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Effect of Rice Husk Ash (RHA) and slake-lime as partial replacement of cement in the production of concrete

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Abstract

This study examines the utilization of rice husk ash (RHA) and slaked lime as substitutes for a portion of the cement in manufacturing concrete. The RHA was acquired from a nearby source, subjected to calcination at temperatures ranging from 500 to 700 °C, and then passed through a sieve to obtain particles with a size of 150 microns. Concrete mixes were made using Ordinary Portland cement (OPC), fine and coarse aggregates, and water, with different amounts of RHA and slaked lime. The concrete mix design adhered to established standards, with a mix ratio of 1:1.5:3 (cement: fine aggregate: coarse aggregate). The experiment was designed using response surface methods, with RHA, slaked lime, and cement as factors, each having five levels. Concrete cubes were formed using 100 mm steel moulds and then submerged in water to assess their workability. The compressive strength was measured using universal testing equipment after 7, 28, and 90 days of cure. The flexural strength of concrete beams was assessed after 7 and 28 days. Samples were subjected to scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) examination after 28 days. The compressive and flexural strengths increased as the curing period progressed, with the 10% RHA substitution showing the maximum strength. The SEM analysis showed that RHA10 exhibited the maximum concentration of silicon, which corresponds to the recommended 10% replacement level of OPC and meets the concrete specifications specified by ASTM M20 grade. Utilising RHA decreases expenses and minimises the amount of concrete that is discarded. The most effective replacement for OPC was 10% RHA, which produced long-lasting and strong concrete.

Keywords: Rice husk ash (RHA); Slaked lime; Pozzolanic material; Compressive strength; Flexural strength; Microstructural analysis; Sustainable construction and cement alternatives

1. Introduction

The cement industry is essential to produce concrete, a highly utilised construction material. Nevertheless, the cement sector has various sustainability obstacles, such as elevated carbon emissions, restricted access to natural resources, and the imperative to minimise waste (Mehta and Monteiro, 2014). In 2015, the United Nations established a consensus on 17 sustainable development goals (SDGs) to safeguard the planet and promote universal prosperity. Some of these objectives pertain to the concrete industry, including SDG 9, which aims to construct durable infrastructure, encourage sustainable industrialisation, and foster innovation. SDG 12 focuses on ensuring sustainable consumption and

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production patterns, while SDG 13 emphasises the need for immediate action to combat climate change and its effects (United Nations, 2015).

A practical method for tackling these difficulties is utilising pozzolans as partial substitutes for cement in concrete manufacturing. Pozzolans undergo a chemical reaction with calcium hydroxide to produce extra-binding compounds, leading to a more compact and long-lasting concrete structure (Taha *et al.,* 2004). As the demand for concrete has increased, getting traditional pozzolans like volcanic ash or clay has become more challenging. Researchers have been motivated to investigate other sources of pozzolans, including industrial by-products and agricultural waste (Bumanis *et al.,* 2020).

An encouraging option involves utilising rice husk ash (RHA) as a pozzolanic substance. Rice husk, a residual material from rice milling, can substitute cement in concrete production if it undergoes appropriate processing and calcination (Tariq *et al.,* 2021). Utilising Recycled High-strength Aggregates (RHA) in concrete can enhance the material's plasticity, robustness, and longevity (Islam *et al.,* 2022).

Nevertheless, the extensive implementation of pozzolans, such as RHA, encounters many obstacles. These factors encompass the accessibility and expense of pozzolans, the necessity for modifications in mix design and curing procedures, and the absence of uniformity in their utilisation (Heikal *et al.,* 2020). It is essential to tackle these problems to encourage the sustainable utilisation of pozzolans in the construction sector.

This study aims to examine the utilisation of RHA and slaked lime as substitutes for cement in the manufacturing of concrete blocks. This study contributes to the ongoing efforts to lessen the environmental effects of the construction industry by investigating the potential of using RHA and slaked lime as sustainable alternatives to traditional cement-based concrete. The aim is to retain the performance and quality of building materials while promoting sustainability.

2. Material and methods

The materials utilised in this investigation comprise rice husk procured from Asero Farm Market, located in Ogun State, Nigeria. The rice husk underwent thorough processing and was subjected to calcination in a furnace at temperatures ranging from 500 to 700 °C for 1 hour and 40 minutes, producing rice husk ash (RHA). The ash was cooled, gathered, and filtered through a 150-micron screen. A specimen of the RHA was obtained and examined to ascertain its chemical composition.

Ordinary Portland Cement (OPC) that adheres to the ASTM C150/C150M-19 standard was procured locally, namely the Dangote Cement brand. The fine and coarse aggregates were sourced from the Civil Engineering Department Laboratory of the Federal University of Agriculture, Abeokuta (FUNAAB) in Ogun State, Nigeria. The coarse aggregate utilised had a diameter of 19 mm, facilitating effortless compaction. The fine aggregate was obtained from a natural river source. It underwent a process of washing, drying, and sieving to exclude finer particles, dust particles, and organic matter. The aggregate was also graded.

Slaked lime (calcium hydroxide) was also used. The compound $Ca(OH)_2$ will undergo a chemical reaction with RHA to improve its pozzolanic characteristics. The reaction will yield Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrates (CAH), which form the final material, as depicted in chemical equation 1.

$$Ca(OH)_2 + SiO_2 + Al_2O_3 = Cao.SiO_2.nH_2O + CaO.Al_2O_3.nH_2O \ \ldots\ldots\ldots\ldots \quad 1$$

Clean water was used for the concrete batching for adequate workability and ease of compaction. The water-cement ratio was 0.55.

2.1. Concrete Mix Design

The concrete mix design adhered to established standards, with a mix ratio of 1:1.5:3 (cement: fine aggregate: coarse aggregate). The experiment was designed using response surface methods, with RHA, slaked lime, and cement as factors, each having five levels.

2.2. Concrete Cube and Beam Casting

Concrete cubes were cast using 100 × 100 × 100 mm steel moulds and cured in water before testing their workability. Concrete beams were cast using 100 × 100 × 700 mm iron moulds for the flexural strength test.

2.3. Compressive Strength Test

The compressive strength of the concrete cubes was determined using a universal testing machine after 7 and 28 days of curing. Three specimens were selected and crushed at the end of each curing period to determine the mean compressive strength.

2.4. Flexural Strength Test

Concrete beams were crushed after 7 and 28 days of curing to determine the flexural strength using the universal testing machine. The specimen was crushed at the end of each curing period.

2.5. Microstructural Analysis

Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) analysis were performed on concrete samples at 28 days to investigate the microstructural characteristics.

3. Results and discussion

3.1. Chemical Analysis

The chemical compositions of the RHA were assessed using the X-ray fluorescence (XRF) approach by collecting and analysing small ash samples with an XRF device. The acquired data was subsequently examined using the International Centre for Diffraction Data (ICDD) to ensure precision. The result obtained is presented in Table 1

Table 1 Chemical properties analysis of Rice Husk Ash (XRF Test)

Component	Ratio of components	ASTM C618-12 Requirement
Potassium oxide (K_20)	10.2	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$
Carbon (C)	<0.0001	
Calcium oxide (CaO)	6.98	
Silicon dioxide (SiO_2)	50.2	
Ferric oxide (Fe_2O_3)	26.6	
Magnesium oxide (MgO)	0.0808	
Potassium oxide (P_2O_5)	5.51	
Sodium oxide (Na_20_3)	-	
Aluminium oxide (Al_2O_3)	0.456	
Total $SiO_2 + Fe_2O_3 + AL_2O_3$	77.256	

Comparing the chemical composition of the RHA obtained in this study (Table 1) to the ASTM C618-12 requirements, it was observed that the total $SiO_2 + Al_2O_3 + Fe_2O_3$ content is 77.256%, which exceeds the 70% minimum requirement. The loss on ignition (LOI) is less than 0.0001%, which falls comfortably under the 10% threshold. Thus, according to the chemical composition analysis, the RHA generated in this research satisfies the ASTM C618-12 criteria for Class N pozzolans. The total $SiO_2 + Al_2O_3 + Fe_2O_3$ content of 77.256% is even higher than the 73.15% value reported by Oyetola and Abdullahi (2006) for RHA, indicating the RHA used here has a higher pozzolanic reactivity.

3.2. Compressive Strength Results

Figure 1 presents the compressive strength test results, providing extensive information on the testing of concrete samples. The test was conducted using different quantities of RHA and RHA mixed with slaked lime as partial substitutes for cement.

The compressive strength of the concrete mixes that solely included RHA exhibited a predictable rise with extended curing periods. The control mix, which contained 0% RHA, had the maximum compressive strength of 23.325 N/mm^2 after 28 days. The increase in the RHA replacement level reduced compressive strength from 21.232 to 8.255 N/mm^2.

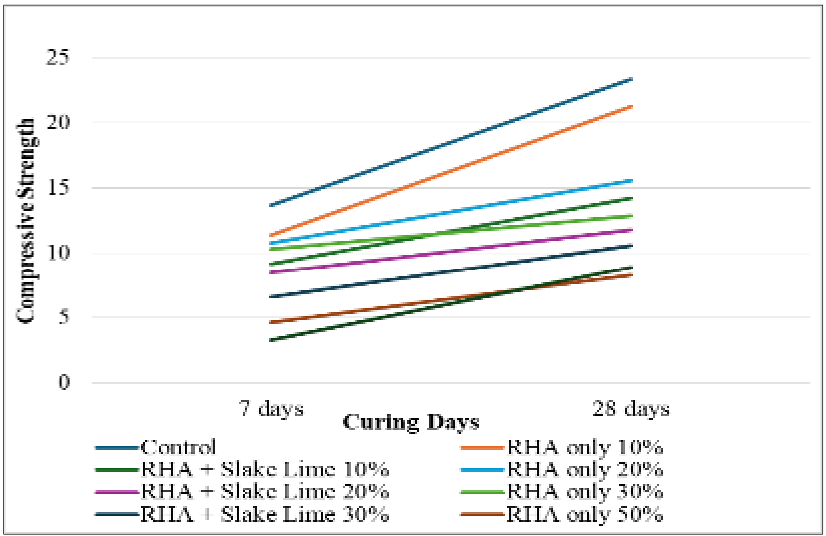

Figure 1 Compressive strength results for 7 and 28 days

The results suggest that the optimum amount of RHA replacement is approximately 10%, while higher replacement percentages led to a drop in compressive strength compared to the control mixture.

The findings are consistent with those of Karim *et al.* (2018), who reviewed using pozzolanic wastes in concrete. They observed that moderate replacement levels can enhance strength and durability, whereas greater levels of replacement result in a decrease in strength. Tariq *et al.* (2021) reported that substituting up to 20% of RHA resulted in a higher compressive strength for lightweight aerated concrete when compared to the control group.

The reduction in compressive strength observed at higher levels of RHA replacement is likely attributed to the dilution effect, whereby the material partially substitutes the cement with a lower inherent strength. Nevertheless, the pozzolanic reaction of RHA can enhance the compactness of the microstructure and improve other performance attributes, as explained in the section on microstructural studies.

As the levels of RHA and slaked lime replacement rose, there was a corresponding decrease in compressive strength, dropping from 11.763 to 8.891 N/mm^2. These findings again demonstrate that the most effective replacement level is approximately 10% RHA paired with 10% slaked lime while increasing the replacement percentages resulted in additional decreases in compressive strength.

In a study conducted by Singh *et al.* (2013), it was determined that a replacement level of 10% slaked lime was shown to be the most effective in enhancing durability while simultaneously reducing compressive strength compared to plain cement concrete. Chowdhury *et al.* (2017) discovered that using 10% slaked lime as a substitute yielded the best results in terms of workability. However, they also observed that higher replacement levels decreased compressive strength, which aligns with our findings.

Based on the compressive strength results, it may be inferred that cement's most effective partial replacement is around 10% RHA, either on its own or in conjunction with 10% slaked lime. This replacement level achieves a harmonious equilibrium between the strength performance and the advantages of utilising these sustainable, pozzolanic materials.

3.3. Flexural Strength Results

Figure 2 shows the flexural strength results for the concrete mixes containing only RHA as a replacement.

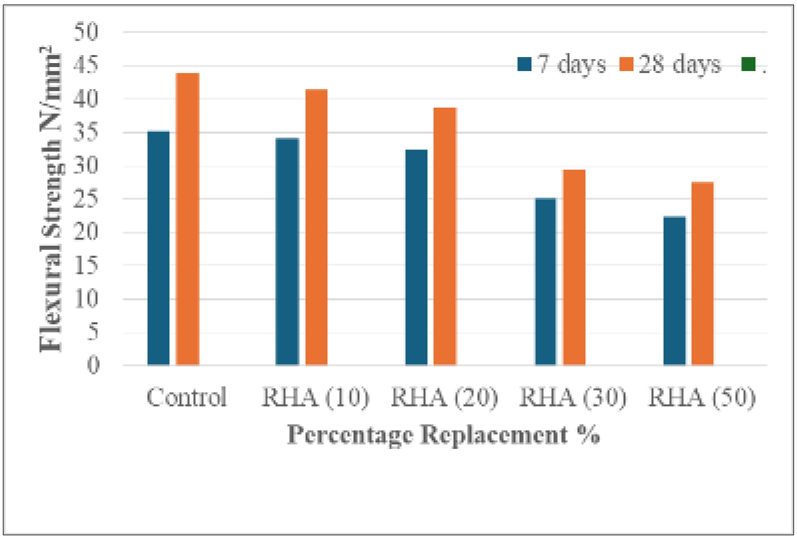

Figure 2 Summary of flexural Strength of RHA only

As expected, the flexural strength rose with extended curing durations. At 28 days, the flexural strength of the control mix (0% RHA) was the greatest at 43.87 N/mm². From 41.33 to 27.53 N/mm², the flexural strength fell as the RHA replacement level increased. This suggests that, as with compressive strength, the ideal RHA replacement level for flexural strength is approximately 10%.

The flexural strength findings for the concrete mixes that substituted slaked lime and RHA for cement are presented in Figure 3.

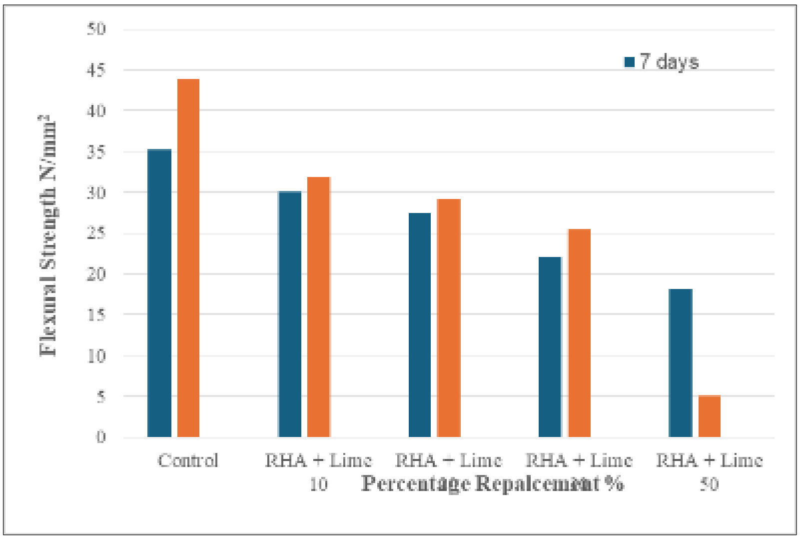

Figure 3 Summary of flexural Strength of RHA and slaked lime

As before, longer curing durations led to an increase in flexural strength. At 28 days, the flexural strength of the control mix (0% RHA, 0% slaked lime) was highest at 43.87 N/mm². The flexural strength dropped to 19.3 N/mm² as the replacement quantities of slaked lime and RHA increased. The flexural strengths of the 10% RHA and 10% RHA + 10% slaked lime mixes are the highest, whereas the overall trends in Figures 2 and 3 demonstrate that the flexural strengths drop as the RHA and slaked lime replacement levels increase.

These results are consistent with prior research that shows that modest replacement levels of pozzolanic material can improve flexural strength, but at larger replacement levels, the dilution effect causes the strength to diminish. To balance strength, workability, and sustainability issues, 10% RHA alone or in combination with slaked lime seems to be the ideal replacement level. According to other research, adding pozzolanic elements to concrete, such as RHA, can increase flexural strength. Tariq *et al*. (2021) investigated the impact of using RHA instead of cement in lightweight aerated concrete. Compared to the control, they discovered that flexural strength increased by up to 20% RHA replacement.

3.4. Microstructural Analysis

Concrete samples were subjected to energy dispersive X-ray (EDX) analysis and scanning electron microscopy (SEM) at 28 days to examine the microstructure. The RHA sample had the highest silicon content compared to the control and RHA + slaked lime mixes at 10%. This corresponds to the suggested 10% OPC replacement level, which satisfies ASTM M20 grade concrete criteria. According to the EDX study as shown in Figure 5, the most prevalent elements were oxygen, titanium, silicon, calcium, and cadmium. The highest trace amounts of silicon and aluminium were found in RHA at 10%. RHA at 10% high pozzolanic reactivity was indicated by its silicon and aluminium levels being marginally greater than the ASTM C618 minimum criterion of 70% for pozzolanic materials.

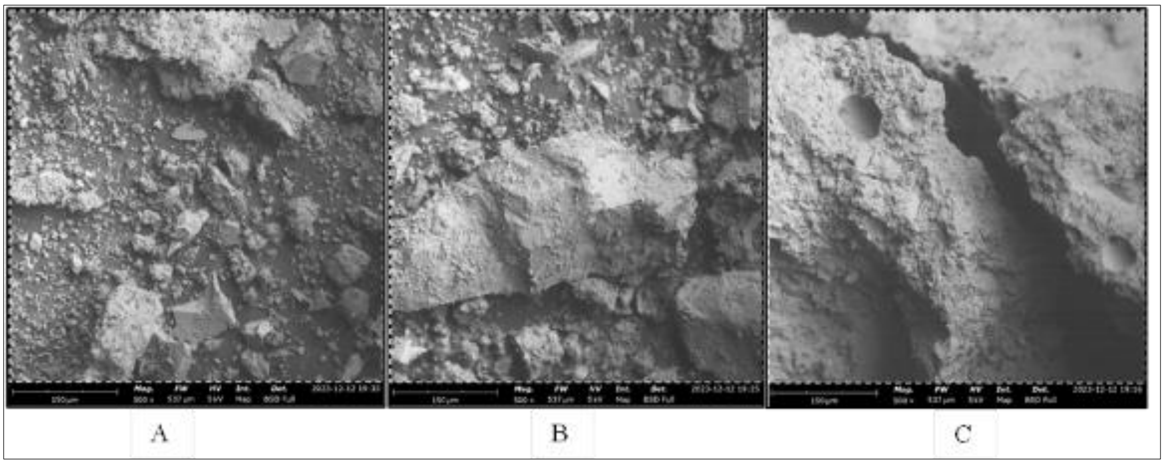

Figure 4 A - Control Spectra at 28 days ; B - RHA10 Spectra at 28 days ; C - RHA + Slake Lime (10) Spectra at 28 days

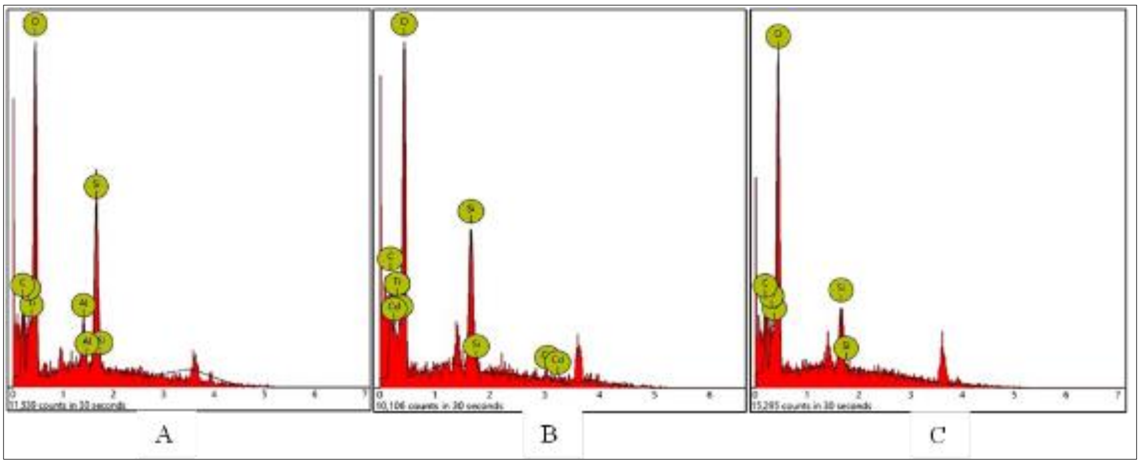

Figure 5 A - RHA10 X-ray mapping (XRF) analysis; B - Control X-ray mapping (XRF) analysis; C - RHA + Slake Lime (10) X-ray mapping (XRF) analysis

The compressive strength performance is clarified in part by these microstructural data presented in Figure 4. RHA at 10% has higher concentrations of silicon and aluminium, suggesting that it is a more pozzolanic material that can react with calcium hydroxide to form a more calcium silicate hydrate (C-S-H) gel. This increases the strength and durability of the concrete by densifying its microstructure. This is consistent with the compressive strength findings and validates RHA's efficacy as a pozzolanic material for constructing sustainable concrete. Based on the microstructural analysis and compressive strength results, 10% RHA is the best partial cement replacement, resulting in high-strength, long-lasting concrete. Higher replacement levels, however, exhibit diminishing returns because of dilution, yet RHA's pozzolanic reactivity can still be advantageous for sustainability and durability.

Pozzolanic materials have been used in other investigations where comparable microstructural improvements have been noted. Heikal *et al.* (2020) discovered that the microstructural refinement of metakaolin resulted in a decrease in permeability and an increase in compressive strength when used in place of cement. According to Karim *et al.* (2018), using rice husk ash enhanced the workability of mortar and decreased water absorption, ascribed to a denser matrix.

4. Conclusion

This study proves that RHA can be a useful pozzolanic material for making strong, long-lasting concrete, especially when replacing 10% of the cement. The longer the curing period, the better the concrete mixes' flexural and compressive strengths were. The compressive strength test results and microstructural refinement comply with ASTM requirements for pozzolanic materials and concrete strength grades.

According to the study's findings, partial cement replacement in concrete manufacturing may be used for rice husk ash (RHA), a potentially helpful supplemental cementitious material. Being an agricultural by-product that would otherwise be thrown away, using RHA as a partial substitute for cement can help minimise waste and lower the total cost of producing concrete.

Recommendation

Further research on the long-term durability and performance of RHA concrete would be beneficial in fully realising its potential as a cement alternative.

Compliance with ethical standards

Acknowledgments

The research was undertaken at the Agricultural and Bioresources Engineering Department and the Concrete Laboratory of the Civil Engineering Department, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria

Availability of data and material

The RHA, Slake lime, cement and aggregates were sourced within and around the university premises. The data were obtained using a standard testing machine and calculated using available standards

Disclosure of conflict of interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions

- POO is the lead researcher of this paper and has made substantial contributions since the conception and towards the design of this research work. He also plays a vital role in acquiring materials, analysing and interpreting data, and drafting this paper.
- JJB contributed substantially to the conception and design of this research work. He also plays a vital role in acquiring materials, analysing and interpreting data, and drafting this paper.
- OOO contributed substantially to the conception and design of this research work. He also plays an essential role in acquiring materials, analysing and reviewing the draft of this paper.
- IUT contributed substantially to the conception and design of this research work. He also plays an essential role in acquiring materials, analysing and reviewing the draft of this paper.
- AAA made substantial contributions to the conception and design of this research work. He also plays an essential role in acquiring materials and analysing and reviewing the draft of this paper.
- OSA made substantial contributions to the conception and design of this research work. He also plays an essential role in acquiring materials and analysing and reviewing the draft of this paper.

All authors have read and approved the final manuscript.

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