Nigerian Journal of Technology (NIJOTECH)
Vol. 42, No. 4, December, 2023, pp.425 - 436
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v42i4.2

RICE HUSK AND SNAIL SHELL ASH AS PARTIAL REPLACEMENT OF ORDINARY PORTLAND CEMENT IN CONCRETE – A REVIEW

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ARTICLE HISTORY:
Received: 03 March, 2023.
Revised: 25 September, 2023.
Accepted: 13 November, 2023.
Published: 12 February, 2024.

KEYWORDS:
Carbondioxide emission, Concrete, Global warming, Rice husk ash, Snail shell ash.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji
Patrick Akpan

FUNDING:
BUK Nigeria, Kogi State Polytechnic, Kogi State Nigeria, and TETFUND

Abstract
This paper examines studies on the use of rice husk ash (RHA) and snail shell ash (SSA) as partial Ordinary Portland cement (OPC) replacements in concrete and their effects on concrete properties. RHA contains over 80% amorphous silica, along with other oxides in small quantities. Scanning electron microscopy (SEM) analysis showed that RHA has irregularly shaped particles with a porous, cellular structure. Similarly, chemical analysis of SSA revealed it contains over 60% active calcium oxide with minor oxides, and SEM analysis showed it has irregular semi-spherical particles with porous surfaces. The replacement of cement with RHA led to improved mechanical and durability properties in concrete, although workability was reduced. RHA also demonstrated resistance to chloride penetration. Combining RHA and SSA has the potential to produce stronger, more durable concrete, and could replace cement in high volumes in concrete production.

1.0 INTRODUCTION

Ordinary Portland cement is one of the main sources of carbon dioxide emissions, contributing between 7 to 8% of global annual carbon dioxide (CO_2) emissions [1] – [4]. Reportedly, each kilogram of Portland cement releases about one kilogram of carbon dioxide into the atmosphere [5] – [9]. To lower the relative cost of concrete and lower the carbon dioxide emissions from cement production, researchers have been investigating materials that have pozzolanic or cementitious properties and that can be used entirely or partially to replace ordinary Portland cement in the production of concrete. This is because ordinary Portland cement is a significant contributor to the cost of concrete production [10] – [12].

Numerous studies have been conducted on the use of wastes and pozzolanic materials such as silica fume, metakaolin (MK), and sawdust ash. fly ash, rice husk ash, snail ash, and cow bone ash, in the production of concrete. Studies have shown that these materials can impact the mechanical properties of concrete and can be cost-effective alternatives to ordinary Portland cement [5], [13]. According to a report referenced by [14], a ton of paddy rice can generate about 200 kg of rice husk, which, when burned, gives about 40 kg of ash [15], [16]. Nigerian rice production increased to

HOW TO CITE:
Alhassan, A., Aboshio, A., and Uche, O. A.“Rice husk and Snail Shell Ash as Partial Replacement of Ordinary Portland Cement in Concrete – A Review”, *Nigerian Journal of Technology*, 2023; 42(4), pp. 425 – 436; *https://doi.org/10.4314/njt.v42i4.2*

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around 8.17 million tons in 2020 [17], with over 1.6 million tons of rice husk produced. This highlights the need for further research into the potential applications of rice husk and its ashes in concrete production, not only for environmental concerns but also for cost-effective and durable concrete production.

According to [18], RHA is considered a class F pozzolan containing a combined proportion of silicon dioxide (S_iO_2), aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3) greater than 70%, depending on the calcined temperature [19], [20], comparable to fly ash [21]. However, Snail Shell Ash made from waste snail shells heated to 800°C has a high calcium oxide (CaO) content [22], [23]. In comparison to RHA, the silica content is lower, and it also contains other oxides like aluminium and iron oxides, as well as trace elements found in ordinary Portland cement [24]. According to studies, SSA is potentially good as an accelerating agent for cement hydration, enhances the formation of more calcium silicate hydrate (C-S-H) which is responsible for strength in concrete, and is an expansive agent in shrinkage treatment in concrete [25].

This review paper aims to address a gap in the literature by exploring the potential benefits of using RHA and SSA as partial replacements for ordinary Portland cement in concrete production.

2.0 PRODUCTION OF RHA AND SSA

The type of ash produced depends on the burning technique used. Rice husk incineration can produce either crystalline or amorphous RHA, depending on the burning technique employed [26] – [28]. [29], [30] reported that controlled burning of RHA at 600°C for 1 to 2 hours results in high SiO_2 content. Table 1 shows the various temperatures and durations used by researchers to produce amorphous silica from RHA.

In the case of snail shell ash, most studies recommend a calcination temperature of 700–800°C for at least 60 minutes to produce high-quality or amorphous calcium oxide [31] – [33].

Table 1: Different temperatures and burning duration used by various researchers for RHA

Researchers	Controlled temperature ℃	Burning duration
[34]	550-700	1hr
[35]	700	3 hr.
[36]	700	1hr
[7]	400-600	4-6hr.
[27]	600	-
[37]	600-750	-
[38]	700-950	3 hr.

2.1 Physical Properties of RHA and SSA

The particle size of RHA plays an important role in its pozzolanic activity. According to [39], RHA particles with a size of less than 45 microns have a higher pozzolanic activity index (PAI) compared to larger particles. [40], [41] also reported that RHA with a particle size less than 20 microns has a higher pozzolanic activity than larger particles. Therefore, reducing the mean particle size of RHA is recommended to enhance its pozzolanic activity, which can lead to concrete with improved strength and durability [42] – [45]. In addition to particle size, physical properties such as specific surface area, specific gravity, and colour also affect the behaviour of RHA in concrete [46], [47].

The specific gravity of RHA ranges between 2.02-2.30, which is lower than that of cement (3.1-3.14). This makes it a suitable replacement for OPC in the production of lightweight concrete [48], [49]. RHA can be white, grey, or black, but dark RHA indicates the presence of unburned carbon in the ash [50], [51]. The specific gravity of RHA can vary depending on the rice variety, geographical location, and combustion conditions during production [49], [52]. For example, RHA produced from a certain type of rice in one location may have a different specific gravity than RHA produced from a different type of rice in another location. The specific gravity of RHA can also be affected by the presence of impurities such as unburned carbon, which can reduce the specific gravity. In general, RHA with a lower specific gravity can produce lightweight concrete with good strength and durability [53], [54].

It is worth noting that the specific gravity of RHA is not the only physical property that can affect its behaviour in concrete. Other important properties include particle size distribution, specific surface area, and colour [47]. SSA, like RHA, also has a lower specific gravity than OPC, making it a suitable substitute for cement in either concrete or mortar. The average particle size of SSA ranges between 63 and 300μm, as shown in studies presented in Table 2.

Table 2: Particle size and specific gravity of SSA

Researcher	Size μm	Specific Gravity
[55]	< 90	3.07
[33]	<90	3.07
[56]	<63	2.44
[32]	<90	---
[24]	---	2.44
[57]	<300	2.47

2.2 Chemical Composition of RHA and SSA

In recent studies as shown in Table 3, it has been observed that RHA has high reactivity due to its high

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silica content which is generally more than 70%. This makes it a suitable alternative to traditional pozzolans in concrete production and is attributed to be responsible for improving the strength and durability of the concrete [58], [59]. In addition to its high silica content, RHA also has a low calcium oxide content which distinguishes it from other pozzolans [60]. On the other hand, the oxide composition of SSA does not meet the requirements for a class F or C pozzolan based on [61]. However, it has been found to have similar oxide compositions to ordinary Portland cement which can have an impact on its behaviour in concrete [33]. The CaO content of SSA can vary depending on factors such as the calcination temperature and time, and the cleaning technique used during production [62], [63].

Table 3: Oxide Composition of RHA, SSA, and OPC

RESEARCHERS – RHA	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	TiO_2	MnO_2	LOI	SAF
[64]	93.0	0.17	0.35	0.91	0.42	0.11	0.63	2.86	--	--	--	4.7	93.5
[65]	86.0	1.16	1.85	0.64	0.77	0.32	1.14	2.54	--	--	--	4.77	89.01
[66]	87.2	0.15	0.16	0.55	0.35	0.24	-	-	--	--	--	5.44	87.51
[67]	93.7	2.11		0.10	0.53	0.45	0.81	1.18	0.96	--	--	0.16	95.81
RESEARCHERS - SSA													
[68]	1.32	1.52	2.53	88.2	0.3	--	--	1.4	0.07	0.01	0.02	4.57	5.37
[55]	0.9	0.51	0.56	56.09	0.69	0.19	1.2	--	0.21	0.03	0.02	35.54	1.67
[69]	0.78	0.83	0.62	50.13	0.59	0.24	1.44	0.17	0.00	0.20	0.03	42.04	2.23
[24]	10.2	4.81	3.15	61.95	0.18	0.03	0.04	0.05	--	0.01	0.01		18.16
[33]	0.60	0.51	0.56	51.09	0..69	0.19	1.2	0.12				40.54	2.20
OPC													
[19]	20.99	6.19	3.86	65.96	0.22	--	--	0.20	--	--	--	1.73	31.04
[70]	20.62	6.01	3.22	59.6	3.65	2.46		0.71	--	--	--	--	29.85

2.3 Microstructure of RHA and SSA

The physical and chemical characteristics, as well as the reactivity of ash, previously mentioned, have also been confirmed by several analytical techniques, including elemental analysis, X-ray fluorescence (XRF), X-ray diffraction (XRD), and scanning electron microscopy (SEM). There was no discernible difference in the chemical composition of the RHAs with different grinding times, as revealed by the X-ray diffraction analysis conducted on the samples under consideration in the study on the effects of grinding fineness on the mechanical, hydration, and porosity properties of RHA [62], [71].

According to [72], the best conditions for a highly active, large surface area that ensures structural porosity and the elimination of residual carbon and other metal impurities are provided by RHA burned at 600°C for 1–2 hours. Reports indicate that RHA burnt for an hour or two at 600°C remains amorphous but crystallizes around 700°C [73], [74]. [75] also reported that below 500°C, organic material remains in the ash, and above 800°C, silica changes its structure from amorphous to crystalline, which decreases the pozzolanic reactivity between remaining portlandite (C-H) from the first hydration reaction and silica from the RHA (i.e., with a crystalline structure of silica, a pozzolanic phase reaction of strength forming hydrates, i.e., C-S-H formation, is not possible). On appearance, SEM revealed that RHA burned at 700℃ for 1 hour is darker than that burned at 600℃ for 1 to 2 hours and contains some black particles as an indication of carbon residues and a high percentage loss of ignition.

Scanning electron microscopy (SEM) and Transmission Electron Microscope (TEM) on selected samples of RHA showed that RHA has a three-layered structure that is inner, outer, and interfacial with honeycombed and interstitial pores [29]. [76] also confirmed that RHA has irregular-shaped particles with a sizable fraction showing a porous cellular structure. These pores are the main reason for the very large specific surface area and very high chemical activity of RHA. The study by [77] on the SEM of RHA revealed that it contains a significant amount of irregularly shaped particles, a significant portion of which showed a porous cellular structure. Additionally, [78] verified that the amorphous powder formed into a well-defined flat, elongated nano-sized rods with a smooth outside surface on the SEM micrographs.

According to [79], X-ray diffraction (XRD) analysis of uncalcined snail shells showed that the major component was ($CaCO_3$) which existed in two crystalline phases, aragonite and calcite, as confirmed by [80]. However, after calcination at a temperature of 800°C or higher, all ($CaCO_3$) was converted into calcium oxide (CaO), as indicated by the sharp and intense peak in the XRD pattern. This finding is consistent with those of previous studies by [80] and [32]. [81], [82] and [32] have shown that calcination of snail shells between 800-900 ℃ resulted in the

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formation of semi-spherical particles of irregular size and a porous surface, as presented in Figure 1. The X-ray fluorescence (XRF) analysis by [81] confirmed that CaO was the main mineralogical element in SSA, with a concentration of 70.113% CaO, 0.362% MgO, 0.159% (Al_2O_3), and 0.109% SiO_2.

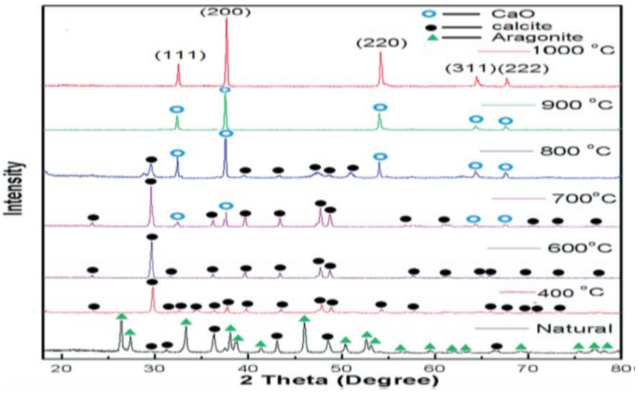

Figure 1: XRD patterns of natural snail shells and calcined snail shells of different temperatures ranging between 400 to 1000 C for 4 h [82]

3.0 EFFECTS OF RHA AND SSA ON FRESH AND HARDENED PROPERTIES OF CONCRETE

3.1 Effects of RHA on the Workability of Concrete

According to [83], workability is one of the fresh properties of concrete which affects strength and durability as well as the cost of labour and appearance of the finished product. In a study by [84], the workability of concrete with RHA was investigated. According to the findings, adding RHA to concrete has a negative impact on its workability. As the proportion of RHA in the mix increases, the total specific surface area and porosity of the cementitious material also increase. This, in turn, increases friction resistance and hinders the flow of the mixture, resulting in reduced slump and workability of the concrete. However, the addition of a superplasticizer improved the workability of concrete with RHA. [85] investigated the effects of RHA on the rheological properties of self-compacting concrete (SCC). The results showed that the incorporation of RHA decreased the workability of SCC due to the increased water demand and reduced flowability. However, the use of a viscosity-modifying agent improved the workability of SCC with RHA.

According to a study by [27], the inclusion of RHA above 7 percent and below 10 percent resulted in decreased workability of concrete. However, the use of RHA was still beneficial for mass concrete. [86] found that the addition of RHA significantly reduced the workability of wet concrete. This was due to the lower density of RHA compared to the ordinary cement matrix. These findings are consistent with earlier studies [87], [88], which identified RHA's large specific surface area and porosity as the main cause for decreased workability in concrete.

In conclusion, the use of RHA as a supplementary cementitious material in concrete has been shown to have a positive effect on the workability, compressive strength, and durability properties of concrete. The studies cited in this literature review demonstrate the potential benefits of using RHA in concrete production. Further research is needed to investigate the optimal amount of RHA to use in concrete mixtures and to study the long-term durability of concrete containing RHA.

3.2 Effects of Snail Shell Ash on the Workability of Concrete

Studies conducted by [68], [89], and [90] have indicated that the workability of concrete decreases with an increase in the percentage of SSA replacement. The reduction in workability is due to the smooth and greasy surface of SSA, which limits its ability to absorb water in comparison to cement [68]. Moreover, the irregular shape of SSA particles at the micro level results in an increased surface area, which leads to higher interparticle friction, requiring a larger amount of paste to ensure a desired level of rheology [89]. However, [89] also noted that the use of sufficient superplasticizers can improve the workability of concrete containing SSA).

In conclusion, the use of SSA in concrete production can have both positive and negative effects on the workability of concrete. The addition of SSA can decrease the workability of the concrete, but the use of a superplasticizer or PCE can improve the workability. Furthermore, the addition of SSA can decrease the compressive strength of the concrete, but the use of PCE can enhance the compressive strength. However, more studies are needed to fully understand the effect of SSA on the mechanical and durability properties of concrete.

3.3 Effects of SSA on Compressive Strength of Concrete

The compressive strength of concrete is the common strength parameter that can be measured under laboratory and on-site conditions. According to [27], the addition of RHA to concrete mixtures in small percentages (2, 4, 7, 10, and 12%) led to an increase in compressive strength. However, an optimum addition of 10% by weight of cement was observed, beyond which an increase in RHA content decreased

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the strength of the concrete, making it dry. The compressive strength of the resulting concrete cubes was measured after 28 days of curing using a universal testing machine. The result of the experiment is represented in Figure 2.

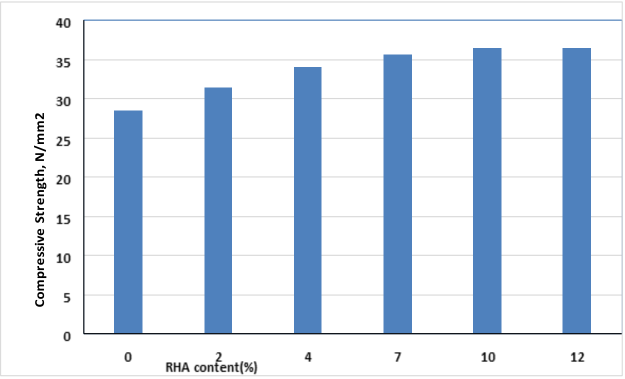

Figure 2: Graph of compressive strength against percentage replacement of RHA

[4] examined the pozzolanic properties of rice-husk ash (RHA) obtained from seven different sources in Nigeria, namely Ogoja, Abakaliki, Adani, Adikpo, Obubra, Makurdi, and Vandikya. Among these sources, the samples from Ogoja displayed the highest pozzolanic properties, characterized by a silica content of 84.55%. For the concrete mix, a ratio of 1:1.5:3 was utilized, and the compressive strength values were measured at 28 days of curing. The results showed that at varying levels of RHA content, the compressive strength ranged from 37 to 42 N/mm² with 5% RHA, 35 to 39.5 N/mm² with 10% RHA, 30 to 34.5 N/mm² with 15% RHA, 27 to 29 N/mm² with 20% RHA, 22 to 25.6 N/mm² with 25% RHA, and 21 to 24 N/mm² with 30% RHA. These values were compared to the control sample, which had a strength of 42.64 N/mm². [91] carried out a comparative study on the use of RHA as a partial replacement for cement in concrete specimens and reported a decrease in compressive strength with an increase in RHA content. The control had a higher compressive strength than any replacement by RHA, and a 10% cement replacement with RHA was found to be optimum for the compressive strength of concrete.

[92] Carried out a study to enhance High-Performance Concrete (HPC) through the utilization of rice husk ash as a partial substitute for Ordinary Portland Cement (OPC), evaluating its effectiveness by preparing concrete cubes with varying percentages of rice husk ash. The study established that substituting Ordinary Portland Cement (OPC) with rice husk ash in High-Performance Concrete (HPC) enhances compressive strength. Concrete cubes with varying rice husk ash percentages revealed peak performance at 7.5% OPC replacement, yielding 66 MPa compressive strength at 28 days. The hydration properties of rice husk ash-containing cubes were examined, affirming their effectiveness in HPC enhancement. In summary, this study showcased rice husk ash as a supplementary cementitious material (SCM) in HPC, boosting strength and durability.

[93] evaluates the use of RHA as an SCM in concrete and its impact on strength performance. The results as shown in Figure 3 indicate that a replacement ratio of 7.5% of RHA achieved an optimum compressive strength of 40.65 MPa at 28 days and 48.79 MPa at 91 days. These findings suggest that RHA can effectively enhance the strength performance of concrete and contribute to sustainable construction practices.

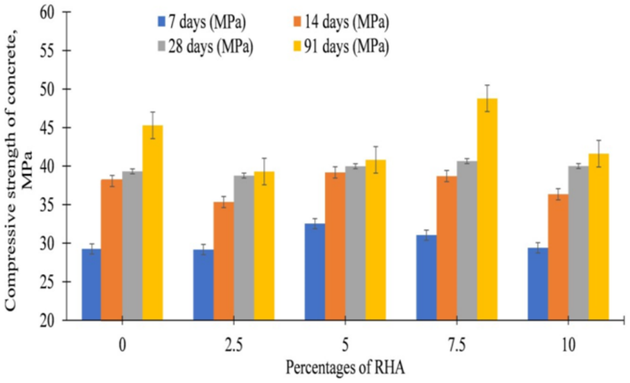

Figure 3: Compressive strength vs Percentages of RHA [93]

[87] investigated the effect and possibility of RHA as an admixture to cement in concrete production. Four different replacement levels (5%, 10%, 15%, and 20%) were selected and the specimens were cured for 7 and 28 days. The study concluded that there was an improvement in compressive strength from a period of 7 days to 28 days for mixes with varying percentages of RHA. Table 4 as presented in the study indicates that the 28-day strength increases from 27 MPa to 29.3 MPa with the incorporation of 10% RHA. This 8.51% enhancement of compressive strength of concrete with RHA was attributed to the increase in pozzolanic action when RHA was added to concrete production, and an increase in RHA content beyond 10% decreased the compressive strength.

Table 4: Compressive strength percentage variation to 0% RHA [87]

% of RHA	Compressive strength for 28 days curing period	Percentage change from 0% replacement
0	27	-
5	24.8	-8.15
10	29.3	-8.51

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15	17.6	34.81
20	16.03	40.62

Although different researchers [53], [94] – [98] reported an increase in compressive strength due to cement replacement with RHA in concrete production to a certain optimal replacement that varies between 5-30%, the increment is generally due to the silica content, fineness, and specific surface area of RHA [76].

3.4 Effects of SSA on Compressive Strength of Concrete

The impact of snail shell ash (SSA) on the compressive strength of concrete has been studied by various researchers. The results indicate that the compressive strength of SSA concrete increases up to a certain percentage replacement of cement by weight, after which it decreases. [68] conducted a compressive strength test on concrete cubes with varying percentages of SSA and found that the compressive strength increased with higher SSA. [55] reported a gradual increase in compressive strength up to 20% replacement of cement with SSA, after which there was a decrease. [24] investigated the use of mollusc shells, including snail shells, as replacements for Ordinary Portland Cement (OPC) and found that 20% SSA content resulted in optimal strength.

[33] also studied the use of snail shell powder (SSP) as a partial replacement for OPC and found that 5% SSP replacement resulted in the highest compressive strength. The decrease in compressive strength at higher percentages of replacement may be due to insufficient burning of the shells, which prevents the conversion of calcium carbonate to calcium oxide.

3.5 Effects of RHA on Durability of Concrete

[91] discovered that utilizing rice husk ash as a partial replacement for ordinary Portland cement or as an admixture could improve the durability of concrete. [98] investigated the impact of RHA on the strength and durability of concrete at different replacement levels. To conduct the study, three types of rice husk ash with varying chemical compositions and physical properties were employed, and ordinary Portland cement (OPC) of grade 52.5N was substituted with 5%, 10%, 15%, 20%, 30%, 40%, and 50% RHA (by weight) for the strength test, with additional samples of 60% RHA replacement for the durability experiment. A superplasticizer was utilized to maintain the consistent workability of the fresh concrete, and the water/cementitious material ratio was maintained at 0.50 throughout the study. Non-steady-state migration tests were used to assess the migration coefficient of chloride ion penetration at 28 days of age. The results revealed that up to 50% RHA (by weight) could be used in concrete without affecting its strength and durability. This was because increasing RHA replacement levels decreased porosity, resulting in increased strength and durability

According to a study conducted by [99], the addition of rice husk ash (RHA) to blended cement concrete results in increased resistance compared to concrete without RHA after 360 days of curing. Additionally, the study found that as the water-to-cement ratio (W/C) increases, concrete without RHA experiences a decrease in resistance to sulfate attack, while concrete with RHA exhibits significant resistance. According to [96], the incorporation of RHA into high-performance fine-grained concrete significantly enhances its resistance to chloride penetration. The study found that the higher the replacement level of RHA, the greater the resistance to chloride penetration. Furthermore, the resistance to chloride penetration of concrete mixed with 15% and 20% RHA was similar to that of concrete mixed with 10% silica fume (SF). It was also noted that the corrosion of reinforced bars can occur when the concentration of chloride in concrete exceeds a certain limit [100], making chloride penetration resistance a crucial factor in ensuring the durability of concrete structures [96].

[96] investigated the mechanical abrasion resistance of concrete samples 28 days after curing. The study found that as the abrasion index increased, the mechanical abrasion resistance decreased. However, the high-performance fine-grained concrete (HPFGC) exhibited high mechanical abrasion resistance. The addition of RHA to HPFGC resulted in a lower abrasion index, indicating improved abrasion resistance. Specifically, the blend containing 10% RHA exhibited the lowest abrasion index measurement of 0.0006 g/mm2. Additionally, the abrasion index of the 10% SF concrete was similar to that of the 10% and 15% RHA samples. [101] conducted experiments to evaluate the corrosion performance of concrete with rice husk ash (RHA) using various techniques, such as compressive strength, bond strength, and split tensile strength. The corrosion performance was assessed using open circuit potential measurements, rapid chloride ion permeation test, and impressed voltage test. The study found that incorporating RHA up to 30% replacement level reduced chloride penetration, decreased permeability, and improved strength and corrosion resistance properties. Based on their findings, the recommended replacement level of RHA is up to 25%. Similarly, [96] reported that the use of RHA significantly enhances the resistance to chloride

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penetration of high-performance fine-grained concrete.

In conclusion, the use of RHA in concrete is beneficial in improving its durability. By reducing porosity, RHA can increase the strength and durability of concrete, making it more resistant to sulfate attack, chloride penetration, and mechanical abrasion. The findings suggest that RHA can be used as a partial replacement of ordinary Portland cement or as an admixture to improve the durability of concrete.

3.6 Effects of SSA on the Durability of Concrete

The durability of concrete produced by partially substituting cement with calcined snail shell ash has been studied and reported in the literature lightly in terms of water absorption, porosity, and resistance to chemical attacks, but other mollusk shell ashes such as periwinkle, oyster, and cockle shells with similar physical and chemical composition have been reported and were found to improve the durability properties of the resulting concrete [24], [102].

Overall, the studies suggest that SSA has the potential to improve the durability of concrete. While the water absorption resistance of SSA may vary depending on the percentage of SSA used, the carbonation, sulphate, and acid resistance of SSA are generally higher than that of conventional concrete. However, further research is needed to optimize the usage of SSA and to investigate its long-term durability in real-world applications.

4.0 CONCLUSION

In summary, rice husk ash (RHA)is composed of mostly silica with small amounts of alkalis and trace elements. The RHA properties depend on the burning temperature, with controlled burning at 500-700°C producing amorphous ash and uncontrolled burning at higher temperatures producing less reactive and crystalline ash. When used in concrete, the calcination temperature, fineness, and specific surface area of RHA all play a role in its effectiveness as a supplementary cementitious material. The addition of RHA in concrete can improve mechanical and durability properties but may reduce workability. Optimal replacement levels for RHA in concrete production are typically around 10% by weight of cement.

Similarly, snail shells (SSA) contain a high percentage of calcium carbonate and can be combusted at a controlled temperature of 700-800°C to produce ash with a high proportion of reactive calcium oxide. This ash, known as quicklime, has an oxide composition similar to OPC and can replace cement in concrete production. However, the inclusion of SSA can also affect the setting time, density, and workability of concrete. Optimal replacement levels for SSA in concrete production typically range from 5 to 20%, depending on the amount of reactive calcium oxide present in the ash. Based on the literature reviewed, it is evident that RHA, classified as a pozzolan, boasts a high Silicon dioxide content. This Silicon dioxide readily combines with portlandite generated during the cement hydration process. Conversely, SSA exhibits a richness in CaO, a component known to produce heat during its formation and inherent expansiveness. By blending RHA and SSA, there is an opportunity to harness their complementary oxide compositions and their filling effect in the interstitial transition zone, potentially leading to the production of high-strength and durable concrete.

Future research in the field of concrete production, which involves the combination of rice husk ash (RHA) and snail shell ash (SSA), encompasses several critical areas of study. These areas include determining the ideal blending ratios to optimize the properties of concrete, evaluating how concrete performs at higher temperatures, examining its long-term durability in various environments, exploring the potential for mitigating alkali-silica reactions, and gaining an understanding of how the microstructure of the concrete changes over time. Furthermore, it is essential to consider the impact of RHA and SSA on the properties of freshly mixed concrete, their compatibility with admixtures, and conduct life cycle assessments to assess their environmental effects. Economic feasibility analyses will be conducted to assess cost implications. This multifaceted research approach collectively advances the development of sustainable concrete technology and its potential applications in the construction industry.

5.0 ACKNOWLEDGMENT

The authors would like to thank BUK, Nigeria, Kogi State Polytechnic, Kogi State, Nigeria, and TETFUND for the support and assistance to achieve this paper.

6.0 CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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