ash, maize cob ash and soya beans ash and cement were carried out at KADPOLY. X2 RANGER model X-ray Fluorescence (XRF) equipment made by BRUKER was used for the test. The test was conducted in accordance with the code [14].

2.3.2. Specific Gravity

The specific gravity test on Rice husk ash, cowpea(beans) ash, locust bean pod ash, maize cob ash and soya beans ash, fine aggregate and coarse aggregate was conducted and computed using Equation 1. However, the specific gravity of cement was determined using the laid down procedure in the code [15], where kerosene was used as presented in Equation 2 and 3 to avoid cement weight lost that could occur if water is used.

$$G_s = \frac{(w2-w1)}{(w4-w1)-(w3-w2)} \quad (1)$$

$$G_{sk} = \frac{(w2p-w1p)}{(w4c-w1p)-(w3p-w2p)} \quad (2)$$

$$G_{sc} = \frac{(w2c-w1p)Gsk}{(w4c-w1p)-(w3c-w2c)} \quad (3)$$

Where; w_1 = weight of empty bottle, w_2 = weight of empty bottle plus sample (MHA, Sand or Coarse aggregate), w_3 = weight of empty bottle plus sample plus water, w_4 = weight of empty bottle plus water, w_{1p} = weight of empty pycnometer, w_{2p} = weight of empty pycnometer plus kerosene, w_{3p} = weight of empty pycnometer plus kerosene plus water w_{4p} = weight of empty pycnometer plus water, w_{2c} = weight of empty pycnometer plus cement, w_{3c} = weight of empty pycnometer plus cement plus kerosene w_{4c} = weight of empty pycnometer plus kerosene, G_s = specific gravity of aggregate, G_{sc} = specific gravity of cement, G_{sk} = specific gravity of kerosene.

2.3.3. Particle Size Distribution

The particle size distribution of oven dried fine and coarse granite aggregates was determined respectively in accordance with the code [16] using the set of standard sieves. The mass retained on each sieve was measured and percentage passing each sieve calculated as the differences between the cumulative percentage mass retained and 100. The particle size distribution test of Rice husk ash, cowpea(beans) ash, locust bean pod ash, maize cob ash and soya beans ash was carried out using hydrometer method. 50 g of various ash passing 75 µm sieve size, mixed with water to give 1000 ml mixture in measuring cylinder and vibrated thoroughly until uniform mixture was achieved. The hydrometer readings (R) were recorded at time interval 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480 and 1440 minutes. The percentage of all ash particle sizes (diameter) was computed using Equation 4 and 5.

$$D = \frac{18\,\eta L}{(Gs-1)g\rho t} \quad (4)$$

$$P = \frac{100R'a}{M} \quad (5)$$

Where, ŋ = viscosity of water (g-sec/cm^2), D = particle diameter (mm), t = hydrometer time reading(sec), L = effective depth (mm), g = 9.81 m/s^2, Gs = particle specific gravity, ρ = density of water, P = Passing (%), a = correction factor = 0.5, R' = corrected hydrometer reading, M = mass of dry soil (g)

2.3.4. Aggregate Crushing Strength of Coarswe Aggregates

The Aggregate crushing strength of coarse aggregate was carried out in accordance with the code [17].

2.3.5. Fineness Modulus

Fineness modulus was determined for the fine and coarse aggregate in accordance with [15]. Fineness modulus is an index number which represents the mean particle size and was computed by equation 6.

$$\text{Fineness modulus} = \frac{\text{sum of cumulative retained by each sieve}}{100} \quad (6)$$

2.4. Effect of Ash on Cement Paste

2.4.1. Consistency Test

The Vicat apparatus was used to conduct this test in compliance with the code [18]. In order to determine the impact of rice husk ash, cowpea (beans) ash, locus bean pod ash, maize cob ash, and soya bean ash on the consistency of cement paste, the proportions of rice husk ash, cowpea (beans) ash, locus bean pod ash, maize cob ash, and soy bean ash in the cement paste were measured by weight in the order of 10 and 15%.

The consistency of the binder is the amount of water that provides standard paste and is given as that percentage of water that allows penetration of 10 mm diameter plunger to a depth between 5 to 7mm above the mould base.

2.4.2. Initial and Final Setting Time

Using the Vicat equipment, this test was conducted in compliance with the code [18]. The impact of rice husk ash, cowpea (beans) ash, locust bean pod ash, maize cob ash, and soy bean ash on cement paste setting times was investigated by substituting cement with rice husk ash, cowpea (beans) ash, locus bean pod ash, maize cob ash, and soy bean ash in proportions of 10 and 15% by weight in the cement paste made with the amounts of water that provide standard consistency, respectively.

The initial setting time is the amount of time measured in minutes from the point at which water was added to the binder during mixing until a 1 mm diameter needle penetrated the binder at a depth of 5 to 7 mm above the mold base, and the final setting time is the amount of time measured until the annular-attached needle failed to leave an impression on the paste.

2.5. Concrete Production

2.5.1. Concrete Mix Design

The British method of concrete mix design, popularly referred to as the "DoE method" and currently referred to as building research establishment (BRE), was adopted for this research work for grade 25 concrete and water – cement ratio not more than 0.6. The computation for the specified mix was carried out using MACMIX 2017. MACMIX 2017 is concrete mix design software developed based on building research establishment (BRE) method.

2.5.2. Mixing, Casting and Curing of Concrete

Using the hand mixing method and the established protocol outlined in the code [19], fresh concrete was created. Using the water-to-cement ratio derived from the mix design, cement, sand, and crushed rock were weighed out and combined evenly. Using the same process and treatment, new concrete was created with 0, 10%, and 15% replacement of cement by weight, respectively. After the concrete's workability was assessed using the slump and compacting factor tests, it was cast in oiled and clean molds to determine its compressive strength. Following a 24-hour hardening time, the concrete was demolded and submerged in a water-filled curing tank until the testing period ended. Figure 2 illustrates the material batching procedure.

Figure 2. Batching of Material

2.5.3. Properties of fresh concrete (workability test)

The workability of the concrete using slump test method was carried out in accordance with [20]. To conduct slump test, a truncated steel cone 30cm high, 20cm diameter at the opened base and 10cm diameter at the opened top was used. The cone was held firmly in position on a solid, flat, impermeable and clean surface. The cone was filled with freshly prepared concrete in four equal layers with each layer being given 25 blows of the ramming rod and the surplus concrete around the cone was wiped off the truncated cone. The extent by which the concrete drops after careful removal of the cone was measured. This value is called the 'slump. Figure 3 shows slump test.

Figure 3. Slump test

2.5.4. Preparation of aggressive media

The aggressive media used in accessing durability properties of agro-based pozzolans are.

- Sewage: wastewater regenerated because of domestic activities.
- 0.5M sulphuric Acid (H_2SO_4): this was prepared using formular; $C_1V_1 = C_2V_2$ using concentrated sulphuric acid and distilled water. Where C_1 = concentration of sulphuric Acid, V_1 = volume of sulphuric acid, C_2 = concentration of distilled water, V_2 = volume of distilled water.
- 0.5M NaCl (sodium chloride): this was prepared using the same approach; $C_1V_1 = C_2V_2$.

The volume of curing water/media was worked at to extract volume through material balance in the laboratory.

2.5.5. Properties of hardened concrete Compressive strength

100 x 100 x 100 mm cubes were used in the test to replace 0, 10, and 15% of the cement by weight in the concrete, respectively. Prior to the compressive strength test, the density of every cube was ascertained. At 7, 14, 21, and 28 days of age, the compressive strength test was conducted in accordance with code [21]. The concrete's compressive strength was calculated using Equation 7.

$$f_c = \frac{F}{A} \tag{7}$$

Were.
fc = compressive strength in N/mm^2, F = crushing load in N, A = section area of cylinder in mm^2

2.5.6. Durability test Effect of hydrogen tetraoxosulphate (VI) acid (H2SO4) on concrete

Representative specimen of concrete cured for 28 days containing 0, 10 and 15 % proportion of Rice husk ash, cowpea(beans) ash, locust bean pod ash, maize cob ash and soya beans ash by weight of cement respectively was fully submerged in 5 % concentration of H2SO4 solution. Each specimen after cured for 28 days was air dried to remove traces of water, weighed and dipped in 5 % H2SO4 concentrated solutions respectively. The specimens were allowed in the solution thereafter reweighed after air dried. Figure 4 shows the samples in the acid curing solution for all the curing days. The effect of H2SO4 solutions on the durability of the various concrete mixes was determined in terms of percentage weight loss as given in Equation viii.

$$\text{Percentage weight loss} = \frac{\text{Loss in weigth}}{\text{Original weigth}} \times 100 \tag{8}$$

Figure 4. Concrete Samples inside Acidic tank

2.5.7. Effect of Wastewater on concrete

Representative specimen of concrete cured for 28 days containing 0, 10 and 15 % proportion of Rice husk ash, cowpea(beans) ash, locust bean pod ash, maize cob ash and soya beans ash by weight of cement respectively was fully submerged in wastewater. Each specimen after cured for 28 days was air dried to remove traces of water, weighed and dipped in wastewater respectively. The specimens were allowed in the wastewater thereafter reweighed after air dried. The effect of NaCl solutions on the durability of the various concrete mixes was determined in terms of percentage weight loss as given in Equation 8.

3. Results and Discussion

3.1. Materials Test Results

3.1.1. Chemical Properties of Binders

Table 1 displays the findings of the oxide composition of the binders (cement, soy bean ash, cowpea bean ash, locust bean pod ash, maize cob ash, and rice husk ash). The cement contains CaO + SiO2: 84.042 (≥ 50%), CaO/SiO2: 3.166 (≥ 2%), SO3: 2.1 (≤ 3.5%), MgO: 2.105 (≤ 5.0%), and Cl: 0.098 (≤ 0.1%), according to the oxide composition shown in the table. This shows that the cement met the [22], recommended limit for the CEM II 42.5N class.

Furthermore, for rice husk, cowpea ash, locust bean ash, maize cob ash, and soy bean ash, the sum of SiO2 + Al2O3 + Fe2O3 is 69.9, 65.3, 78.3, 69.52, and 77.39%, respectively. These values are all higher than the standard (≥ 50%) [22]. However, because the conditions were met, locust bean ash and soy bean ash may be considered class F pozzolana, whereas rice husk ash, cowpea ash, and maize cob ash could be considered class C pozzolana.

Table 1. Oxide Composition of Binder

Oxides	RICE HUSK ASH (%)	COWPEA ASH (%)	LOCUST BEAN ASH (%)	MAIZE COB ASH (%)	SOYA BEANS ASH (%)	CEMENT (%)
SiO_2	67.26	41.641	56.08	63.59	49.02	20.171
Al_2O_3	1.93	13.682	14.93	5.93	25.24	4.101
Fe_2O_3	0.68	10.066	7.28	-	3.13	3.899
CaO	0.38	20.542	2.09	3.48	26.0	63.871
MgO	3.49	2.001	3.09	2.29	-	2.105
SO_3	0.63	1.401	-	1.18	0.85	2.1
Na_2O	3.75	0.234	0.18	3.75	-	0.011
K_2O	3.16	1.135	2.0	8.46	22.9	0.938
P2O5	0.18	1.879	0.23	2.48	5.98	0.117
TiO_2	0.09	0.086	-	0.63	0.79	0.209
MnO	0.15	0.287	-	0.15	0.389	0.036
LoI	13.38	0.001	10.63	8.57	-	2.093

3.1.2. Specific Gravity Test

Table 2 reports the specific gravities of the materials. The cement's specific gravities fall between the 3.10 to 3.16 range that the code [23] recommends. In comparison to cement, a less volume of agro-based ash is needed to obtain the same mass since rice husk, cowpea ash, locust bean ash, maize cob ash, and soy bean ash are less dense than cement. For average weight aggregates, the specific gravities of fine and coarse aggregates are within the range of 2.6 to 3.0 and 2.4 to 2.8, respectively, as stated in the code [24].

Table 2. Specific Gravities of Concrete Materials

Materials	Values
Cement	3.152
Rice husk Ash	2.22
Cowpea Ash	2.15
Locust Bean Ash	2.61
Maize Cob Ash	1.16
Soya Bean Ash	2.7
Fine Aggregate	2.69
Coarse Aggregate	2.92

3.1.3. Particle Size Distribution

According to the code [26] grading limits for fine aggregates, the fine aggregate's particle size distribution, as shown in Figure 5, indicates that it has a fineness modulus of 2.57 and is classified as zone II. The coarse aggregate has a dominant particle size of 20 mm, with only 71.82 and 21.96 percent of the particles retained and passing through a 14 mm sieve, respectively, according to the results of the particle size distribution of the coarse aggregates as shown in the figure. Therefore, it is possible to consider the coarse aggregate to be 20 mm in size. Furthermore, the coarse aggregate has a fineness modulus of 3.0.

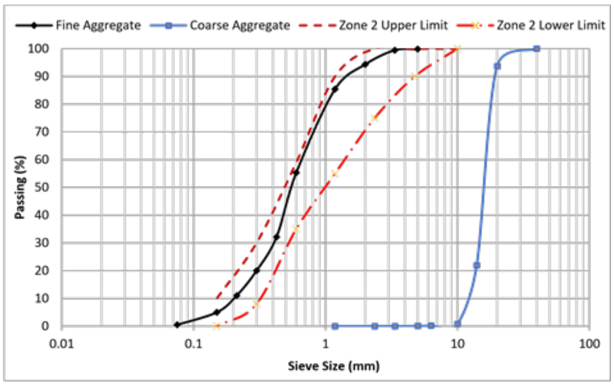


Figure 5. Particle Size Distribution of Fine and Coarse Aggregates

3.1.4. Aggregate Crushing Strength of Coarse Aggregate

The aggregate crushing strength was 24.7%. The crushing value result shows that the aggregate is strong since it is < 45% as specified by the code [26]. The experimental value obtained was within the expected range. Typical aggregate crushing values for 19 mm were within the range.

3.1.5. Effects of Selected Agro-Based Pozzolans on Cement Paste

Table 3 lists the cement, rice husk ash, cowpea ash, locust bean ash, maize cob ash, and soy bean ash consistency, beginning setting time, and final setting time. The range of consistencies is 33% to 39.5%. This implies that as the replacement content of cement pastes increases, so do their consistencies. The increased loss of ignition (LOI) in comparison to cement may be the cause of this rise. This could also be the result of a lower specific gravity in contrast to cement. This result is consistent with observations [1].

Table 3. Normal Consistency and Setting time of OPC blended Agro-based pozzolans

Replacement of OPC with Agro-base pozzolans	Consistency (%)	Initial setting time(Minutes)	Final setting time (Minutes)
Cement	28	74	152
10% Rice husk Ash	33	92	180
15% Rice husk Ash	36	102	200
10% Cowpea Ash	33	100	225
15% Cowpea Ash	35	125	255
10% Locust Bean Ash	30	114	191
15% Locust Bean Ash	32	156	212
10% Maize Cob Ash	34	175	306
15% Maize Cob Ash	37	183	314
10% Soya Bean Ash	38	200	350
15% Soya Bean Ash	39.5	225	400

3.1.6. Effects of Selected Agro-Based Pozzolans on Workability

To evaluate the impact of the chosen agro-based pozzolans on the characteristics of fresh concrete, the workability of the concrete was tested using the slump test method in compliance with the code [20]. The outcome, as shown in Figure 6, indicates that for all of the chosen agro-based concretes, the workability of the fresh concrete decreases as the replacement dosage increases. Because the pozzolans absorb a lot of water, the mix may become less fluid, which would reduce workability. Furthermore, the decrease may also be explained by the mix's decreasing density as its agro-based portion rises [1].

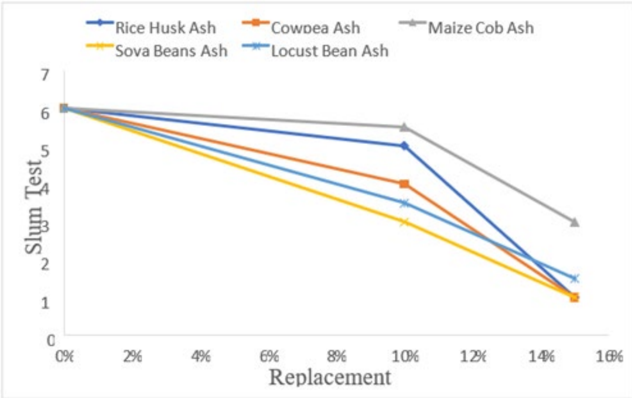


Figure 6. Workability of Selected Agro-based Concrete

3.1.7. Effects of Selected Agro-Based Pozzolans on the Density of Concrete

Figures 7 to 9 illustrate how specific agro-based pozzolans affect concrete density. As the chosen agro-based pozzolans content rises in all three solutions (H2SO4, NaCl, and wastewater), the concrete's density falls. The consequences of substituting a small volume of cement of same weight with a significant volume of certain agro-based pozzolans in concrete may be the cause of the density decrease.

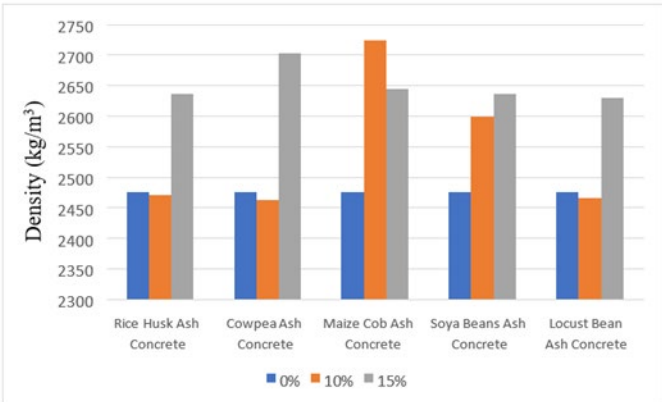


Figure 7. Effects of H2SO4 on Density of Concrete

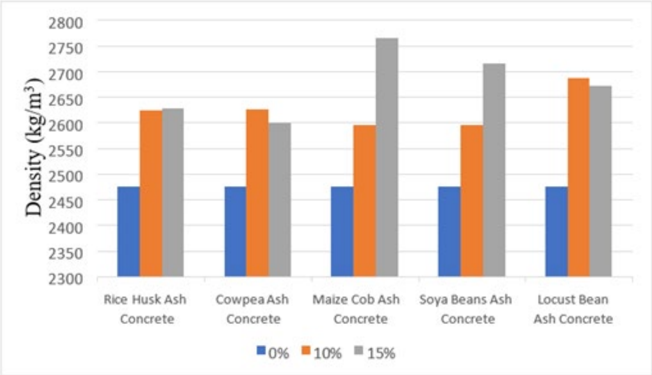


Figure 8. Effects of NaCl on Density of Concrete

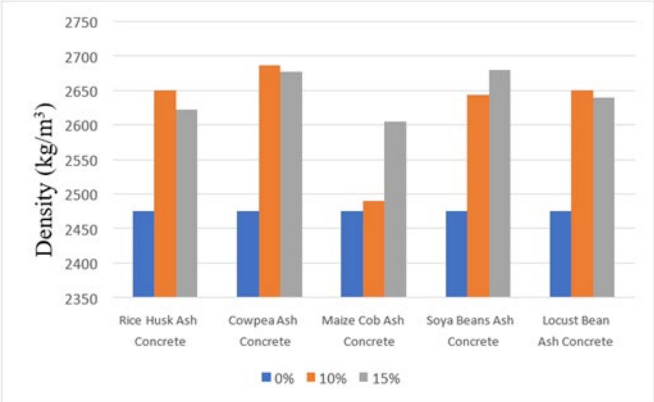


Figure 9. Effects of wastewater on Density of Concrete

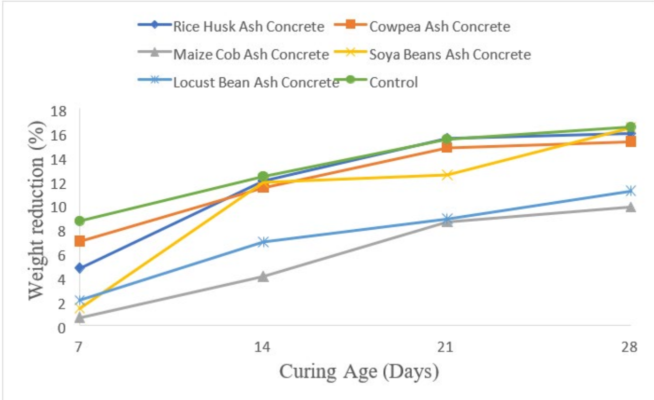


Figure 10. Effects of H2SO4 on weight of selected Agro-base concrete

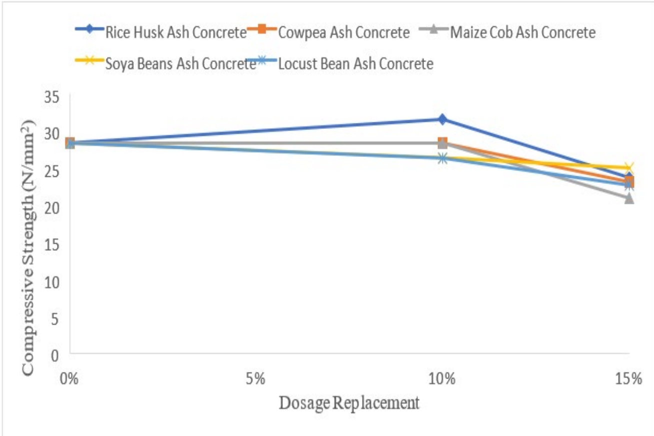


Figure 11. Effects of H2SO4 on Compressive Strength of selected Agro-base concrete

3.2. Effect of Agro-Base Pozzolans on the Durability

3.2.1. The Effect of H_2SO_4 on the Durability of Concrete in Acid

The effect of 5 % concentration solution of H2SO4 on selected agro-based pozzolans - concrete is shown in Figures 10 and 11, where Figure 10 illustrates the percentage weight reduction due to sulphuric acid exposure, highlighting the enhanced durability of concrete with agro-based pozzolans compared to control samples and Figure 11 shows compressive strength changes under acidic conditions, demonstrating improved resistance in rice husk ash and cowpea ash concrete blends. It is clear from the Figure that sulphuric acid decreases the weight of concrete. The decrease in weight (%) can possibly be attributed to the large amount of CaO in the Portland cement and its hydration products Ca (OH)2, which is primarily responsible for the poor resistance of concrete exposed to acidic attack. However, concrete incorporating agro-base pozzolans have less CaO and with reduced Ca (OH)2 in the products of hydration, hence the improvement of the durability of the concrete [1]. However, the attack by sulphate reduces with rice husk ash concrete, cowpea ash concrete and Maize cob ash concrete as shown in Figure 11. The reason for the improvement could be attributed to the increase in silica content in the concrete.

3.2.2. The Effect of NaCl on the Durability of Concrete in Acid

The effect of 5% concentration solution of NaCl on the selected agro-base pozzolans - concrete is shown in Figures 12 and 13, in which Figure 12 presents weight reduction due to sodium chloride exposure, indicating better performance of maize cob ash concrete in resisting salt-induced deterioration and Figure 13 details the compressive strength variations in concrete exposed to sodium chloride, where locust bean ash exhibited moderate resistance. It is clear from the Figures that NaCl decreases the weight of concrete. The percentage decrease in weight (%) can be attributed to the large amount of CaO in the Portland cement and its hydration products Ca (OH)2, which is primarily responsible for the poor resistance of concrete exposed to acidic attack. From the Figure 12, it means maize cob ash offers the least weight loss in NaCl solution compared to all the pozzolans considered and obviously, none of the pozzolans proffers a solution of durability in NaCl medium.

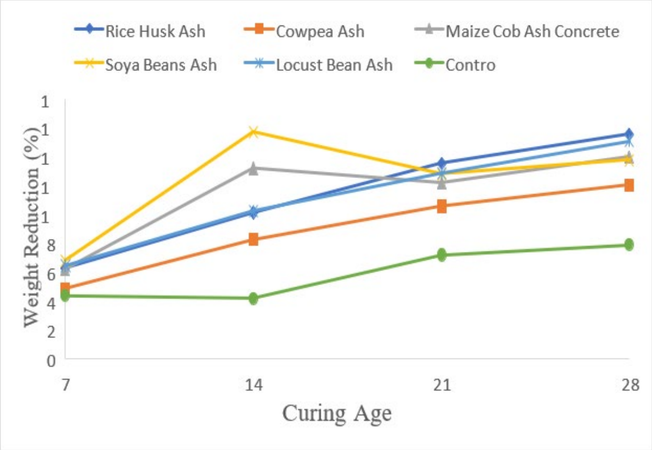


Figure 12. Effects of NaCl on weight of selected Agro-base concrete

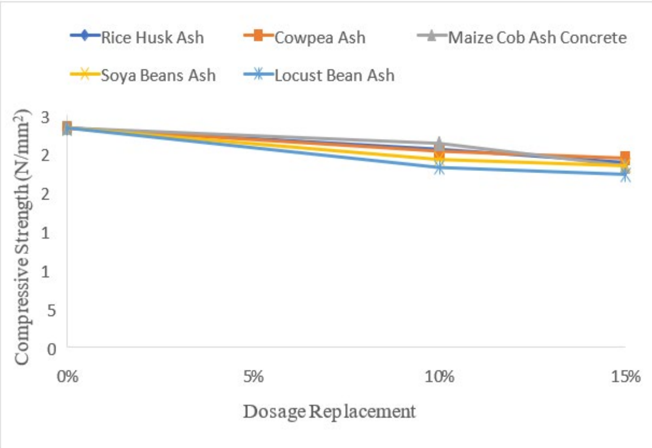


Figure 13. Effects of NaCl on Compressive Strength of selected Agro-base concrete

3.2.3. The Effect of Wastewater on the Durability of Concrete in Acid

The effect of wastewater on the selected agro-base pozzolans - concrete is shown in Figures 14 and 15, where Figure 14 demonstrates weight reduction in concrete due to wastewater exposure, with rice husk ash mixtures showing minimal weight loss. It is clear from the Figure that wastewater decreases the weight of concrete.

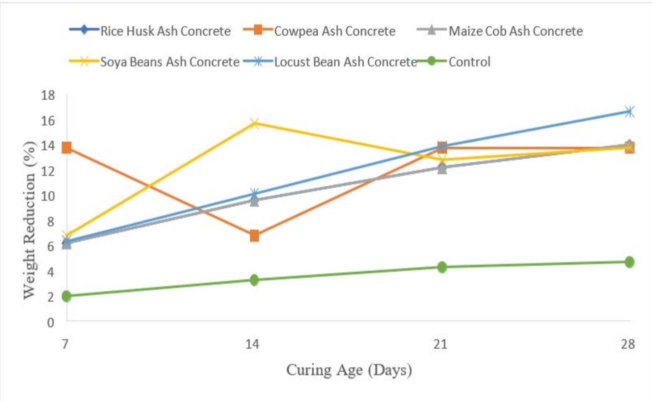


Figure 14. Effects of Wastewater on weight of selected Agro-base concrete

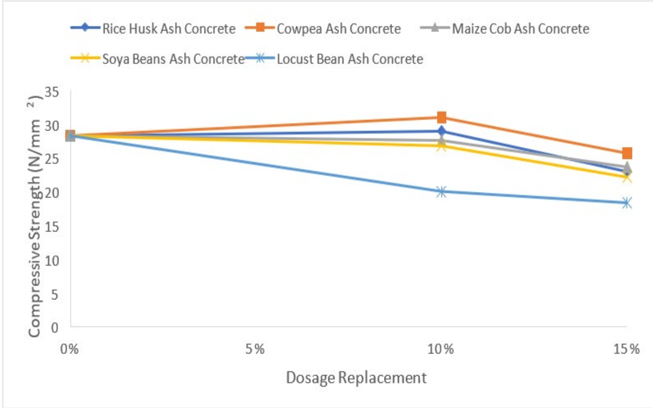


Figure 15. Effects of Wastewater on Compressive Strength of selected Agro-base concrete

3.3. Analysis of Compressive Strength Result Agro-Based Pozzolan

Two-way analysis of variance tests was carried out to determine the level of significance of the percentage replacement of selected Agro-base pozzolan on the compressive strength of the concrete and the significance each of the Selected Agro-base pozzolan on the compressive strength of the concrete. The results are presented in tables 4 - 6.

The result shows that the effect of percentage replacement of selected Agro-base pozzolan and significance of each of the selected Agro-base pozzolan on the compressive strength after immersed in H2SO4 after 28 days was statistically significant, (FCAL = 106.4 > FCRIT = 3.84) for effect of the selected pozzolans while (FCAL = 7.9 > FCRIT = 4.5) for percentage replacement. Although it is more pronounced for the Effect of selected agro-base pozzolans than percentage replacement.

The result shows that effect of percentage replacement of Selected Agro-base pozzolan and significance of each of the selected Agro-base pozzolan on the compressive strength after immersed in NaCl after 28 days was statistically significant, (FCAL = 296.1 > FCRIT = 3.84) for effect of the selected pozzolans while (FCAL = 12.2 > FCRIT = 4.5) for percentage replacement. Although it is more pronounced for Effect of selected agro-base pozzolans than percentage replacement.

Table 4. Two-Factor without Replication for durability of concrete immersed in H_2SO_4

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
	3	0.25	0.083333	0.005833
Rice Husk Ash Concrete	3	83.4	27.8	15.79
Cowpea Ash Concrete	3	79.6	26.53333	9.363333
Maize Cob Ash Concrete	3	77.5	25.83333	18.25333
Soya Beans Ash Concrete	3	79.5	26.5	2.92
H2SO4	5	113.2	22.64	160.178
	5	114.5	22.9	165.92
	5	92.55	18.51	107.4255

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1702.09	4	425.5225	106.3673	5.72E-07	3.837853
Columns	60.661	2	30.3305	7.581677	0.014228	4.45897
Error	32.004	8	4.0005			
Total	1794.755	14				

Table 5. Two-Factor without Replication for durability of concrete immersed in NaCl

Anova: Two-Factor Without Replication						
SUMMARY	Count	Sum	Average	Variance		
	3	0.25	0.083333	0.005833		
Rice Husk Ash Concrete	3	77.8	25.93333	4.923333		
Cowpea Ash Concrete	3	78	26	4.17		
Maize Cob Ash Concrete	3	78	26	6.07		
Soya Beans Ash Concrete	3	76.1	25.36667	6.613333		
NaCl	5	113.2	22.64	160.178		
	5	101.6	20.32	128.282		
	5	95.35	19.07	112.0195		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1591.169	4	397.7923	296.0682	1.01E-08	3.837853
Columns	32.81633	2	16.40817	12.21224	0.003706	4.45897
Error	10.74867	8	1.343583			
Total	1634.734	14				

The result shows that effect of percentage replacement of Selected Agro-base pozzolan and significance of each of the selected Agro-base pozzolan on the compressive strength after immersed in wastewater after 28 days was statistically significant, (F_{CAL} = 176.9 > F_{CRIT} = 3.84) for effect of the selected pozzolans while (FCAL = 10.2 > FCRIT = 4.5) for percentage replacement. Although it more pronounced for Effect of selected agro-base pozzolans than percentage replacement.

Table 6. Two-Factor without Replication for durability of concrete immersed in Wastewater

Anova: Two-Factor Without Replication						
SUMMARY	Count	Sum	Average	Variance		
	3	0.25	0.083333	0.005833		
Rice Husk Ash Concrete	3	80.3	26.76667	10.76333		
Cowpea Ash Concrete	3	85	28.33333	7.023333		
Maize Cob Ash Concrete	3	79.5	26.5	6.43		
Soya Beans Ash Concrete	3	77.2	25.73333	10.46333		
Wastewater	5	113.2	22.64	160.178		
	5	114.5	22.9	164.99		
	5	94.55	18.91	111.7355		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1728.077	4	432.0192	176.9	7.74E-08	3.837853
Columns	49.83433	2	24.91717	10.20289	0.006291	4.45897
Error	19.53733	8	2.442167			
Total	1797.448	14				

In general, the ANOVA results confirm statistically significant differences in compressive strength across the mix ratios and curing conditions. This analysis validates the effectiveness of the selected agro-based pozzolans in enhancing concrete durability.

4. Conclusions

This study demonstrates the potential of agro-based pozzolans, such as rice husk ash, cowpea ash, and maize cob ash, as sustainable partial replacements for cement. These materials enhance concrete durability in aggressive environments while reducing costs and environmental impact. However, further research is needed to optimize mix designs for specific applications and to evaluate the long-term performance of pozzolan-modified concretes under varying environmental conditions. Economic feasibility studies and advanced characterization techniques, such as SEM and XRD analysis, are recommended to support large-scale implementation.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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