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EVALUATION OF RHA/BLA POZZOLANIC CEMENT CONCRETE PROPERTIES

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Abstract — In this study, the effects of using ordinary Portland cement (OPC) as a binary pozzolanic cement and combining it with bamboo leaf ash (BLA) and rice husk ash (RHA) were investigated. Three kinds of pozzolanic cement concrete mixes were prepared using BLA, RHA, and a binary combination of equal proportions of RHA and BLA, each of which was used to partially replace OPC at 4%, 8%, 12%, and 16% respectively in concrete. A total of one hundred and thirty-two cube specimens of 150 mm × 150 mm × 150 mm were prepared using 1:2:4 concrete mix and 0.55 water-cement ratio. Slump and compaction factor tests were conducted on the fresh concrete, and compressive strength tests were conducted on the hardened concrete at 7, 21, 28, and 56 days of curing. The results obtained from the research show that the addition of BLA, RHA, and RHA/BLA binary composition pozzolans greatly improved the workability and compressive strength of concrete, with an optimum replacement level of 8%. Additional statistical studies demonstrate that their substitution did not materially affect the concrete compressive strength at this level of replacement. As a result, these pozzolans are advised to replace OPC in concrete partially, with a preference for RHA due to its superior performance.

***Keywords*:** bamboo leaf ash, rice husk ash, pozzolanic cement concrete, compressive strength, pozzolan

1.0 INTRODUCTION

The continuously rising price of ordinary Portland cement (OPC), a component of concrete, is one of the causes of the lack of affordable housing in Nigeria. As a result, quite a number of structures under construction have been abandoned, and the quality of the concrete used in construction has been intentionally decreased. The demand for infrastructure in metropolitan areas increases as a result of rapid urbanization and population rise [1]. Cement manufacture also consumes a lot of energy and is not environmentally friendly. A ton of carbon dioxide is estimated to be released during the manufacture of one ton of Portland cement [2]. It is therefore evident that available sustainable alternatives for cement will help mitigate the aforementioned problems. This has led many researchers to direct efforts into the development of pozzolans as alternative materials for cement. Pozzolans are substances with little to no cementitious qualities, but when they are ground to a fine powder and exposed to moisture, they react with lime to produce substances with cementitious capabilities [3]. Hence, these materials can be used as viable materials for the replacement of cement in concrete, with high prospects of improving the workability, compressive strength and durability properties of concrete. The mechanism of the pozzolanic reaction is explained by Equation (1) [4]:

$$\text{Calcium Hydroxide} + \text{Silica} \rightarrow \text{Calcium Silicate Hydrate}$$
$$3Ca(OH)_2 + 2[SiO_2] \rightarrow [3(CaO).2(SiO_2).3(H_2O)] \tag{1}$$

When cement undergoes hydration, the tricalcium silicate and dicalcium silicate from the cement reacts with water to produce calcium silicate hydrate (CSH), which contributes to the compressive strength of concrete, accompanied by the release of heat and calcium hydroxide ($Ca(OH)_2$). This free lime reacts with silica (SiO_2) from the pozzolan to produce more calcium silicate hydrate (CSH), thus improving the concrete strength. When the $Ca(OH)_2$ has been completely depleted due to the pozzolanic reaction, the remaining pozzolanic material acts as filler in the concrete [4].

Recent studies have continued to show that pozzolans have significant benefits when applied in concrete. A study by Bayiha et al. [5] showed that both natural and artificial pozzolans can significantly improve the setting time, and water absorption properties of cement mortar, with good mechanical properties. The effect of incorporating waste glass powder into high-volume fly ash (HVFA) concrete was examined by Onaizi et al. [6]. The results of the study demonstrated that 5% glass nanoparticles significantly improve the compressive strength of HVFA concrete. Mohamed et al. [7] evaluated the impact of selected supplementary cementitious materials (fly ash and ground granulated blast furnace slag) on the mechanical properties and chloride penetration resistance of the self-compacting concrete (SCC) mix. It was observed that the chloride penetration resistance of the concrete improved by up to 40% fly ash addition. However, even though the construction and cement industries have recognized the need to incorporate pozzolanic materials like fly ash, slag, silica fume, and burnt shale into the cement manufacturing processes with standard specifications for their inclusions, researchers are still in search of cheaper alternatives to the aforementioned pozzolanic materials [8–10].

Agro-wastes produced in enormous quantities all over the world, have been known to contain silicon and other intriguing components that can be used to make inorganic cementing binders [11]. According to [12], agricultural crop wastes have a better potential to partially substitute cement up to 10%, decreasing the environmental pollution and energy requirements in the production of cement. Examples of these agro-wastes with pozzolanic properties include rice husks, bamboo leaves, coconut shell, maize cobs etc. With the estimated 742 million metric tonnes of rice produced worldwide, there is usually a generation of around 148 million metric tonnes of rice husk as a byproduct [13]. Also, the menace created by waste leaves from the harvest of bamboo can be dealt with when applied in producing bamboo leaf ash (BLA) [14].

Due to their pozzolanic capabilities, rice husk ask (RHA) and BLA can significantly alter the characteristics of cement, concrete, and mortar. This lowers the overall cost of producing the aforementioned products and reduces the negative environmental impact involved in the production of cement. Raw rice husks are burned for around two hours at a controlled temperature of 600°C to produce RHA, which contains a sizable amount of silica. Studies on the chemical components, microstructure, and pozzolanic activity of RHA have revealed that its high activity is primarily caused by its high content of amorphous silica components, the existence of nanoscale silica gel particles, and the size and surface area of RHA particles, and these properties aid its effectiveness in improving the strength and durability properties of concrete [15, 16]. [17] observed that with addition of an optimum level of 7.5% of RHA in replacement of cement, the compressive and split tensile strength of concrete is comparative to that of normal concrete. [18] showed that 45% RHA combined with 2% hooked steel fibers can be used in production of high strength fibre reinforced recycled aggregate concrete. Addition of fine RHA particles in replacement of cement was shown to improve the flexural, compressive and tensile strength, and durability properties of concrete [19]. It was also observed by [20] that with an addition of 9% RHA, the sulfate erosion resistance of concrete exposed to sulfate environment can be significantly enhanced.

Studies by many authors have also demonstrated that BLA is an amorphous substance with excellent pozzolanic properties for use in concrete [21–23]. BLA is produced when bamboo leaves are dried in the sun, burned outdoors, and then heated for two hours at 600°C in a muffle furnace. [24] showed that 30% replacement of cement with BLA in mortars gives promising compressive strength results. A study by Abebaw et al. [25] showed that with 5% and 10% BLA addition, the target strength can be achieved and durability properties such as water absorption and sulfate resistance can be significantly improved. In a research by Onikeku et al. [26], BLA exhibited impressive split tensile, flexural and compressive strength performance, as well as good water absorption and sorptivity properties with an optimum replacement level of 10%. Odeyemi et al. [27] also showed that, with 5% BLA in replacement of cement, there is a significant improvement in the microstructure and strength properties of high-performance concrete.

From the foregoing, this study sought to investigate the workability and compressive strength of concrete produced from the singular and binary addition of RHA and BLA in partial replacement of cement.

2.0 MATERIALS AND METHODS

2.1. Materials

For this study, ordinary Portland cement with a specific gravity of 3.15 that is made in Nigeria under the Dangote brand was employed. Sharp sand with a specific gravity of 2.65 was utilized as the study's fine aggregate, and crushed granite stones with a nominal size of 19 mm were used as the coarse aggregate. Two pozzolans were used-BLA and RHA. Bamboo leaves from a plantation were gathered, burned, and sieved at the Federal University of Technology in Akure, Ondo State, to make the ash. The ash was made by burning and sieving rice husks that were obtained from the Igbemo Rice Processing Company Limited, located in Igbemo-Ekiti, Ekiti state, Nigeria. The concrete was mixed using clean, potable water that was provided by the water supply system.

2.2. Methods

2.2.1. Ash production

The various biogenic materials (bamboo leaves and rice husks) were air-dried and then heated to 700 °C for around 6 hours in a muffle furnace to preserve the ash in an amorphous state. After cooling for 72 hours, the entirely burned ash was collected and finely crushed using a home blender. Following grinding, the particles were sieved via a 45µm sieve. A sample of the manufactured RHA and BLA is shown in Figure 1.

Figure 1 Samples of RHA (left) and BLA (right)

2.2.2. Blending of cement

Three different types of concrete cubes were produced based on the mixture of the pozzolans and the cement used in the concrete.

i. BLA pozzolanic cement concrete (in which the OPC has been replaced by given percentages of BLA)
ii. RHA pozzolanic cement concrete (in which the OPC has been replaced by given percentages of RHA)
iii. RHA/BLA binary pozzolanic cement concrete (in which the OPC has been replaced with given percentages of BLA and RHA in equal proportions)

Ordinary Portland cement was partially replaced by ash at intervals of 0%, 4%, 8%, 12%, and 16%. The mixture compositions of the prepared samples are displayed in kg/m^3 in Table 1.

Table 1 Composition of the Concrete Mix in kg/m^3

Concrete	Cement (kg/m^3)	Pozzolan (i.e. BLA or RHA or BLA/RHA) (kg/m^3)	Fine aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
0%	341.2	-	680.4	1360.8	188.2
4%	327.6	13.6	680.4	1360.8	188.2
8%	313.9	27.3	680.4	1360.8	188.2
12%	300.3	40.9	680.4	1360.8	188.2
16%	286.6	54.6	680.4	1360.8	188.2

2.2.3. X-Ray fluorescence (XRF) spectrometry test

To identify the chemical components in the RHA and BLA samples, the pozzolans underwent an X-ray fluorescence (XRF) Spectrometry test. Figure 2 displays the XRF spectrometer configuration. The Herzog Gyro-mill (Simatic C7-621) was used to pulverize each sample for 60 seconds after it had been crushed using an electric crusher [28]. The pulverized samples were used to make pellets by grinding 20g of each specimen with 0.4g of octadecanoic acid for 60 seconds each time, followed by thorough cleanings of the Gyro-mill to prevent contamination. To serve as a binding agent, 1g of octadecanoic acid was measured into an aluminium cup. The cup was then filled with the sample until it reached the level point. The cup was then brought to Herzog pelletizing equipment and processed through for 60 seconds at a 200kN pressure. The Phillips PW-1800 X-ray machine's sample holder was added with the 2mm pellets for analysis. The different oxide content percentages in the ashes are shown in Table 2.

Figure 2 XRF spectrometer setup

2.2.4. Tests on RHA, BLA, and aggregates

The moisture content in the aggregates was assessed using the oven-drying method in accordance with BS 812-109 [29]. The density bottle method was used to calculate the specific gravity of fine aggregates in line with BS 812-2 [30]. To ascertain the particle size distribution, sieve analysis was conducted on the RHA, BLA samples, and aggregates in consonance with BS 812-103 [31]. About 250g of the sample material was weighed, after weighing and arranging a set of sieves in order of their sizes. The weighed sample was then poured into the top layer of the set of sieves and agitated vigorously for about 10 to 15 mins. The mass of the samples retained on each sieve was then recorded. The amount of silt and/or clay in fine aggregates was also measured using a silt/clay content test. A 250ml measuring cylinder was filled with sodium chloride solution up to 50ml mark. The fine sand to be tested was then added till the level of the solution got to the 100ml mark, after which the salt solution was added till the 150ml mark. The mixture of the fine sand and the salt solution was then shook vigorously and left undisturbed for 3 hours. Thereafter, the thickness of the silt layer, which was above the sand layer, was measured. On the coarse aggregates, aggregate crushing value (ACV) test and aggregate impact value (AIV) test were conducted in accordance with BS 812-110 [32] and BS 812-112 [33] respectively. To determine the ACV, coarse aggregate samples passing through the 14mm sieve but retained on the 10mm BS sieve were oven-dried. The sample was filled into the ACV apparatus in 3 layers, each layer tamped with 25 strokes of a tamping rod and weighed. Thereafter, the ACV apparatus was placed in the compression testing machine with the plunger in position and loaded at a uniform rate to achieve 400kN load in 10 minutes. The load was then released, and the sample was sieved through the 2.36mm sieve, after which the sample fraction passing through the sieve was weighed and recorded. The test was repeated thrice and the average value taken. For the AIV, the test sample was first prepared as described in the ACV procedure. The AIV was then calculated using the formula presented in Equation (2). The cylinder was then placed in the AIV apparatus, and subjected to a total of 15 impact blows from the free-falling hammer of the AIV apparatus. The crushed aggregate was then poured into a tray and the weight recorded. The specimen in the tray was then sieved through the 2.36mm test sieve, and the fractions passing and retained on the sieve were recorded. The AIV was then calculated using the formula presented in Equation (3).

$$ACV = \frac{M_2}{M_1} \times 100 \quad (2)$$

where M_1 represents the mass of the test specimen, and M_2 represents the mass of the material passing through the 2.36mm test sieve.

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2.2.5. Tests on concrete

The fresh concrete's workability was evaluated using compaction factor and slump tests (Figures 3 and 4). Concrete cubes were tested for compressive strength by loading them until failure in a compressive strength testing machine after being cured in water for 7, 21, 28, and 56 days. The formula in equation (4) was then used to determine the cubes' compressive strength:

$$\text{Compressive strength} = \frac{\text{Load at failure (N)}}{\text{Surface area (mm}^2\text{)}} \quad (4)$$

Also, the strength activity index for the pozzolanic cement concrete was determined using the formula given in equation (5):

$$\text{Strength Activity Index (SAI)} = \frac{A}{B} \times 100 \quad (5)$$

where A = average compressive strength of pozzolanic cement mortar cube
B = average compressive strength of control mortar cube

Figure 3 Slump test

Figure 4 Compacting factor test

The flow chart for the methodology is presented in Figure 5.

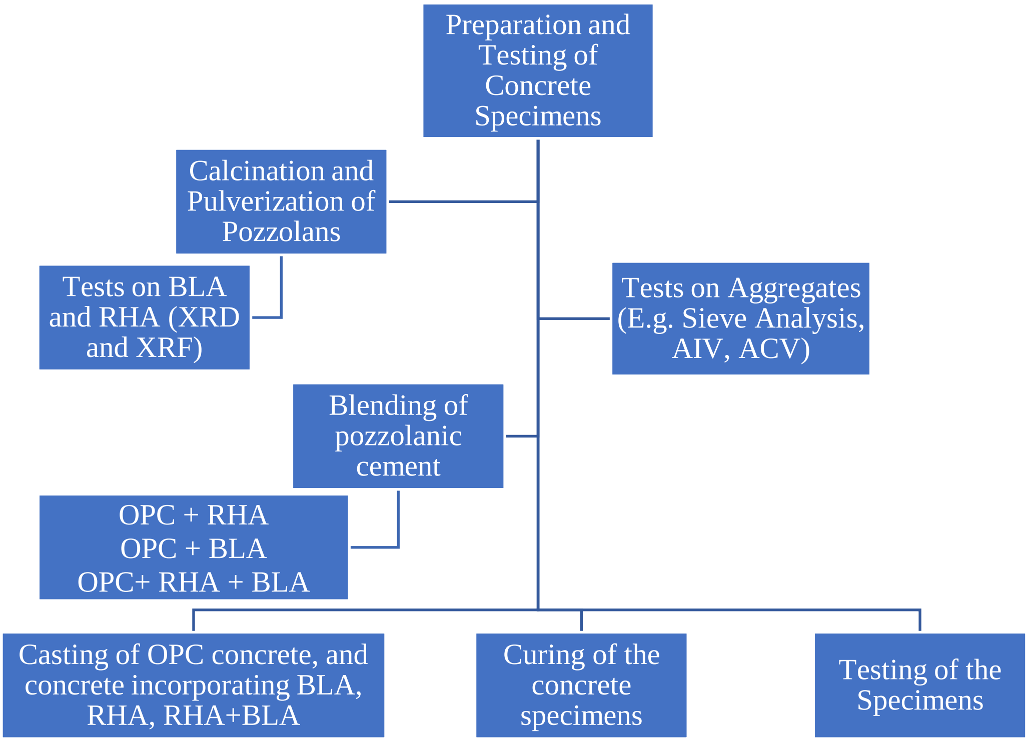

Figure 5 Flow chart of the methodology adopted in the research

3.0 RESULTS AND DISCUSSION

3.1. Chemical Composition

Table 2 shows the findings of the XRF spectrometry test conducted on the pozzolans, BLA and RHA. According to ASTM C618 [34], pozzolans must include at least 70% of the oxides SiO2, Al2O3, and Fe2O3 when combined. The results show that the BLA and RHA, respectively, contained 91.1% and 77.13% of those oxides. Additionally, magnesium oxide, which could render pozzolan(s) unstable when over 4%, was not identified, indicating that it may only be present in very small amounts. The loss on ignition for the pozzolans was far lower than the 10% ASTM C618 [34] maximum allowable amount. This indicates that the BLA and RHA can be classified as Class F pozzolans.

Table 2 Percentage Oxide Composition and Loss on Ignition of BLA and RHA

Oxide	Chemical formula	Percentage composition (%)	
		BLA	RHA
Silica	SiO_2	43.00	49.00
Alumina	Al_2O_3	32.00	21.00
Ferric oxide	Fe_2O_3	16.10	7.13
Calcium oxide	CaO	2.40	3.20
Magnesium oxide	MgO	ND	ND
Manganese oxide	MnO	0.92	1.90
Zinc oxide	ZnO	0.92	1.90
Potassium oxide	K_2O	ND	1.40
Loss on Ignition	LOI	2.00	3.50

3.2. Results of Tests on Aggregates

The result of the sieve analysis is presented in Figure 6.

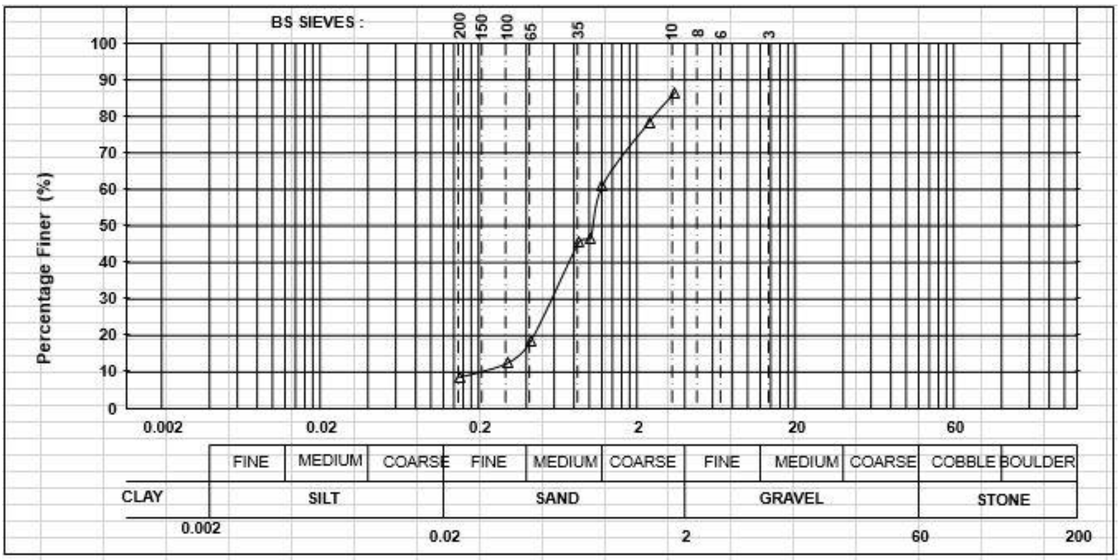

Figure 6 Sieve analysis of fine aggregates

The graph in Figure 6 shows that the fine aggregate is well graded with a fineness modulus of 2.47, which is in the range of 2.3 and 3.1 as specified by ASTM C33 [35]. The silt/clay content test conducted showed that the silt/clay content in the sample was 8.1%. This indicates that the sample needed to be washed before being used, having not met the required standard of 4% specified in British standards for fine aggregates [18], this was done in the process of the research work. The average aggregate crushing value (ACV) result was 29.4% which is approximately the same as the 30% minimum specified by BS 812-110 [32].

3.3. Workability Tests

Figure 7 shows the findings of the slump tests conducted on the fresh concrete, while that of the compacting factor test is presented in Figure 8.

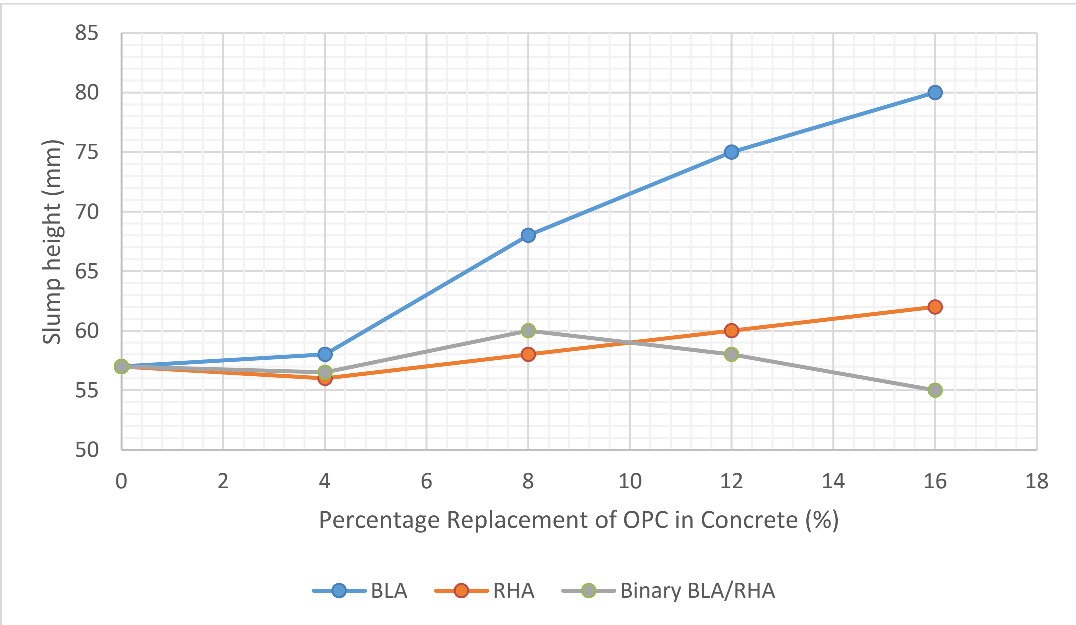

Figure 7 Slump test on concrete based on the replacement of the OPC

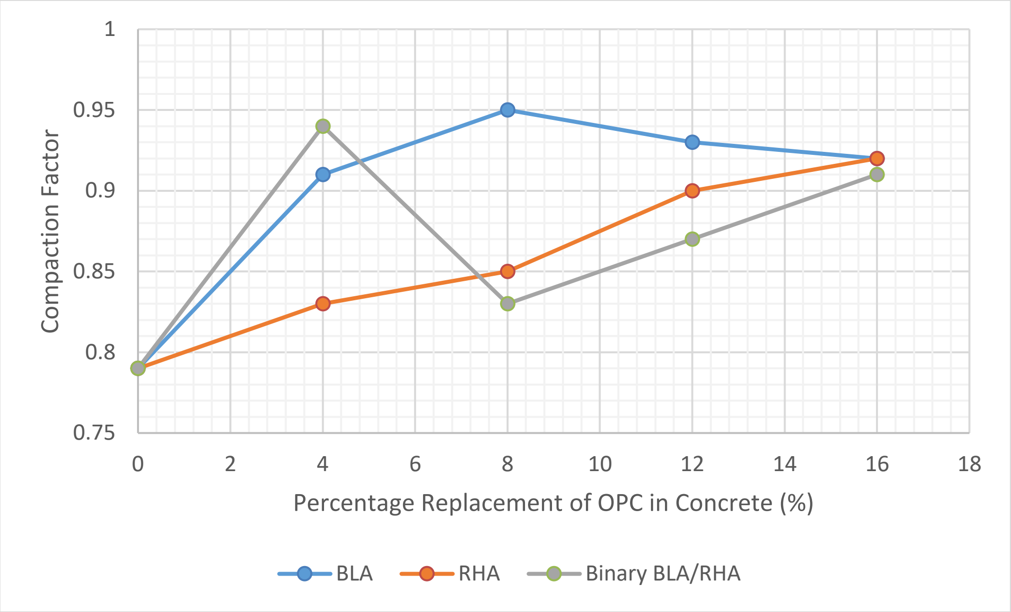

Figure 8 Compacting factor test on concrete based on the replacement of OPC

As shown in Figure 7, the slump of the freshly prepared concrete, using ordinary Portland cement was 57mm. Upon the addition of BLA, the slump progressively increased from 58mm at 4% BLA content to 80mm at 16% BLA content. Following a similar trend, the slump progressively increased from 56mm at 4% RHA content to 62mm at 16% RHA content. This implies that BLA shows more potential in increasing the workability of the concrete than the RHA. However, upon addition of the binary mix of BLA and RHA in the concrete, the slump decreased first and rose to a maximum of 60mm at 8% BLA/RHA binary content, and gradually decreased to its lowest value at 16% addition of BLA/RHA. This trend can be due to the high water absorption rate of the pozzolans when added to the concrete. This is similar to the observation made by Hamada et al. [36] and Prusty et al.[37]. On the other hand, the compacting factor test gave a value of 0.79 without replacement of the cement. Upon addition of BLA, an increasing trend was observed with a maximum of 0.95 at 8% BLA content and later a gradual decrease. RHA, on the other hand, showed an increasing trend all through, with a maximum of 0.92 at 16% RHA content. Meanwhile, with the binary addition of BLA/RHA, the maximum compacting factor was 0.94 obtained at 4% BLA/RHA binary content. These findings suggest that the concrete was made more workable by the addition of BLA, RHA, and a binary mix of BLA/RHA.

3.4. Compressive Strength Test

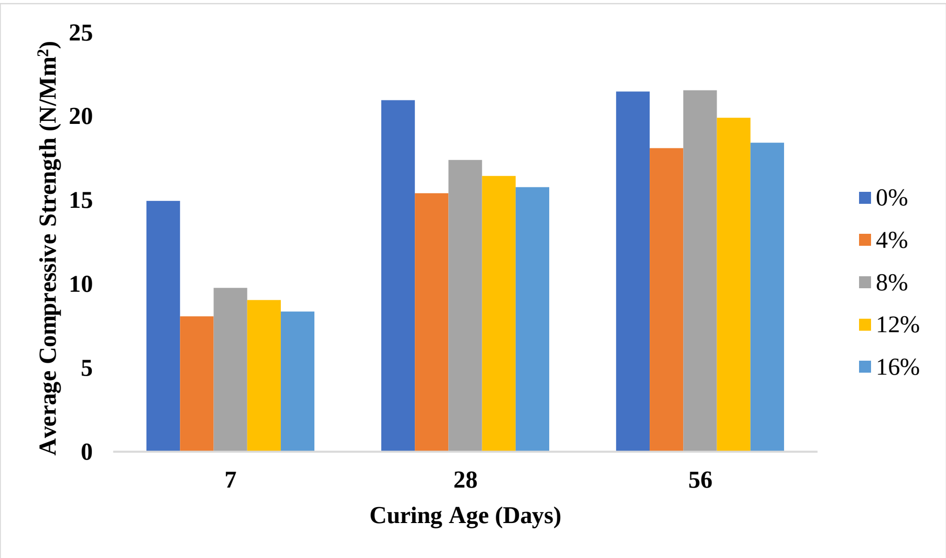

Figure 9 Average compressive strength of BLA pozzolanic cement concrete

Compressive strength tests were conducted on the OPC concrete and the pozzolanic cement concrete after curing in water for 7, 21, 28, and 56 days. The results of the tests are presented in Figures 9, 10, and 11. The figures show that the OPC compressive strength values were highest at all curing ages, except for RHA pozzolanic cement concrete where the compressive strength (21.70N/mm^2) was slightly higher than that of OPC concrete (21.48N/mm^2) at 56 days curing age and 8% RHA content.

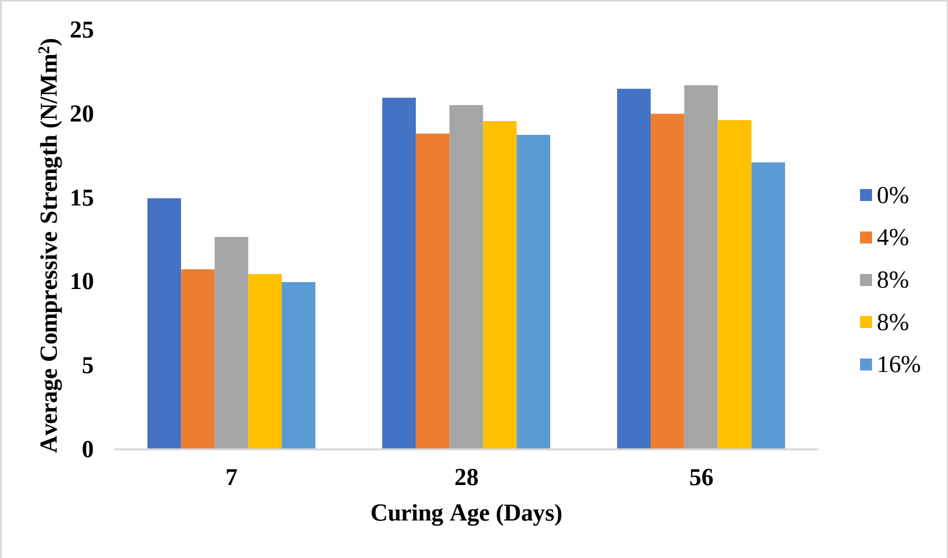

Figure 10 Average compressive strength of RHA pozzolanic cement concrete

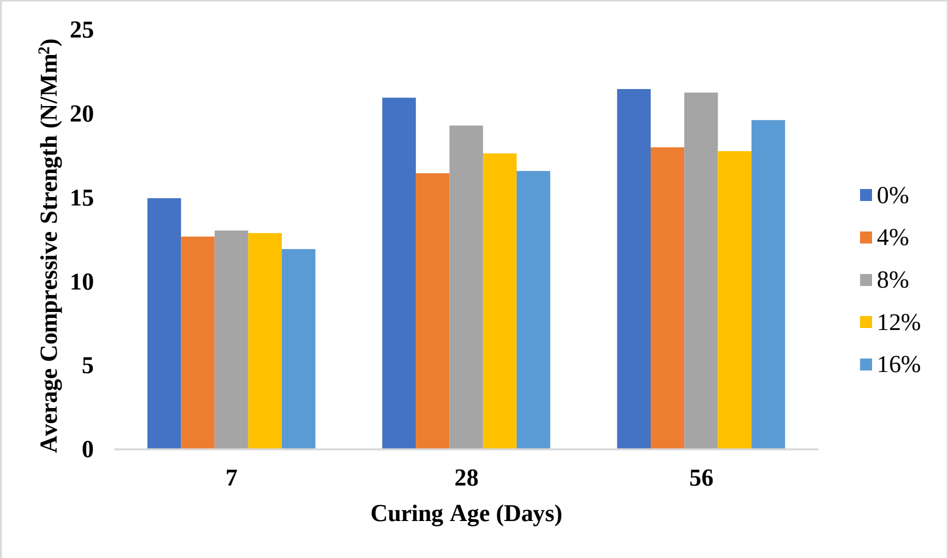

Figure 11 Average compressive strength of binary BLA/RHA pozzolanic cement concrete

The same trend of growth in compressive strength was noticed in the BLA and RHA pozzolanic cement concrete, but a slight difference was observed in the BLA/RHA binary pozzolanic cement concrete at 56 days of curing. At this age, the compressive strength at 16% BLA/RHA binary content was higher than that at 12% as observed in the other mixes. It can be inferred from these results that the optimum percentage addition for these pozzolans in concrete is 8%.

3.5. Strength Activity Index

Table 3 shows the results of the strength activity index. The highlighted values in the table show the values that are not up to the required standard. It was observed that most of the pozzolans attained the required strength activity index at 28 days, except for BLA at 4% addition.

Table 3 Comparison of Strength Activity Index for OPC and Pozzolanic Cement Concrete

Type of Concrete	Mix	Percentage replacement of OPC (%)	Compressive Strength (Mpa)		Strength Activity Index (SAI)		ASTM C618-12a [18] Limit for SAI	
			7 days	28 days	7 days	28 days	Ratio to control @ 7days	Ratio to control @ 28days
Control	OPC	0%	14.96	20.96	100	100		
Pozzolanic Cement Concrete	BLA	4%	8.08	15.41	54.01	73.52	75 minimum	75 minimum
		8%	9.78	17.41	65.37	83.06		
		12%	9.04	16.44	60.43	78.44		
		16%	8.37	15.78	55.95	75.29		
	RHA	4%	10.74	18.81	71.79	89.74		
		8%	12.66	20.52	84.63	97.90		
		12%	10.44	19.56	69.79	93.32		
		16%	9.97	18.74	66.64	89.41		
	BLA/RHA	4%	12.67	16.45	84.69	78.48		
		8%	13.04	19.3	87.17	92.08		
		12%	12.89	17.63	86.16	84.11		
		16%	11.93	16.59	79.75	79.15		

Observations gathered from all the different tests conducted show that the optimum result can be achieved at 8% OPC replacement. Figure 12 shows a comparison of the growth in compressive strength for the OPC and the pozzolanic cement concrete at 8% optimum OPC replacement.

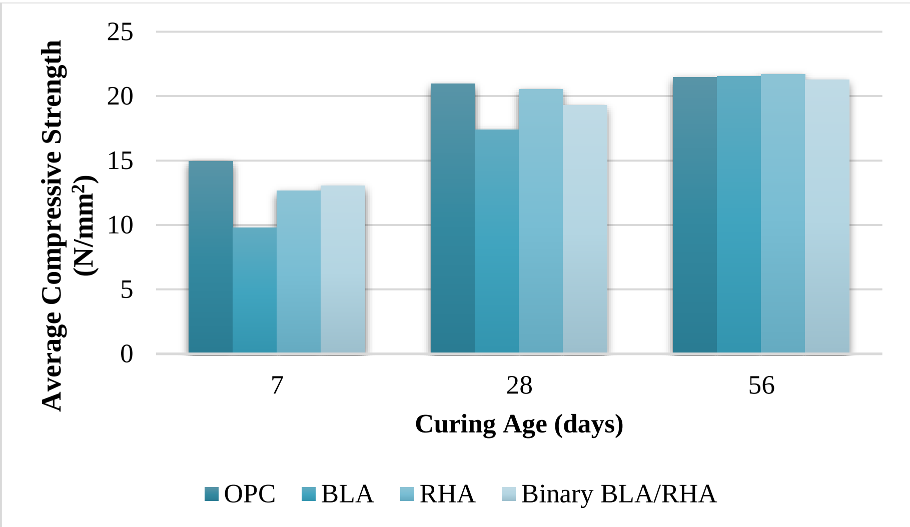

Figure 12 Comparison of strength for OPC and pozzolanic cement concrete at 8% optimum content

From these results, RHA proves to be the most credible pozzolan for OPC replacement among the three pozzolans, with higher compressive strength than the other two at both 28 and 56 days. Moreover, the observed strength activity index was highest for the RHA at 8% optimum content with a value of 97.9 at 28 days curing age and exceeds the required minimum of 75 as specified in ASTM C618-12a [21]. The results of the compressive strength shown in Figures 7 to 9 show that with long-term curing, hydration in the concrete will progress in the presence of pozzolans, hence leading to improved compressive strength.

3.6. Statistical Analysis

3.6.1. Analysis of variance (ANOVA) of the compressive strength results

The analysis of variance for comparing the compressive strengths of each percentage of all pozzolanic cement concrete at 56 days of curing is shown in Table 4. The table shows that there is a significant difference between groups which implies that the result is not by chance but depends on a particular factor. The follow-up test, Least Significant Difference (LSD) result in Table 5 reveals that there was no significant difference between OPC concrete which serves as control, and BLA at 8%, BLA at 12%, RHA at 4%, RHA at 8%, and Binary at 8%. This confirms that 8% obtained as the optimum percentage of replacement for RHA, BLA, and Binary (RHA/BLA) can successfully replace cement without altering the compressive strength significantly.

Table 4 ANOVA for Comparing Compressive Strength of BLA, RHA, and RHA/BLA Binary Pozzolanic Cement Concrete with OPC Concrete on 56 days of Curing at Different Percentages

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	86.737	12	7.228	13.490	.000
Within Groups	13.931	26	0.536		
Total	100.668	38			

Table 5 LSD Test for Comparing Compressive Strength of BLA, RHA and RHA/BLA Binary Pozzolanic Cement Concrete with OPC Concrete on 56 days of Curing at Different Percentages

i	**j**	**MD(i-j)**	**p**	**Remark**
1	2	2.92333*	.000	*
	3	-.55667	.360	NS
	4	1.07667	.083	NS
	5	2.55667*	.000	*
	6	1.00000	.106	NS
	7	-.70333	.250	NS
	8	1.37000*	.030	*
	9	3.88667*	.000	*
	10	3.00000*	.000	*
	11	-.26000	.667	NS
	12	3.22000*	.000	*
	13	1.37333*	.030	*

4.0 CONCLUSION

The following conclusions have been observed from this study:

- BLA, RHA and a binary combination of both BLA and RHA are pozzolans suitable for partially replacing ordinary Portland cement (OPC) in concrete.
- The addition of BLA and RHA to OPC individually improved the concrete workability with increasing pozzolan percentage, but BLA/RHA binary combination gave lower workability with increasing percentage beyond 8%.
- The initial strength (7 days strength) of OPC concrete was generally higher than that of pozzolanic cement concrete. However, when OPC was partially replaced with the optimum content of BLA, RHA, or BLA/RHA binary composition and subjected to a longer period of curing (56 days), the strength improved tremendously and became comparatively equal.

- RHA was seen to be more credible than BLA and BLA/RHA binary composition since it showed better strength performance at the curing ages compared to the other two.
- The optimum percentage of BLA, RHA, or BLA/RHA in replacing OPC observed in this study is 8%. This has also been confirmed through the use of statistical analysis that RHA, BLA, and Binary (RHA/BLA) can successfully replace cement without significantly altering the compressive strength.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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