Evaluation of Fresh and Hardened Properties of Concrete made with Rice Husk Ash admixed with Snail Shell Ash

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ABSTRACT

The objective of this study is to evaluate the properties of concrete incorporating Rice Husk Ash (RHA) and Snail Shell Ash (SSA) as partial replacements for cement. Cement production is a significant emission source of CO2, necessitating environmentally friendly alternatives. This research examines the combined impact of these ashes on concrete performance. RHA and SSA were employed as Supplementary Cementitious Materials (SCM) to partially replace Portland cement. The replacement levels were: RHA at 0%, 5%, 7.5%, 10%, 12.5%, and 15% and SSA at 0%, 15%, 17.5%, 20%, 22.5%, and 25% by weight. A response surface methodology was employed to design the experiments, resulting in 18 experimental runs or mixes. A number of experiments were conducted, including slump, compressive strength, flexural strength, splitting tensile strength, and water absorption tests. The results demonstrated that the workability of the fresh concrete decreased with the addition of ashes. However, the RHA-SSA concrete exhibited enhanced strengths and durability. The optimal mix, M11, which contained 15% RHA and 15% SSA, exhibited the highest strength values at both 28 and 90 days. The RHA-SSA concrete displayed reduced porosity, with M10 (15% RHA, 25% SSA) demonstrating the lowest water absorption (5.1%) compared to 13.1% for the control mix. These findings substantiate the use of RHA-SSA concrete as a sustainable alternative in construction, addressing both environmental and performance-related concerns.

Keywords-cement; CO_2; rice husk ash; snail shell ash; concrete

I. INTRODUCTION

Carbon dioxide emissions from industrial activities, particularly those associated with Portland cement production, have a significant impact on the environment [1-3]. Ordinary Portland cement is a substantial contributor to the CO_2 emissions, accounting for approximately 7-8% of the global emissions on an annual basis [4-6]. The production of one kilogram of Portland cement results in the release of an equivalent amount of CO_2 [7]. In order to mitigate these emissions and reduce the high cost of Portland cement [8, 9], researchers are exploring alternative materials with pozzolanic or cementitious properties that could be used to replace Portland cement in concrete. The hydration reaction of Portland cement produces ettringite, Calcium Silicate Hydrate (C-S-H), and portlandite [10, 11]. The formation of C-S-H enhances the mechanical properties of concrete. The reaction of pozzolans with portlandite results in the formation of new binding products. However, only approximately 22% of free portlandite reacts with pozzolans to generate secondary C-S-H, with some forming additional ettringite [12, 13]. Research has concentrated on the usage of waste and pozzolanic materials, including fly ash, silica fume, blast furnace slag, metakaolin, RHA, SHA, cow bone ash, and sawdust ash, in concrete. These materials are cost-effective and have an impact on the mechanical properties of concrete [7, 14, 15]. Rice husk, a copious agro-waste product, yields approximately 40 kg of ash per ton of paddy rice [16, 17]. RHA is classified as a class F pozzolan according to ASTM C618 [18]. It contains a minimum of 70% silicon dioxide, aluminum oxide, and iron oxide. The optimal cement replacement ratio with RHA is approximately 10% by weight, which has been demonstrated to enhance the strength of concrete [19, 20]. RHA, an agricultural waste product, was discovered to contain a considerable quantity of silica, rendering it an excellent substitute for cement in the production of geopolymer and concrete [21].

Calcined at 800°C, SSA, which is rich in calcium oxide, accelerates cement hydration, thereby providing additional portlandite for C-S-H formation [22, 23]. Given a calcium oxide content of approximately 50%, SSA is an appropriate SCM, with an optimal replacement rate of around 10%. However, up to 15% can enhance the properties of concrete [24-26]. To enhance the mechanical properties of concrete while reducing its cost, numerous studies were performed on the combination of cement, RHA, and SSA in the production of concrete. Furthermore, authors in [27] discovered that incorporating 15% RHA as an admixture into concrete, in comparison to the standard M30 concrete with a constant water-to-cement ratio of 0.45, resulted in enhanced compressive, tensile, and flexural strength at 28 days, along with augmented ultimate load for reinforced beams. Authors in [28] investigated the use of RHA to partially replace cement in lightweight, aerated concrete. Their findings indicated that 10% RHA significantly enhanced the strength and durability properties of the concrete, including density, compressive, split tensile, and flexural strength, as well as resistance to corrosion and sulfate attack at various curing periods (3, 7, 28, and 90 days). Additionally, the incorporation of aluminum powder (0.5% of binder weight) was observed to facilitate aeration. Authors in [29] examined the potential of snail shell waste as a means of enhancing concrete. The replacement of 6% of the cement with snail shell powder resulted in a 12% increase in compressive strength, an 8% increase in axial strength, and a 9% increase in bending tensile strength. The axial tensile strength increased by 11%, and the elastic modulus increased by 8%. The results of the microstructure analysis validated these enhancements, indicating that a dosage of 6% is the optimal level for achieving effective improvement. Authors in [30], examined the corrosion resistance of SSA in marine settings indicating that SSA-cement blends, with replacement levels ranging from 0% to 50%, enhanced corrosion resistance and strength at critical levels from 20% to 30% SSA. This suggests that SSA could be a viable substitute for natural limestone in cement production, potentially improving concrete performance in marine environments while reducing dependence on natural resources. In a related study, Authors in [31] evaluated the use of snail shell powder in cement mortar, replacing cement by up to 35% in 5% increments. The optimal usage level was determined to be 30%, which led to enhanced durability. X-ray diffraction (XRD) was employed to ascertain the composition, while mechanical property and durability tests were conducted to evaluate the material's performance. A microstructural analysis revealed the presence of C-S-H gel formations in both mortar types. Authors in [32] explored the potential of SSA as a partial cement replacement in concrete. They analyzed the effects of varying SSA levels (0%, 5%, 10%, 15%, and 20%) in a 1:2:4 concrete mix with a water-cement ratio of 0.5. The findings of the study indicate that concrete incorporating SSA can be used for structural applications with SSA levels below 20%.

It is noteworthy that cement has the greatest impact on the cost and quality of concrete. Furthermore, cement is the most environmentally detrimental material used in concrete production, resulting in the emission of considerable quantities of CO_2 into the surrounding environment. Therefore, one method of mitigating these consequences is by reducing the usage of cement. This can be accomplished by incorporating materials (in finely powdered form) that contain pozzolanic and/or cementitious substances to partially substitute for cement in concrete. RHA has been found to possess high pozzolanic properties (SiO_2), yet its incorporation as a SCM in concrete does not significantly enhance the material's properties. In contrast, SSA contains a high calcium (CaO) content. It is therefore anticipated that the use of blends of RHA and SSA will significantly promote the pozzolanic and hydration reactions in concrete through the combined effects of SiO_2 and CaO. While the benefits of RHA and SSA have been well documented, their combined effect in concrete remains relatively unexplored. This research project examines the mechanical and durability properties of concrete using RHA and SSA as partial cement replacements, with the objective of determining the optimal substitution rate through the testing of various proportions. The objective of this study is to develop a sustainable and high-performance concrete that exploits the properties of RHA and SSA.

II. MATERIALS AND METHOD

A. Materials

The research employed ordinary Portland cement (Dangote 3X Cement, grade 42.5N) sourced from Dangote Cement PLC in Nigeria. This cement met the ASTM C150 [33] standards. RHA was procured from a rice mill in Dakace, Zaria, Kaduna State. It was produced via controlled burning at 650°C, in accordance with the methodology outlined by authors in [34, 35], and then sieved through a 75 μm mesh. SSA was procured from Owo, Ondo State, subjected to calcination at 800°C for an hour and a half, and then sieved in a manner consistent with the aforementioned procedure. The oxide compositions were analyzed using X-ray Fluorescence (XRF) at the Dangote Cement Factory Obajana, following the methodology described by authors in [36], with specific gravities determined according to the provisions of BS-EN-12620 [37], as described in Table I. The crushed granite used in the study was procured from a conventional quarry site operated by Abduljalil Hajaig and

Sons Ltd. The coarse aggregate has a nominal diameter of 20mm and complies with the specifications set forth in BS 882 [38]. The specific gravity of the coarse aggregate was determined to be 2.68 in accordance with the standards set forth in BS-EN-12620 [37]. The fine aggregate was procured from the River Challawa in Kano state, and its physical characteristics were found to align with the specifications outlined in BS 882 [38]. The results of the sieve analysis, as shown in Figure 1, indicate that the fine aggregate falls within Zone 2.

TABLE I. PROPERTIES OF BINDER

Chemical composition (%)	Cement	RHA	SSA
CaO	59.6	0.68	53.03
SiO_2	20.62	79.94	0.79
Al_2O_3	6.01	1.15	0.09
Fe_2O_3	3.22	0.68	0.32
SO_3	2.46	–	0.19
K_2O	0.71	0.17	0.07
MgO	3.65	0.44	–
Cl	0.98	–	0.034
P_2O_5	0.117	–	–
TiO_2	0.209	2.91	–
Cr_2O_3	0.001	–	–
Mn_2O_3	0.036	0.345	0.02
ZnO	–	–	–
Loss of Ignition	3.2	11.81	36.89
$SiO_2+Al_2O_3+Fe_2O_3$	29.85	81.77	1.2
Specific Gravity	3.16	2.1	3.01

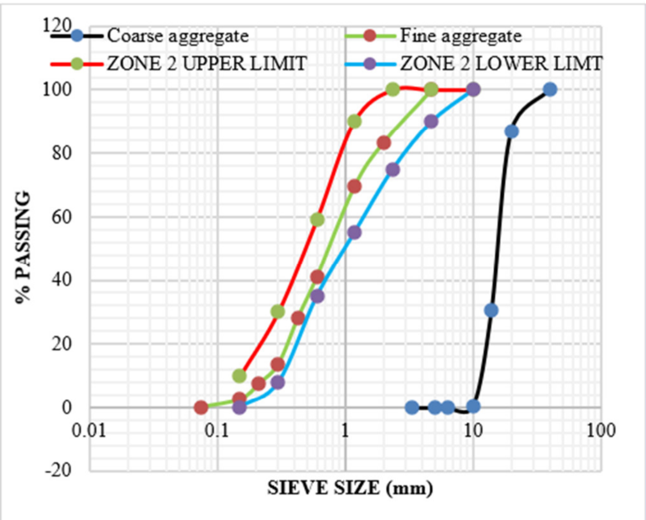

Fig. 1. Particle size distribution of aggregates.

B. *Mix Proportioning and Samples Preparation*

The mix design was developed in accordance with the DOE method for grade 30 concrete, with the objective of achieving a mean strength of 38.25 N/mm² and a 1:1.8:2.9 mix ratio for cement, sand, and coarse aggregate. Additionally, an adjusted water-binder ratio of 0.6 was incorporated to ensure workability (30 mm-60 mm). The Response Surface Methodology (RSM) in Design Expert 13 software was employed to optimize the mix proportions for RHA and SSA concrete. The User-Designed option yielded 17 experimental runs or mixes, in addition to the control mix, with RHA at 0%, 5%, 7.5%, 10%, 12.5%, and 15% by weight of cement, and SSA at 0%, 15%, 17.5%, 20%, 22.5%, and 25% by weight of cement. The parameters measured were compressive strength, flexural strength, splitting tensile strength, and water absorption. The optimized mix proportions, as evidenced in Table II, were employed to assess the effects and interactions of RHA and SSA in concrete. The contents of the cement, RHA, and SSA were varied, while the coarse aggregate, fine aggregate, and water contents remained constant across the mixes. The constituents of the RHA-SSA concrete mixture were measured by weight in accordance with the designed experimental runs or mixes generated using RSM, which incorporated SCMs in accordance with the specified specifications. The mixing process was conducted manually with a shovel and tray, in accordance with the guidelines set forth in BS EN 206 [39]. Mechanical strength and durability tests were conducted on specimens prepared in the laboratory. These included compressive strength tests on 100mm cubes, flexural strength tests on 100 mm x 500 mm prisms, splitting tensile strength tests on 100 mm x 200 mm cylinders, and water absorption tests on 100 mm cubes. Immediately following the testing of each mixture, concrete specimens were cast. To facilitate the removal of the concrete after setting, the molds were lubricated. The concrete was compacted in three stages to reduce the number of voids. Following the casting process, the samples were left to stand for a period of 24 hours prior to demolding and labeling. The specimens were submerged in curing tanks at a temperature of (27 ± 2) °C for durations of 3, 7, 28, 56, and 90 days, with the exception of the water absorption specimens, which were cured for 28 days.

TABLE II. MIX PROPORTIONS

Mix ID.	Variables (%)		Constituent materials in kg/m^3					
	RHA	SSA	Cement	F.A	C.A	Water	RHA	SSA
M1	0	0	382	705	1,103	210	0	0
M2	7.5	20	279.95	705	1,103	221.6	28.65	76.4
M3	12.5	17.5	297.40	705	1,103	234	35.25	49.35
M4	10	22.5	257.85	705	1,103	221.6	38.2	85.95
M5	10	20	267.40	705	1,103	225.4	38.2	76.4
M6	10	17.5	294.45	705	1,103	229.2	38.2	49.35
M7	5	15	251.60	705	1,103	217.7	19.1	57.3
M8	5	25	267.40	705	1,103	210	19.1	95.50
M9	12.5	22.5	248.30	705	1,103	229.2	47.75	85.95
M10	15	25	229.20	705	1,103	233.0	57.30	95.50
M11	15	15	367.4	705	1,103	244.5	57.30	57.3
M12	10	15	286.5	705	1,103	233.0	38.2	57.3
M13	12.5	20	257.85	705	1,103	233.0	47.75	76.4
M14	7.5	22.5	263.40	705	1,103	213.9	28.65	85.95
M15	15	20	244.3	705	1,103	236.8	57.30	76.40
M16	5	20	282.50	705	1,103	210	19.1	76.40
M17	10	25	244.30	705	1,103	217.7	38.2	95.50
M18	7.5	17.5	304	705	1,103	221.6	28.65	49.35

C. *Test Methods*

A slump test was performed on the reference and other mixtures in accordance with the BS EN 12350-8 [40] standard, to evaluate the impact of RHA-SSA on concrete workability. The density of the concrete mixture was evaluated in accordance with the standards set forth in BS EN 12390-7 (2009). The compressive strength was evaluated at 3, 7, 28, 56, and 90 days by employing a 100 mm x 100 mm x 100 mm cube in accordance with the BS EN 12390-3 [41] standard. The assessment of flexural strength was performed in accordance with the BS EN 12390-5 standard [42], using a simple prism of 100 mm x 100 mm x 500 mm in size and employing two-point flexural loading at 3, 7, 28, 56, and 90 days. The splitting tensile strength test was executed on 100 mm x 200 mm cylinders in accordance with the specifications outlined in BS EN 12390-6 [43]. The water absorption test was conducted in compliance with the standards set forth in BS 1881-122 [44], using 100 mm cubes that were subjected to a 28-day curing period.

III. RESULTS AND DISCUSSION

A. *Workability*

The outcome of the workability properties evaluated via the slump cone test is presented in Figure 2. The workability of fresh concrete is reduced with the addition of RHA-SSA content. The slump values exhibited a range from 22 mm to 52 mm across the various mixtures, with Mix M1 reaching 52 mm and Mix M10, comprising 60% cement, 15% RHA, and 25% SSA, registering the lowest at 22 mm, below the design range of 30 mm to 60 mm. An increase in SSA content is associated with a reduction in the workability of RHA-SSA concrete. This indicates that the blending of RHA and SSA has a considerable impact on the workability of concrete, which is likely due to the decreased fluidity resulting from the high-water demand. This observation is consistent with the findings of previous studies [34, 45], which indicated comparable effects of supplementary materials on slump values in concrete. Furthermore, the reduction in workability may be attributed to a reduction in the density of the mixture as the proportion of RHA-SSA increases [46], as well as a reduction in its fineness modulus in comparison to that of cement. The data indicate that mixes with higher proportions of RHA and SSA tend to exhibit lower slump values, which is indicative of reduced workability.

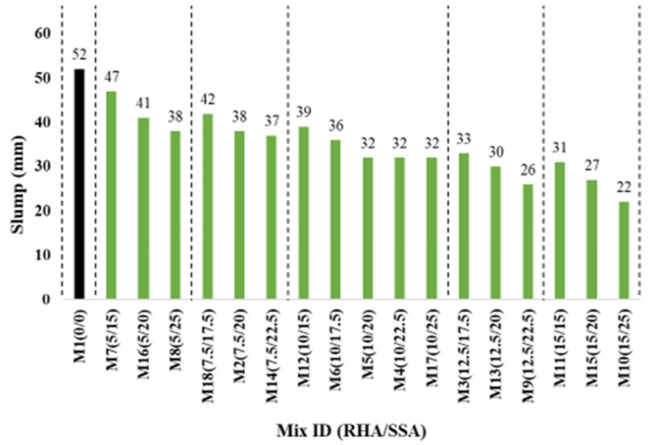

Fig. 2. Slump test results.

B. *Hardened Density*

The concrete mix densities, as shown in Figure 3, exhibited a range from 2,652 kg/m³ to 2,810 kg/m³. The control mix M1 exhibited the highest density, while the mix M10 (comprising 15% RHA and 25% SSA) demonstrated the lowest. The observed variations can be attributed to the specific gravities of the cement, RHA (2.1), and SSA (3.01), which impact the mass per unit volume. The incorporation of greater proportions of RHA resulted in a reduction in density. This finding is consistent with the results reported by authors in [47], which showed a reduction in density with an increase in the proportion of RHA and cow dung. Similarly, authors in [48] reported a decline in density in RHA concrete with an increase in the proportion of RHA.

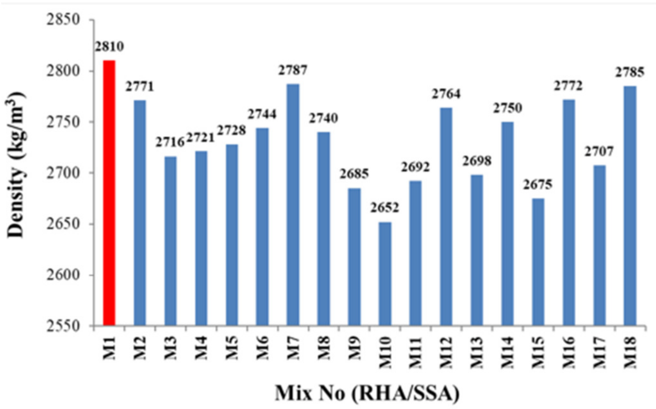

Fig. 3. Hardened density results.

C. *Compressive Strength*

The results of the compressive strength tests are presented in Figure 4. The early curing ages demonstrate a reduction in Compressive Strength (CS) in ternary RHA-SSA mixtures relative to the control concrete, which can be attributed to a delayed pozzolanic reaction or high cement replacement (20%-40%). Authors in [49, 50], concluded that the addition of excessive ash results in a reduction in the strength of concrete. The CS of the concrete specimens exhibited an increase over the curing periods, with values ranging from 8.2 N/mm² to 46.0 N/mm² at 90 days. By day 28, mixes M2 (7.5% RHA and 20% SSA), M3 (12.5% RHA and 17.5% SSA), M5 (10% RHA and 20% SSA), and M6 (10% RHA and 17.5% SSA) exhibited the highest compressive strength. The target CS of 30 N/mm² was attained by the following mixes: M5 (5% SSA), M7 (5% RHA and 15% SSA), M11 (15% RHA and 15% SSA), M12 (10% RHA and 20% SSA), M13 (12.5% RHA and 20% SSA), and M15 (15% RHA and 20% SSA). Among the mixtures, M5 exhibited the lowest (CS of 30.3 N/mm² with a 30% replacement. The highest CS of 35.8 N/mm² was observed for M11, which contained 15% RHA and 15% SSA. The target strength at 28 days was not attained by the following mixes: M4, M8, M9, M14, M16, M17, and M18. Mixes containing 10% to 15% RHA and 15% to 20% SSA demonstrated superior performance compared to those with lower RHA and higher SSA content. This trend is noteworthy, with the exception of instances where combined RHA and SSA percentages were below 30%. The enhanced performance can be attributed to the higher concentration of amorphous silica reacting with calcium hydroxide (C-H), forming secondary Calcium Silicate Hydrate

(C-S-H), which is a crucial phase in the development of strength. An increase in compressive strength from 30.5 N/mm² to 46.2 N/mm² was observed between 56 and 90 days in RHA-SSA concrete, which is likely due to the further formation of calcium silicate hydrate from the reactions between calcium oxide, silica, and water present in the blended concrete. Figure 5 illustrates the CS for RHA-SSA mixes, expressed as percentage changes relative to the control (M1). In comparison to M1, M11 exhibits a 2.87%, 4.46%, and 3.82% enhancement in compressive strength at 28, 56, and 90 days, respectively. The enhancement is attributed to an elevated pozzolanic reaction and the ashes' filling capacity [51, 52].

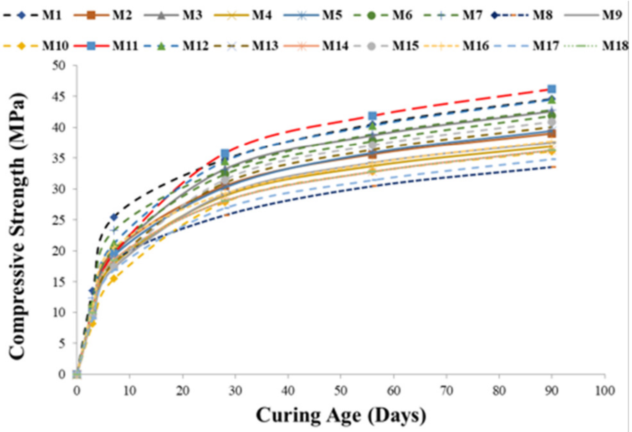

Fig. 4. Compressive Strength vs Age of Curing.

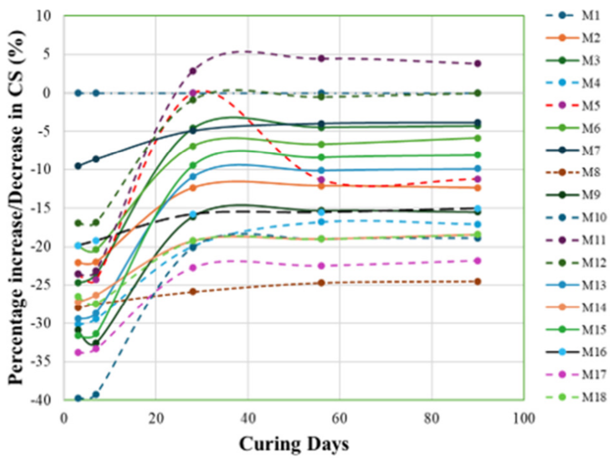

Fig. 5. The rate of RHA concrete compressive strength enhancement compared to the control (M1).

D. Flexural Strength

The capacity of concrete to withstand bending stresses is largely contingent upon its Flexural Strength (FS). Figure 6 portrays the observed FS values at various curing ages (3, 7, 28, 56, and 90 days). The FS assessments vary significantly across the eighteen mixes for each curing age, indicating that the incorporation of RHA and SSA in varying proportions can have a considerable impact on the strength of concrete. As shown in Figure 6, an increase in SSA is associated with a reduction in the FS values. There is a noticeable increase in FS along with an increase in the curing age, which is consistent with the typical concrete behavior, as observed in previous studies [50, 53]. The FS values ranged from 0.89 N/mm² to 1.49 N/mm² at three days to/and from 4.11 N/mm² to 5.68 N/mm² at 90 days. Across all curing ages, Mixes M6, M7, M11, and M12 consistently demonstrated higher FS values, while Mixes M8, M9, and M10 exhibited lower FS values. It is noteworthy that a considerable increase in flexural strength was observed between the 7th and 28th days. At 90 days, the RHA-SSA concrete exhibited robust long-term potential, although the early FS values were comparatively lower than those of the control mix M1. The incorporation of RHA and SSA was found to enhance the FS of concrete [19, 54]. These findings are consistent with the typical FS values for grade 30 concrete with additional cementitious materials [34, 52, 55, 56]. The early-stage hydration of the normal mixed concrete was observed to be higher than that of the RHA-SSA blends. However, significant hydration of the blended concrete occurred at a later stage, facilitated by the production of calcium hydroxide. The primary and secondary hydration processes led to the formation of C-S-H gel, which contributed to the overall strength of the material. Nevertheless, the incorporation of a greater quantity of RHA-SSA resulted in a reduction in the cement content, which in turn constrained the early-stage strength development. At 28 and 90 days, M11 (15% RHA, 15% SSA) exhibited elevated FS values of 4.67 N/mm² and 5.68 N/mm², respectively, signifying increases of 2.64% and 4.03% in comparison to the control mix, as displayed in Figure 7. The optimal FS was achieved with 15% RHA and 15% SSA replacement, although 10% RHA and 15% SSA replacements exhibited a slight decrease in strength relative to the control mix.

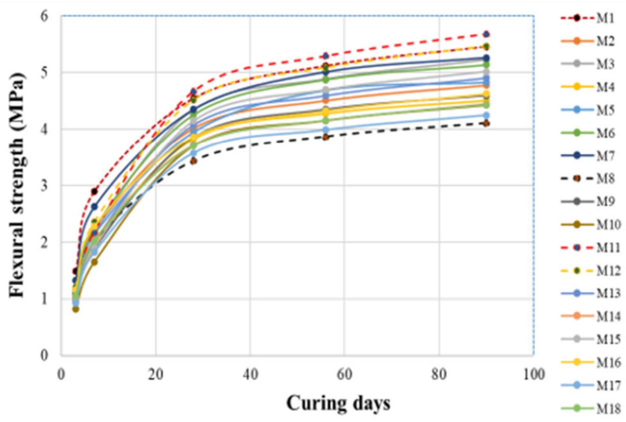

Fig. 6. Flexural strength vs age of curing.

E. Splitting Tensile Strength

The mean Splitting Tensile Strength (STS) for each of the eighteen RHA-SSA mixtures was recorded and presented in Figure 8. The STS values reflected the trends observed in the compressive strength, with values ranging from 0.79 N/mm² to 5.26 N/mm² across all curing ages (3, 7, 28, 56, and 90 days). M11 exhibited the highest STS of 5.26 N/mm², with increases of 2.87%, 4.46%, and 3.82% compared to M1 at 28, 56, and 90 days, respectively. The earliest strength gains were observed in mixes M5, M6, M7, M11, and M12, while M10, M14, M15, and M17 exhibited comparatively lower early values. At 28 days and beyond, mixes M11, M12, M7, and M6 consistently demonstrate elevated STS, whereas mixes M10, M14, M15, and M17 remain below the level of the control mix (M1). Mixes M11 and M12 exhibit elevated STS values throughout the curing period, indicative of robust performance. As shown in Figure 9, a higher SSA content is associated with a reduction in STS, as evidenced by M10 (15% RHA, 25% SSA).

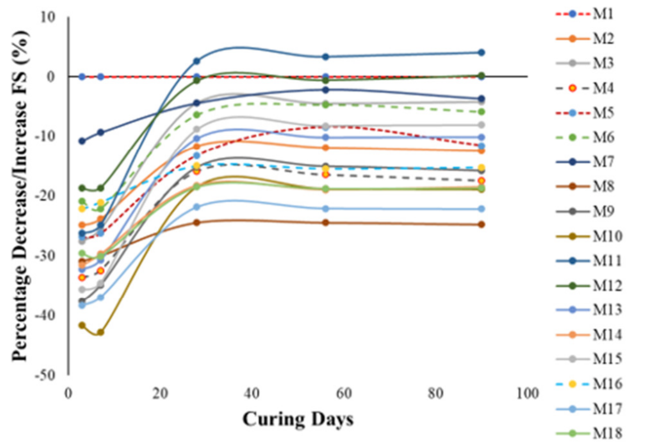

Fig. 7. The rate of RHA concrete Flexural strength enhancement compared to the control (M1).

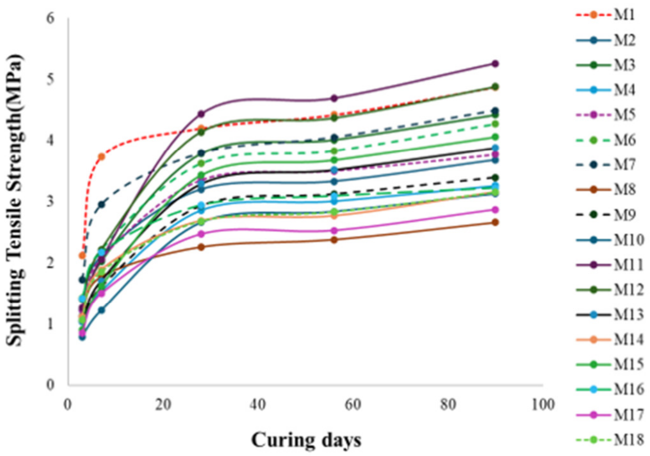

Fig. 8. Splitting tensile strength vs age of curing.

Conversely, M11 exhibited the highest STS, which can be attributed to the optimal availability of silica and calcium hydroxide. Authors in [57] observed that the initial void filling by supplementary materials enhances tensile strength, while excessive filling diminishes it. Therefore, an increase in the SSA content results in a reduction in STS.

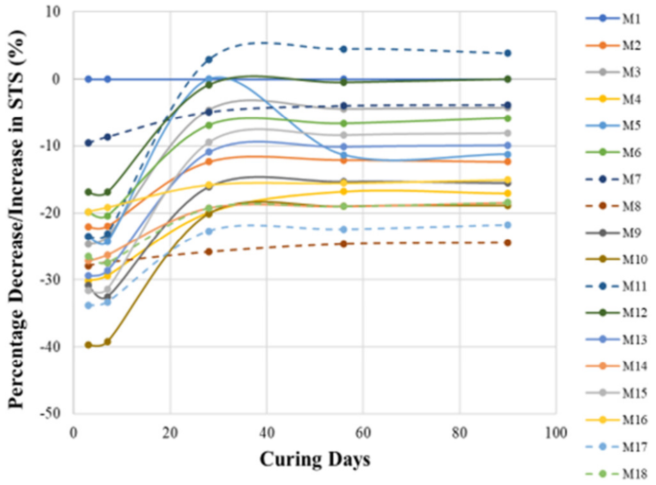

Fig. 9. The rate of RHA concrete tensile splitting strength enhancement compared to the control (M1).

F. Water Absorption

The percentage of water absorption for the various RHA-SSA concrete mixtures (M1-M18) over the 28-day curing period exhibited a range from 5.1% to 13.1% ?, as illustrated in Figure 10. The RHA-SSA blends resulted in lower water absorption than the control mix, M1. It is noteworthy that the concrete mix containing 15% RHA and 25% SSA exhibited the lowest water absorption, at 5.1%. The incorporation of RHA and SSA into concrete results in a reduction in the water absorption due to the highly porous nature of these particles, which possess a substantial surface area. This effectively fills the gaps between the cement particles. This results in a denser microstructure and decreased permeability [58]. Moreover, the pozzolanic reaction between RHA and Calcium Hydroxide (CH) from cement hydration and the reaction of CaO from SSA with water form additional C-S-H gel, which further densifies the concrete matrix, reduces capillary porosity [59]. These combined effects demonstrate the efficacy of RHA and SSA in enhancing the water resistance properties of concrete.

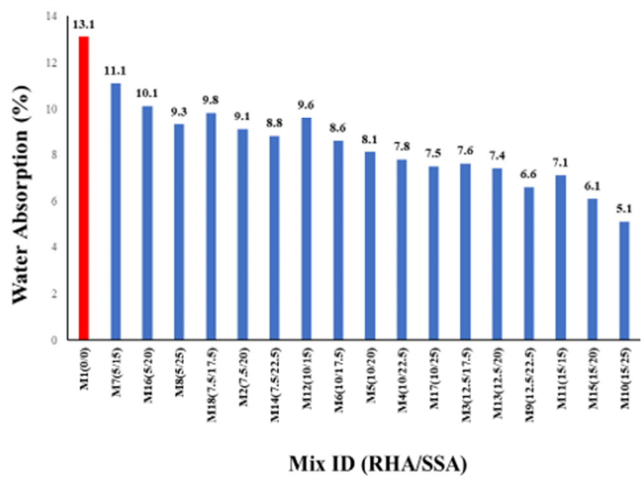

Fig. 10. Water absorption results.

IV. CONCLUSIONS

This study examined the effects of using Rice Husk Ash (RHA) and Snail Shell Ash (SSA) as partial substitutes for cement in concrete on both the fresh and hardened properties of sustainable concrete. Based on the findings of the experimental work and the subsequent analysis of the results, the following conclusions were drawn:

- Both RHA and SSA and their mixture as a cement replacement material in concrete retard the setting of concrete by increasing both the initial and final setting of concrete. Therefore, blending RHA and SSA in concrete is beneficial especially when delayed setting is required, such as in hot weather concrete or prolonged placement.
- Blending RHA and SSA as cement substitutes in concrete reduced the consistency (workability) and density of the concrete. The lowest slump value of 22 mm in the mix series was obtained by blending 15% RHA and 25% SSA as cement replacements. The density of the concrete containing blends of RHA and SSA falls within the range of normal weight concrete and can be therefore used for general purpose applications.
- Blending of RHA and SSA as partial replacement of cement resulted in the reduction of compressive strength, splitting tensile strength, and flexural strength of concrete at all ages of curing. Thus, all concrete mixes containing different levels of RHA-SSA blends achieved the design strength of 30 MPa at 56 and 90 days.
- The optimum dosages of 15% RHA and 15% as cement replacement in the concrete have the highest strengths of 46.2 MPa, 5.26 MPa, and 5.26 MPa for compressive strength, flexural strength, and splitting tensile strength at 90 days, respectively.
- The incorporation of RHA and SSA as partial substitutes for cement resulted in a notable reduction in porosity, as evidenced by the results of the water absorption test. The combination of 15% RHA and 25% SSA yielded the optimal and lowest water absorption rate of 5.1%. It can be thus concluded that blends of RHA and SSA have the potential to enhance the durability performance of concrete.
- RHA and SSA derived from agricultural by-products have the potential to be used as pozzolanic materials in concrete, thereby partially substituting cement for the purposes of enhanced waste management, environmental sustainability, and the reduction of CO2 emissions associated with cement production.

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