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EFFECTIVENESS OF AGRO-WASTES MATERIALS IN MINIMIZING ALKALI-SILICA REACTIONS IN CONCRETE PAVEMENT

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Abstract

This study assesses the effectiveness of three agro-waste-based supplementary cementitious materials: Sawdust Ash (SDA), Rice Husk Ash (RHA), and Bamboo Leaf Ash (BLA) in reducing alkali-silica reaction (ASR) in concrete pavement. The partial replacement of cement with agricultural waste materials to manufacture concrete pavements can considerably contribute to Sustainable Development Goal 11 (SDG 11), which aims to make cities and human settlements inclusive, safe, resilient, and sustainable. Given the growing concern about concrete durability and environmental sustainability, the study investigates the application of these pozzolanic materials as partial cement replacements (0-30%) in preventing alkali Silica reaction (ASR) induced expansion. A grade 15 concrete samples with dimensions of 30 mm by 30 mm by 100 mm were produced using a water cement ratio of 0.55 for ASR evaluation, while another set of concrete samples with 100 mm by 100 mm were created for water absorption tests. The accelerated mortar bar test (ASTM C1260) was used to measure ASR potential, as well as water absorption tests to determine the materials' durability. X-ray Fluorescence (XRF) analysis showed that all three ashes met ASTM C618 criteria, with combined SiO_2, Al_2O_3, and Fe_2O_3 composition surpassing 70%, indicating pozzolanic potential. RHA demonstrated the most effective ASR reduction, with expansions as low as 0.010% at 10-15% replacement. BLA and SDA both demonstrated effective performance at optimal replacement levels (10-15%), however SDA had a narrower effective range and became reactive at higher dosages. To maintain both durability and reactivity control, all materials should be replaced at 10-15% intervals.

Keywords: *Agro-waste, Sawdust ash, Rice husk ash, Bamboo leave ash, alkali-silica reaction, concrete pavement*

Introduction

In the modern world, the development of machinery Concrete is a manmade composite material possessing properties that are comparable to naturally occurring limestone pebbles (Ajayi *et al.,* 2023a). Globally, concrete is widely used, but one of its main drawbacks is that it is not environmentally friendly due to the way cement, one of its essential ingredients, is produced (Ikumapayi *et al.,* 2024). Highway construction professionals continued to study materials that can ensure pavement longevity and serviceability, with concrete and reinforced concrete roads being the preferred option (Njoku, 2012). Concrete pavements, also known as rigid pavements, are increasingly advocated since they are seen as the finest for heavily frequented roads, whereas flexible pavements are thought to be ideal for low volume, often used routes (Mohod & Kadam, 2016). Concrete can serve as an alternative pavement's material for Nigerian roadways (Onwuemenyi, 2022).

Alkali-aggregate reaction (AAR) is causing concrete pavement deterioration that highway and pavement experts are now dealing with. When AAR results in cracking and substantial volume expansion of concrete, it is harmful (Ahsan & Hossain, 2018). Alkali-silica reactions (ASR) and alkali-carbonate reactions (ACR) are the two types of AAR (Ahsan & Hossain, 2018). The most common type of AAR is ASR, which is a chemical reaction between the alkali hydroxide from hydraulic cement and the silica content of the aggregate used in concrete (Santos *et al.,* 2020). There are more hydroxyl ions in concrete when alkalis are present. Alkali silica gel is created when these hydroxyl ions combine with reactive siliceous aggregates. Alkali silica gel causes pressures in concrete structures as it expands over time. ASR causes fractures to form, which causes concrete members to shift (Munir, 2016). ASR reduces the longevity of concrete structures (Adanikin *et al.,* 2019). According to the study of Foroughi *et al*. (2012), alkali silica reactions in concrete are addressed and expansion potential is decreased when SCMs are partially substituted for cement.

Supplementary cementitious materials (SCMs) are incorporated into the manufacturing process of concrete in order to effectively solve environmental and waste management concerns (Chimmaobi *et al*., 2020). This is required because burning fuel and other industrial activities during the cement manufacturing process results in large amounts of CO_2 emissions, which are two major causes of global warming and ozone layer depletion. In addition to reducing the overall cost of building construction, the use of SCMs promotes resource efficiency, sustainability, and environmental responsibility in infrastructure development (Lothenbach *et al*., 2011; Onyelowe, 2019). Numerous agro-waste materials, including rice husk ash, bamboo leaf ash, sugar cane bagasse ash, cow bone ash, sawdust ash, eggshell ash, and many more, have been widely used in the investigations of (Ajayi *et al.,* 2023; Ahsan & Hossain, 2018; & Adanikin *et al.,* 2019) among others to independently lower the occurrence of ASR in concrete. One area where there is a knowledge vacuum is comparing the efficacy of different agro-waste materials (sawdust ash, rice husk ash, and bamboo leaf ash) in resolving ASR in rigid concrete and finding their areas of strength. Therefore, the goal of this research is to reduce the quantity of greenhouse gas emissions caused by the manufacture of cement using SCMs to achieve SDG goal 13, which is focused on climate action. The Sustainable Development Goal 11 (SDG 11), which aims to make cities and human settlements inclusive, safe, resilient, and sustainable, can be significantly advanced by partially substituting agricultural waste materials for cement in the production of concrete pavements.

Materials & methods

Collection of Materials

During the investigation, reactive aggregates were taken from a quarry in Akure. Bamboo leaves, sawdust, and rice husk were gathered from various areas of Ondo state, dried outdoors, and then burned in an electric furnace set to 750°C for 90 minutes. After being ground into a fine powder, the clinker was run through sieve #200, which is equal to 75µm, or 0.075 mm. Portland limestone cement (PLC), which complied with the requirements of (EN 196-*1,* 2016), was utilized in this experiment.

Chemical evaluation of the agro waste used

X-ray fluorescence (XRF) was used to determine the chemical composition of sawdust ash (SDA), rice husk ash (RHA), and bamboo leaf ash (BLA).

Creation of Samples

Following a thorough mixing of fine sand and cement, the coarse aggregate was added and manually swirled to ensure that it was uniformly distributed between the two materials. To partially replace cement by weight, the weights of SDA, BLA, and RHA at 0%, 5%, 10%, 15%, 20%, and 30% were measured and appropriately mixed. One Molar (1 M) of NaOH was added to the water used to cure the produced samples for the accelerated mortal bar test (AMBT). The constituent batching procedure is depicted in Figure 1.

Figure 1: batching of constituents for AMBT

Water Absorption test.

British Standard was followed for conducting the water absorption (WA) test (BS 1881-122, 2011). The concrete samples were weighed and kept in a curing tank for 28 days before the water absorption was measured. The specimens were shaken to remove most of the water, and then they were quickly dried with a cloth until the surface was free of any remaining water. Following a reweighing of the specimens, Equation (1) was used to calculate each specimen's percentage of water absorption.

$$WA = \frac{wet\ weigth\ - dry\ weight}{dry\ weight} x\ 100 \qquad (1)$$

Mortar Bar expansion.

Following VicRoads (2014) and ASTM C1260 (2009) guidelines, mortar bar specimens were prepared. After 7, 14, and 28 days, expansion was measured using ASTM C1293-20a (2020) and ASTM C1293 (2018) Standard methods for determining the length change of hardened cement paste, mortar, and concrete. The idea behind the test is that when ASR happens, concrete expands, and the extent of this expansion may be used to gauge how well SCMs suppress ASR. This test attempts to ascertain the amount of SCMs required to lessen the effect of ASR in the concrete by monitoring mortar bar expansion below the ASTM threshold.

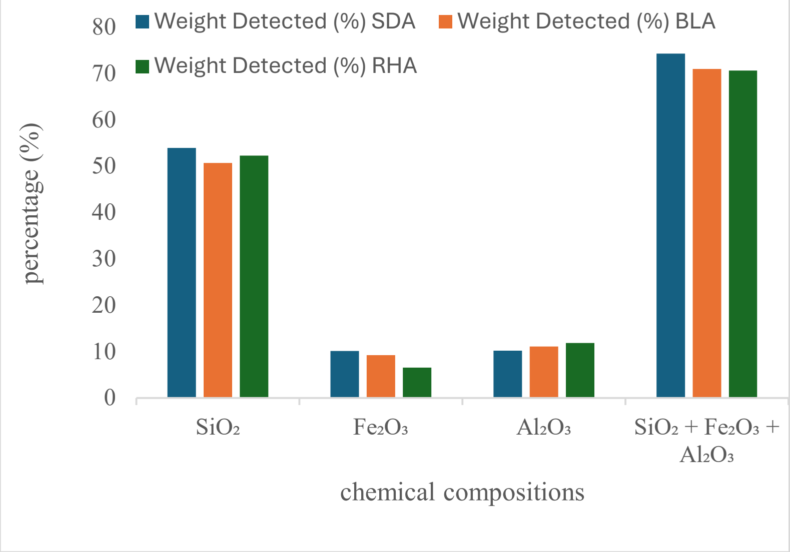

Figure 2: Chemical composition of the SCMs

Table 2: Classification of Standard Concrete Reactivity

Extension of Mortar Bars				Category
VicRoads 2013 and 2014 specification		ASTM C1260, (2009).	ASTM C 1293, (2018 & 2020)	
10 Days	21 Days	14 Days	28 Days	
< 0.010*	< 0.010*	< 0.020	< 0.040	Non-reactive
= 0.010*	= 0.010*	= 0.020	= 0.040	Slowly reactive
> 0.010*	> 0.010*	> 0.020	> 0.040	Reactive

Table 1: Water absorption result

Percentage replacement	Water Absorption result at 28 days of curing (%)		
	RHA	BLA	SDA
0	1.54	1.54	1.54
5	1.90	2.51	1.59
10	2.21	2.80	1.70
15	2.58	3.02	1.81
20	4.65	3.10	2.33
30	5.05	4.66	5.01

Because it shows a strong correlation between the 2-year expansion and the 14-day expansion of the accelerated mortar bar experiment, the experiment has gained widespread recognition (ASTM C1260, 2009). By monitoring the expansion of the concrete samples throughout the procedure, the test assesses how well SCMs inhibit ASR (Ajayi *et al.,* 2023b).

RESULTS & DISCUSSION

Chemical composition test Result

Pozzolanic reactivity of a material is mostly determined by its chemical composition, specifically the proportions of silica (SiO_2), aluminum oxide (Al_2O_3), and ferric oxide (Fe_2O_3). The secondary hydration processes in cementitious systems, which generate additional calcium silicate hydrate (C-S-H) phases that increase mechanical strength and durability, depend on these oxides. According to (ASTM C 618-94, 1994), a material must have at least 70% by weight of SiO_2, AlO_3, and FeO_3 to be regarded as class N pozzolan which is suitable for use in concrete. The result of X-ray fluorescence (XRF) investigation is shown in Figure 3.

All three materials surpass the ASTM C 618-94 (1994) minimum 70% specification, as seen in Figure 2. SDA, BLA, and RHA had respective total combined oxide contents of 74.24%, 70.94%, and 70.60%. This suggests that each of these ash types has enough reactive oxides to behave pozzolanically when mixed with Portland cement. A considerable potential for interaction with calcium hydroxide generated during cement hydration is suggested by the high silica concentration, especially in SDA and RHA. Furthermore, the higher concentrations of iron oxide and alumina aid in the production of calcium alumino-ferrite and calcium aluminate hydrates, which can further densify the cement matrix's microstructure.

Result of Water Absorption Test

Table 1 displays the water absorption results of cementitious mixtures that were partially replaced with rice husk ash (RHA), bamboo leaf ash (BLA), and sawdust ash (SDA) after 28 days of curing.

From Table 1, water absorption was highest for RHA, which increased continuously from 1.54% at 0% to 5.05% at 30%. Between 20 and 30 percent replacement, the increase was especially sharp. Additionally, water absorption rose with an increase in BLA replacement, but more slowly than with RHA. It increased significantly from 20% to 30%, reaching 4.66% to 30%. At lower percentages, SDA showed comparatively modest absorption (1.54% to 2.33%), but at 30%, it sharply increased to 5.01%.

The rate of change in absorption revealed that RHA absorption rose consistently by about 0.31% for every 5% replacement, with a more significant increase at 30%. BLA showed moderate increases, with a larger jump between 20% and 30%. SDA absorption rose marginally up to 20%, but increased significantly by 2.68% to 30%, indicating a threshold impact. The presence of silica and the bigger surface area of the ash sample account for the increased water need. This is because the cement hydration reaction utilizes less water than the silica-lime reaction (Salau *et al.*, 2012: Ugboaja *et al.*, 2022). The results are also consistent with the findings of Chimmaobi *et al.* (2020) and Olatokunbo *et al.* (2018).

Result of Accelerated mortal bar test

Table 2 displays the classification of standard Concrete Reactivity whereas Figures 3, 4 and 5 provide the findings of the AMBT test for BLA, SDA, and RHA, respectively.

In line with the specification of VicRoads (2014) as shown in Table 2 and the results shown in Figure 5, 0% replacement recorded a value of 0.012, indicating that it is reactive to ASR; at 5%, a value of 0.01 was recorded, indicating that it is slowly reactive; at 10%, 15%, and 20%, the samples are classified as non-reactive; and at 30% replacement, it is classified as slowly reactive. The ASTM C1293 (2018) classification, based on a 14-day immersion in 1M of NaOH, revealed that 0% replacement can be classed as reactive to ASR incidence with a value of 0.021, which is greater than the maximum value of 0.020. At 5%, 10%, and 15%, the values were 0.018, 0.017, and 0.010, respectively, and were considered non-reactive to ASR incidence. The ASTM C1293 (2018) standard demonstrated that 0% is slowly reactive, with a value of 0.040 after 28 days. 5%, 10%, 15%, and 20% measured 0.020, 0.023, 0.020, and 0.035, respectively, which is less than the necessary value of 0.040 and hence can be classed as non-reactive to ASR development. The 30% replacement recorded a value of 0.040, which can be classed as slowly reacting

BLA replacement in concrete is an efficient countermeasure against alkali-silica reactivity (ASR), with 10% and 15% BLA mixtures working ideally in terms of lowering expansion and mitigating the danger of ASR-induced cracking. These findings support the usefulness of BLA as a pozzolanic material in reducing alkali availability in the mix, hence mitigating the negative impacts of ASR. However, excessive BLA replacement (more than 20%) may result in reduced returns or even negative impacts, most likely to changes in the cementitious balance and porosity of the matrix, which impair the overall durability of the concrete.

Figure 5 shows that 5% has a value of 0.010 and is consequently designated as slow reactive under VicRoads (2014) specifications as shown in table 2. 10% and 15% are categorized as nonreactive, with reported values of 0.005 and 0.007, respectively. 20 and 30% replacement, with values of 0.019 and 0.018, respectively. According to ASTM C1293 (2018) classification, 5%, 10%, and 15% of the samples are non-reactive, with recorded values less than 0.020. Values greater than 0.020 indicate that 20 and 30% replacement are reactive to ASR occurrence. They recorded 0.025 and 0.030, respectively. In line with ASTM C1293 (2018) standard, 5, 10, and 15% replacements with reported values of 0.037, 0.019, and 0.022 are non-reactive. 20 and 30% replacement had values of 0.041 and 0.045, respectively, and are thus classified as reactive to ASR incidence. The optimal replacement level was determined to be 10%, which provided the least amount of expansion while providing the best performance. SDA at this level efficiently reduces alkali availability and improves durability by forming secondary C-S-H. However, replacement levels greater than 15% resulted in reactivity resurgence, most likely due to decreased cement content, insufficient pozzolanic reactivity, or poor matrix densification.

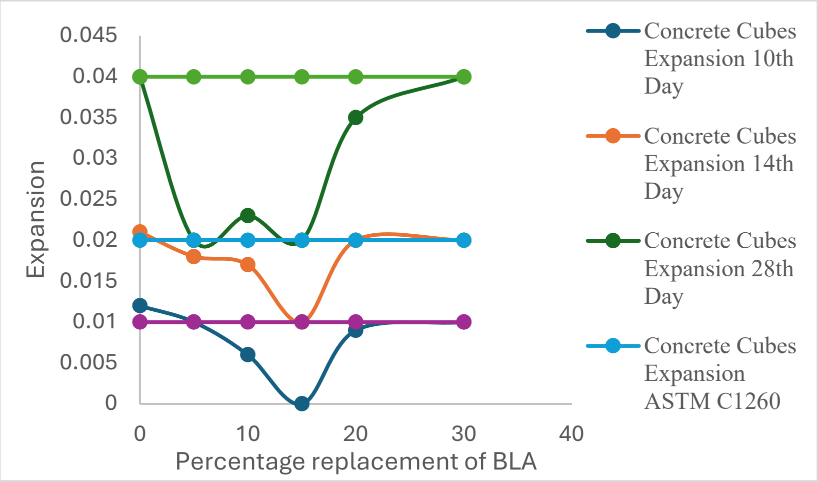

Figure 3: AMBT result for BLA

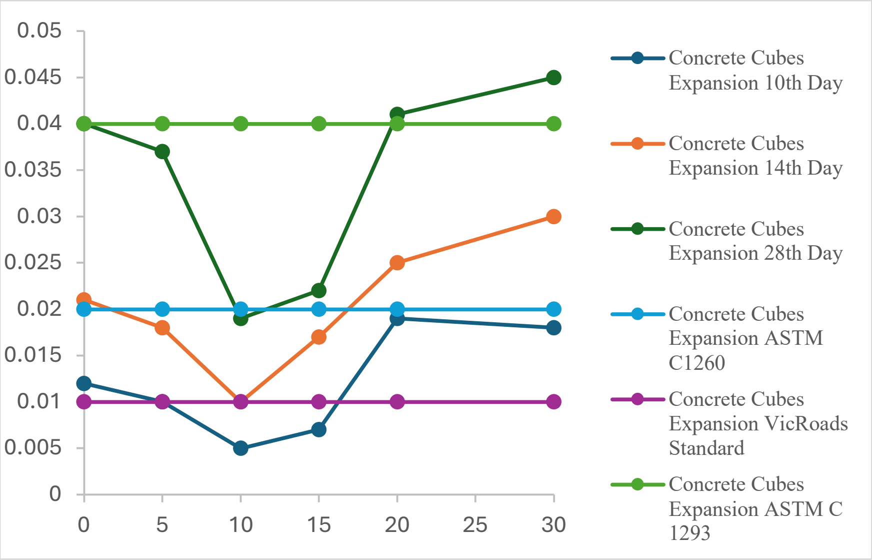

Figure 4: AMBT result for SDA

VicRoads (2014) categorization displayed in table 2 shows that 5% (0.12) is reactive. 10% and 15%, with values of 0.01 and 0.004, are classified as non-reactive. 20 and 30% are categorized as reactive, with expansion values of 0.016 and 0.017, respectively. ASTM C1293 (2018) reveals that 5%, 10%, and 15% recorded values of 0.013, 0.0003, and 0.007, respectively, and are categorized as non-reactive to ASR development. Twenty and thirty percent are known to be reactive, with extension values of 0.027 and 0.025, respectively. ASTM C1293 (2018) classified 5%, 10%, and 15% as non-reactive at values of 0.02, 0.01, and 0.11, respectively. The 20 and 30% RHA samples had 0.047 and 0.045, respectively, and were consequently classed as reactive. The best replacement amount was found to be 10-15%, with minimum expansion and concrete that was consistently non-reactive. RHA at this level improves concrete durability by lowering alkali availability and improving the pore structure via pozzolanic reaction. In contrast, replacement levels more than 15% resulted in increased expansion and reactivity, most likely due to decreased cement concentration, increased porosity, or incomplete combustion residues in the ash.

Comparative Analysis of BLA, RHA, and SDA on ASR Mitigation

According to ASTM, C1260. (2009), expansions less than 0.040% are deemed non-reactive. Among the three, RHA performed the best, with 10% and 15% replacements lowering 28-day expansions to 0.010% and 0.011%, respectively well below the reactive threshold. This is due to RHA's high amorphous silica content and higher pozzolanic activity, which effectively bind alkalis and decrease ASR gel formation. BLA also showed substantial

ASR mitigation, particularly at 10% and 15%, with expansions of 0.023% and 0.020%, defining it as non-reactive. Although slightly less effective than RHA, BLA provides consistent performance and long-term stability. SDA produced non-reactive classifications at 10% (0.019%) and 15% (0.022%), but its effectiveness declined as levels increased, with expansions greater than 0.040% at 20% and 30%. This implies that SDA has a shorter optimum range and is less chemically efficient than RHA and BLA. RHA excelled both BLA and SDA in terms of minimizing ASR-induced expansion, with BLA coming in second. SDA performed moderately with limited dose flexibility.

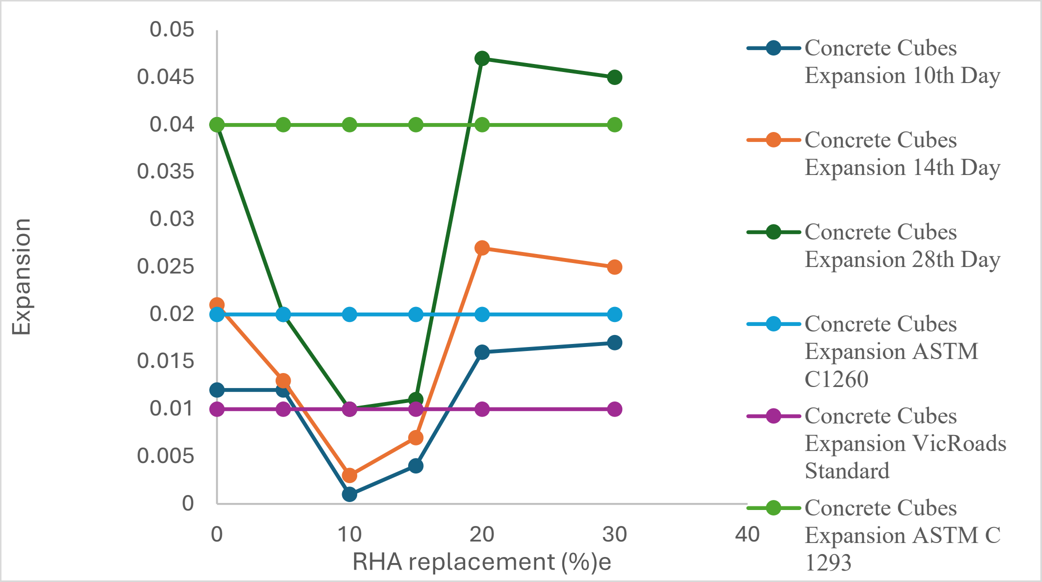

Figure 5: AMBT result for RHA

Conclusion

The study leads to the following conclusions:

- All three materials surpass the minimum requirement for class N pozzolan. SDA, BLA, and RHA had respective total combined oxide contents of 74.24%, 70.94%, and 70.60% for SiO_2, AlO_3, and FeO_3 and it is therefore classified as class N pozzolan. This suggests that each of these ash types has enough reactive oxides to behave pozzolanically when mixed with Portland cement.
- The result of the water absorption shows that the pozzolanic concrete samples absorbed more water than the control samples.
- RHA demonstrated the most effective approach to ASR mitigation. It has the lowest expansion values at 10-15% replacement and is best suited to aggressive ASR-prone situations.
- BLA demonstrated excellent and consistent performance. 10-15% replacement reduced expansion to 0.020-0.023%. BLA has long-term durability due to progressive pozzolanic activity and alkali binding, making it suited for general-purpose ASR mitigation.
- SDA gave reasonable ASR control. SDA is 10-15% effective, with expansions ranging from 0.019% to 0.022%. Its performance decreased by ≥20%, indicating a reactive state.
- Agro-wastes materials such as RHA, SDA and BLA should not be used at a replacement higher than 15% for effective ASR controls in concrete pavements.

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