Improvement in the Properties of Concrete Containing Rice Husk Ash as A Partial Replacement for Portland Limestone Cement

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Abstract **:- The rising concern about environmental resilience, as well as energy conservation with minimal economic impact, has motivated researchers to investigate novel cement alternatives generated from waste and by-products. RHA is a residue of rice husk combustion that consists of non-crystalline silicon dioxide with a high specific surface area and pozzolanic reactivity. The review of available work has focused on the efficacy of RHA produced under controlled conditions and grinding time, with little attention given to the effect of uncontrolled conditions and non-ground RHA on the mechanical and durability properties of the derived concrete. Therefore, the aim of this study is to investigate the mechanical proprieties and durability of concrete incorporating uncontrolled burnt and non-ground RHA with varying chemical composition as a partial replacement for Portland limestone cement. A total of 240 specimens of standard concrete cubes (150mmx150mmx150mm) were produced and cured at 20ºC for 3, 7, 14, and 28 days to the design target strength of 25N/mm^2. To establish the appropriate percentage of RHA for partial replacement of cement, concrete mixes containing 0 to 30% RHA were prepared and their mechanical properties were evaluated. The effect of RHA on concrete durability was also investigated. Concrete with compressive strengths ranging from 24.27 to 41.48N/mm^2 was produced in 28 days when mixed with Portland limestone cement at percentage replacements of 5, 10, 15, 20, 25, and 30. These findings exceed the minimal standard compressive strength requirement of 20N/mm^2 and 25N/mm^2 for IS 4098-1967 and BS 8110: Part 1. The use of RHA up to 30 percent of the cement replacement level densifies the concrete matrix and reduces the volume of voids, resulting in a slower rate of water absorption and chemical ion penetration. Remarkably, partial replacement of cement with uncontrolled burned and non-ground RHA of variable chemical composition produces RHA that is equivalent to RHA produced under controlled conditions.**

Keywords: Cement; compressive strength; concrete; RHA; pozzolan; water absorption

1. INTRODUCTION

Concrete is becoming the most commonly utilised building material on a global level. Concrete is a mixture of fine and coarse aggregates held together by a hardened paste of hydraulic cement and water. Concrete is characterised by the aggregate composition, with crushed granite aggregate concrete being considered conventional. Others are lateritic concrete, which is formed from laterite or laterite rock, and concrete which is made by partially substituting cement with cementitious materials. Because of its low cost, exceptional durability, great mechanical strength, and convenience and ease of application, concrete and cement mortar are the most widely used material for building and infrastructure development [1].

With expanding global growth and an ever-increasing population, the need for infrastructure and building construction is skyrocketing. Nigeria, like other developing countries, is grappling with a scarcity of housing, and cement being the most expensive of the materials required to build a housing unit. Most building methods demand natural raw materials, require a great deal of energy, are expensive, and generate a lot of waste throughout the material handling and construction process [2]. However, in some situations, the negative environmental consequences of some construction materials are rising. Cement manufacturing is an expensive operation; it requires limestone as a raw material, consumes a lot of energy, and produces a lot of Carbon dioxide [3]. The production of Portland limestone cement (PLC) accounts for approximately 5 to 8% of global CO_2 emissions [4-5]. This means that producing one tonne of cement emits about one tonne of CO_2 into the atmosphere, while producing approximately one tonne of cement requires the use of 1.6 tonnes of natural resources [6].

The growing concern for environmental sustainability as well as energy saving with minimum economic effect has prompted researchers to explore for new cement alternatives derived from waste and by-products. This results in ecologically friendly, green, and resilient building. Supplementary cementitious materials (SCM) must have suitable bonding with aggregates (similar to cement) and have acceptable pozzolanic activity [7]. Several of these materials have improved the properties of concrete, making these attempts even more successful. Silica fume is a popular cement substitute where engineering properties and long-term durability of the hardened concrete are the most important considerations [8-10]. Its ultrafine particles and high SiO_2 concentration are two of silica fume's most significant benefits. However, the exorbitant cost of silica fume prevents it from being widely used in concrete production, particularly in the developing world. Several additional pozzolanic materials are also being explored for similar uses as a result of this discovery.

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Table 1: Some agricultural waste ashes with outstanding pozzolanic characteristics

Ref	Products	Compositions (%)							
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	P_2O_5	Na_2O
[11]	Groundnut shell	27.7	8.3	10.3	24.8	5.4	8.5	3.70	0.8
[12]	Olive husk 29.4	8.4	6.3	14.5	4.2	4.3	2.5	26.2	
[11]	Coconut shell	69.3	8.8	6.4	2.5	1.6	8.8	1.6	4.8
[13]	Coconut trunk	42.7	13.94	8.28	11.74	5.37	10.41	3.55	2.05
[14]	Wheat straw	52	0.6	1.1	9.2	1.8	21.9	3.2	0.3
[15]	Bagasse	72.29	7.99	6.16	4.16	2.34	4.49	0.93	0.95
[16]	Sugarcane bagasse	45.88	20.55	15.45	4.31	3.22	1.67	0.89	096
[17]	Oil palm bunch	49.10	0.46	1.28	6.53	-	12.8	1.12	1.25
[12]	Almond shell	10.7	2.7	2.8	10.5	5.2	48.7	4.5	1.6
[18]	Rice husk	89.39	0.22	0.4	1.3	0.57	5.04	0.87	0.35

Rice husk ash (RHA) is a pozzolanic additive in concrete that is comparable to silica fume. RHA has sparked considerable interest in the use of environmentally friendly and sustainable SCM in concrete [19-20]. Because of its large surface area, amorphous form, and compatible with cement-concrete, RHA contains approximately 90% silica and possesses outstanding pozzolanic characteristics. [7, 21-23] Rice husks (RHs), which are rice paddy wastes, represent a huge disposal challenge and environmental strain. RHA is made through controlled and uncontrolled combustion of RHs, which are subsequently ground to the desired fineness. According to the United States Department of Agriculture (USDA), global production of rice in 2019/2020 would be 499.31 million metric tonnes. This figure was 499.37 million metric tonnes in 2018/2019 [24]. Each kilogram of rice milled yielded 0.28 kilograms of rice husk. As a result, a massive amount of waste is generated each year. These RHs are used as fuel in a variety of sectors to generate heat energy, including combustion and burning units. Following complete incineration of rice husk, 20 to 25 percent RHA by weight is generated [25]. In India, over one hundred million tons of paddy are harvested each year, resulting in almost four million tons of RHA [26]. A very small amount of the RHA is then used as a fertiliser agent in the field, and the vast bulk of it is regrettably dumped in open landfills.

Benefits of Pozzolanic Materials

- Spherical shape: RHA particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures.
- Ball bearing effect: The "ball bearing" effect of RHA particles creates a lubricating action with concrete in its plastic state.
- Economic savings: Pozzolans replace higher volume of the costliest cement with typically less cost per volume.
- Higher strength: Pozzolans combine with free lime increasing structural strength overtime.
- Decreased permeability: - Increased density and long term pozzolanic action, which ties up free lime; resulting in fewer bleed channels and decreases permeability.
- Increased durability: Dense pozzolanic concrete helps to keep aggressive compounds on the surface. While destructive action is lessened. Pozzolan concrete is more resistant to attack by sulphate, mild acid, soft (lime hungry) water and sea water.

RHA includes non-crystalline silica and CaO, making it the ideal SCM for concrete [27-28]. In addition to improving strength and durability, using RHA in concrete reduces the cost of materials because of the savings in cement, and it also has environmental advantages in terms of waste management [29]. To turn the ash into active pozzolanic materials, the quality of RHA depends heavily on the production method and conditions. Also, because of differences in incinerating conditions, heating rate, geographic location, and fineness, the ash properties vary [31-34]. When RHA is burned under controlled conditions, highly reactive RHA is produced. However, RHA cannot be used alone in construction due to its lack of cementitious properties [35]. As a result, it's used in combination with binders like lime, cement, calcium chloride, and lime sludge for construction projects like soil stabilization [36-37]. In general, increasing the fineness of the RHA improves reactivity [32-33, 38-39]. However, Mehta [40] believes that because RHA's pozzolanic activity is mostly derived from the interior surface area of the particles, grinding RHA to a high degree of fineness should be avoided. According to Hwang and Chandra [41] the particle size of RHA in the 10 to 75μm range displays excellent pozzolanic behaviour.

Table 2: Some physical properties of RHA

GT(minutes)	MPS (μm)	SG (gm/cm^3)	% Fineness(45μm)	SSA (m^2/g)	Ref.
	3.80	2.06	99	36.47	[42]
	6.00	2.10	-	2.33	[43]
90	63.8	-	-	-	[38]
180	31.3	2.11	-	-	
270	18.3	-	-	-	
360	11.5	-	-	-	

GT: grinding time; MPS: mean particle size; SG: specific gravity; SSA: specific surface area

Table 3: Chemical composition of RHA

Chemical compositions (%)										
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loi	Others	Ref.
87.22	0.70	1.68	2.12	1.18	0.04	0.20	1.12	1.06	0.46	[44]
91.56	0.19	0.17	1.07	0.65	0.47	0.16	3.76	-	-	[45]
87.89	0.19	0.28	0.73	0.47	-	0.66	3.43	4.36	-	[46]
94.0	1.2	0.37	2.93	0.60	0.30	-	0.50	-	-	[47]
91.71	0.36	0.90	0.86	0.31	-	0.12	1.67	3.13	-	[48]
91.3	1.4	0.60	2.4	2.1	-	0.3	1.9	-	-	[49]
86.81	0.50	0.87	1.04	0.85	-	0.69	3.16	4.6	-	[50]
93.44	0.21	0.18	0.76	0.43	0.16	0.05	1.98	1.27	-	[51]
77.19	6.19	3.65	2.88	1.45	-	-	1.82	5.43	-	[52]

In other cases, due to the high carbon concentration, a lesser grade residual RHA is generated. The increased carbon content increases water consumption and results in a deeper hue in mortar and concrete. However, the filler effect has been shown to be much stronger than the pozzolanic effect [53]. As a result, by grinding up to an adequate particle size, the pozzolanic reactivity of residual RHA can be improved, lessening the negative effect of the high carbon content in the ash and increasing material homogeneity, but the process comes at a high cost [54]. The optimised RHA has been used as a pozzolanic material in cement and concrete via controlled burn and/or grinding. It has several advantages, including improved strength and durability, as well as environmental benefits related to waste disposal and reduced carbon dioxide emissions [39, 45].

According to current study, RHA may be applied as a 100 percent replacement for PLC in concrete mixes. The quantity of PLC replacement, the particle size of RHA, the chemical properties of RHA irrespective of aggregate, and the water/cement ratio of the concrete mix all influence the performance of concrete containing RHA. However, for optimal strength development, 10 to 25% PLC replacement is suggested [21, 25]. Until far, little research has been conducted in Nigeria to examine the usage of RHA as a supplementary material in cement and concrete production. None have examined how RHA production methods and conditions affect the properties of fresh and hardened concrete. Against this backdrop, the purpose of this research is to investigate at the properties and durability of concrete that contains uncontrolled burned and non-ground RHA with varying chemical composition as a partial replacement for Portland limestone cement.

2. MATERIALS AND METHODS

The materials used for the production of concrete for this work were fine aggregates (River sand) cement, Rice Husk Ash (RHA in varying percentage with cement), Coarse aggregates (Granite) and Water. The UNICEM brand of Portland limestone cement (PLC) of grade 32.5 was used in which the composition and properties are in compliance with the Nigerian and BS standard organization's defined standard of cement for concrete production (BS 12: 1996). The cement was purchase in a merchant shop near the study area. The research work was restricted to washed sand for fine aggregates. The sand was collected to ensure that there was no allowance for deleterious materials contained in the sand. Granites of 5mm to 20mm maximum sizes were used as coarse aggregates. Proper inspection was carried out to ensure that it was free from deleterious materials. Rice Husk Ash (RHA) rich in silica was used in this project. The rice husks were gotten from different locations (Ogoja, Abakaliki, Adani and Adikpo) in the country. They were burnt in open air and the ash collected and stored in dry area in the laboratory. Chemical analysis was conducted on the ashes to determine the elemental composition of each ash. Water is crucial in the production of concrete (mix) because it initiates the reaction between the cement and the aggregates. It aids the hydration of the mixture. The water used in this study was pipe-borne and devoid of pollutants. It meets the ASTM C1602-12 [55] water requirement for use in concrete mixes.

Concrete is made up of water, cement, coarse and fine aggregate, and additives. It is critical that the constituent materials remain uniformly distributed within the concrete mass during the various stages of handling and that full compaction is achieved, as well as that the concrete characteristics that affect full compaction, such as consistency, mobility, and compatibility, are in compliance with appropriate codes of practice. Physical properties such as specific gravity, particle dispersion, and bulk density were evaluated on the aggregates. Slump tests were performed on fresh concrete to assess its workability. Furthermore, in the hardened state of the concrete, the following properties were tested: density, water absorption/permeability, and compressive strength.

Slump test was performed in line with ASTM 143-90a and BS 1881 part 102:1993. This test was carried out using a 300mm high truncated cone (Frustum), a 16mm diameter steel rod (for compaction), and a meter rule. For mix proportions of 1:3:6, 1:2:4, and 1:1.5:3, with water cement ratios of 0.70, 0.75, 0.80, 0.50, 0.55, 0.60, and 0.65, freshly mixed concrete was batched by volume. The samples were loaded into the cone in three layers and compacted. The steel rod was tamped 25 times on each layer. The foot-rests anchored to the mould helped to keep the mould securely against its base. Immediately after filling, the cone was slowly removed and the unsupported concrete was allowed to sink. The difference in height between the cone and the centre of the displaced top of the concrete was measured and recorded each time using the metre-rule.

Plate 1: A: slump test showing true slump; B: slump test showing shear slump

Density is simply stated as the mass per unit volume of a material. The cubes were weighed, and the mass was divided by the volume to get the density value, which is used in concrete classification. The test was carried out in accordance with BSEN 206, 2001 Part 3. The PLC was supplemented in part with pozzolans at a dose of up to 30% by weight of cementitious material. The mixes were meant to produce concrete with a grade of 45 N/mm^2 in 28 days. The samples were Prepared and concrete well mixed to achieve a homogenous mix, placed in the mould and vibrated in three layers. The samples were then demoulded after 24 hours and then cured at 20^{o}C for 7, 14, 21 and 28 days respectively. Thereafter, they were crushed by a constant rate of stress increase of 15Nmm^2 immediately after removal from the curing tank. The cube test gives information for the determination of the characteristic strength of concrete which is given as the strength below which not more than 5% of the tests results would fall. The samples were prepared and tested as shown below.

The characteristic strength is given by

$$f_{cu} = f_m - 1.6\sigma \quad (1)$$

Where f_{cu} = characteristic strength

f_m = Mean strength

σ = Standard deviation

Water absorption/permeability test was also carried out on the samples after demoulding. Freshly mixed RHA concrete of 5%, 10%, 20%, 25% and 30% replacement of different water cement ratio sand concrete of the same water cement ratio. The choice of water cement ratio was influenced by the maximum strength and acceptable workability. The original weights for both fresh and hardened concrete were taken at the start of the experiment. The cubes were then immersed in curing tank filled with water for 28 days and then re-weighed.

Plate 2: Determination of the compressive strength of RHA concrete.

Plate 3: (a) Test Samples in the curing Tank, (b) Samples after removal from the curing Tank

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RESULTS AND DISCUSSION

3.1 Consistency

Workability is a measure of the ease and consistency with which a fresh concrete mix can be mixed, laid, consolidated, and finished [56]. The slump test findings ranged from 50mm to 105mm on average and varied with RHA-PLC replacement levels. The workability of concrete varies depending on particle size, quantity, water-cement ratio, component properties, and mix ratio. Regardless of the aforementioned parameters, the workability of RHA concrete in this study diminishes as the quantity and fineness of RHA increases, as proven by [57]. This is due to the presence of macro and mesopores inside RHA particles, and as fineness rises, so does the specific surface area. Following that, fine RHA absorbs a significant amount of water on its surface and stores it in its pores, resulting in a decrease in free water and a lower slump value [56]. Furthermore, the increased reactivity of RHA could be another element that reduces the flow of concrete [52, 58 & 59]. The workability test results show that RHA concrete can be graded under S2 using the European classification ENV 206:1992 having the slump of 50mm-90mm and by TRRL classification, the workability is described as medium with slump of 50mm-105mm.

3.2. Density

The density of RHA was investigated as stated in the methodology, the results which are analysed and presented as a ratio of the mass to that of the volume concrete are given in Tables 4 to 7. From the results of densities, the density of RHA is in the same range for all replacement levels and they agree with the results of the investigation carried out by [60] and B.S 877: 1997. In addition, according to Umasabor and Okovido, 2018 [61] in a comparable research, the hardened densities of concrete with 0%, 5%, 10%, and 15% RHA vary between 2360-2400 kg/m^3, 2360-2475 kg/m^3, 2365-2515 kg/m^3, and 2050-2255 kg/m^3, respectively. Densities of RHA-blended concrete were still increased at up to 30 percent replacement level in this study, which might be attributable to proper silica dissolution, pozzolanic reaction, high pozzolanicity, filler effect, and pore refinement of RHA particles as prescribed by [2]. According to BS 877, the densities of RHA-blended concrete in this study may be classified as light weight concrete.

Table 4: Density values for various RHA concrete mixes from Ogoja sample

	Age		Percentage replacement with RHA					
			5	10	15	20	25	30
Average	3		2346.27	2290.96	2306.67	2282.86	2269.63	2269.63
Densities		7		2342.91	2304.59	2266.57	2272.59	2214.62
2214.62								
of RHA	14		2364.74	2317.33	2316.44	2288.69	2262.12	2262.12
Concrete		21		2357.43	2335.70	2331.26	2317.04	2272.10
2272.10								
(kN/m^3)	28		2326.22	2350.72	2343.70	2274.17	2296.20	2296.20

Table 5: Density values for various RHA concrete mixes from Abakaliki sample

	Age		Percentage replacement with RHA					
			5	10	15	20	25	30
Average	3		2326.91	2315.56	2347.95	2282.44	2282.47	2222.72
Densities		7		2338.27	2301.73	2378.37	2271.80	2215.80
2234.07								
of RHA	14		2365.33	2325.73	2328.69	2357.83	2283.46	2241.48
Concrete		21		2359.41	2341.04	2333.83	2335.21	2300.84
2257.78								
(kN/m^3)	28		2340.64	2371.65	2339.06	2307.75	2324.74	2258.47

Table 6: Density values for various RHA concrete mixes from Adani sample

	Age		Percentage replacement with RHA					
			5	10	15	20	25	30
Average	3		2325.43	2239.60	2286.62	2282.86	2269.63	2223.41
Densities		7		2305.28	2238.02	2292.74	2273.58	2214.62
2228.84								
of RHA	14		2360.59	2359.90	2342.32	2288.69	2262.12	2242.57
Concrete		21		2324.05	2277.33	2327.31	2317.04	2272.10
2253.53								
(kN/m^3)	28		2347.75	2365.15	2345.88	2285.05	2299.16	2263.70

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Table 7: Density values for various RHA concrete mixes from Adikpo sample

	Age	Percentage replacement with RHA					
		5	**10**	**15**	**20**	**25**	**30**
Average Densities of RHA Concrete (kN/m^3)	3	2344.30	2293.73	2307.36	2282.86	2269.63	2223.41
	7	2340.94	2301.93	2267.06	2273.59	2214.62	2228.84
	14	2362.57	2319.01	2318.42	2288.69	2262.12	2242.57
	21	2356.44	2335.31	2331.65	2317.04	2272.10	2253.53
	28	2324.25	2345.68	2344.69	2274.17	2296.20	2263.70

3.3. Compressive strength

The compressive strength of concrete is proportionate to its density [62-63]. The compressive strength of RHA concrete was investigated at 3, 7, 14, 21 and 28 days curing age as explained in section two. The summary of the results is presented graphically from Figures 1 to 4 for different replacement percentages of RHA. The variation trends in the compressive strength values of RHA concrete produced using RHA from different locations are the same for the various percentage replacements but there is variability in strength values for the different locations. The effects of RHA on the compressive strength of concrete shows incremental characteristics in strength with values ranging from 24.27 to 41.48N/mm^2 and variability in strength in samples from different locations. It can be seen that the compressive strength is reasonably enhanced and increases favourably with the addition of RHA of 5-15%. The strength values increase in the samples with RHA of higher pozzolanic composition. Furthermore, compressive strength is influenced by mix proportion, aggregate and cement properties, water-cement ratio, curing period, and RHA replacement level. Regardless of other considerations, the fineness and concentration of RHA are the primary characteristics that determine strength development in concrete because they influence pozzolanic reactivity and binder hydration.

The optimum RHA content, which varies depending on RHA characteristics and binders used in this study, was also observed in a study conducted by [64-66], with the optimum cement replacement level being around 20 to 30 percent for RHA. In their work, increases in RHA concentration (up to 15% cement replacement) resulted in increases in strength of about 3%, 5%, and 8% (for 7, 14, and 28 days, respectively) when compared to the control mix. The variation in strength is reliant on the curing age, and so the strength of concrete rose linearly as the curing duration increased in this study. More hydration products are produced as the curing period lengthens, and so is the strength. However, when both the pozzolanic reaction and hydration completion were lessened (due to random reasons), the compression strength in the concrete was also reduced [47, 50]. However, after the optimum level of replacement, concrete strength is predicted to decline as RHA increases [67]. There was no substantial indication of optimum content level at 30% RHA replacement with PLC since the strength increased with each increase in RHA.

When RHA was compared to other agro-based supplementary cementitious materials in concrete, the results reveal that RHA concrete has a significant strength improvement over others. Ikumapayi (2018) [68] investigated the compressive strength and setting time of ordinary Portland cement (OPC) blended groundnut shell ash (GSA). OPC/GSA blended cement was mixed with fine and coarse aggregates in a 1:2:4 mix ratio with a water-cement ratio of 0.6. Concrete cubes of 150mm^3 in size were produced, cured, and tested with up to 16 percent GSA replacement level. The maximum compressive strength was obtained at 4% GSA replacement, whereas at 12% GSA replacement, the strength obtained was fairly comparable to that of OPC concrete at 28 days. Adajar et al. (2020) [69], investigated the use of coconut shell ash (CSA) as a partial replacement for cement in concrete. With proportional concrete materials, the CSA content used for testing were 0%, 10%, 20%, 30%, and 40% of cement by weight. The compressive strength values from the 7 to 90 days curing period showed that the compressive strength of the samples increases as the curing period increases. However, when the CSA content of the concrete increases, the compressive strength of the concrete tends to decrease. Adesanya and Raheem (2009) [70] investigated the compressive strength of corn cob ash CCA blended cement concrete using 1:1.5:3, 1:2:4, and 1:3:6 mixes with w/c ratios of 0.5, 0.6, and 0.7, respectively, and observed that it was weaker compared to the control concrete at early curing ages. After a longer curing period, the compressive strength of the concrete improved considerably more than the control concrete. The researchers discovered that an 8 percent CCA substitution was the best replacement level in all of the mixtures studied. Similarly, Ettu et al. (2013) [71] discovered the similar pattern. Based on the 90-day compressive strength of OPC with CCA blended concrete, the 10 percent CCA plus 90 percent OPC blended concrete had a greater compressive strength than other proportions, including the control concrete. Because of the slower rate of pozzolanic response, the rate of strength increases up to 21 days was shown to be quite sluggish. This is attributable to the fact that CCA are just filler materials and do not contribute to the development of strength [72].

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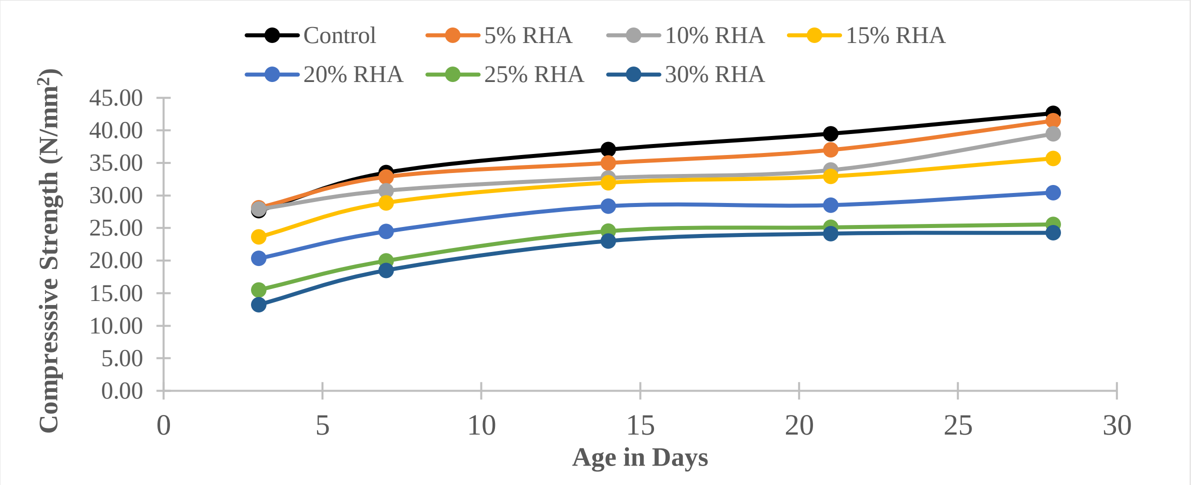

Figure 1: The relationship between compressive strength and age for Ogoja RHA sample

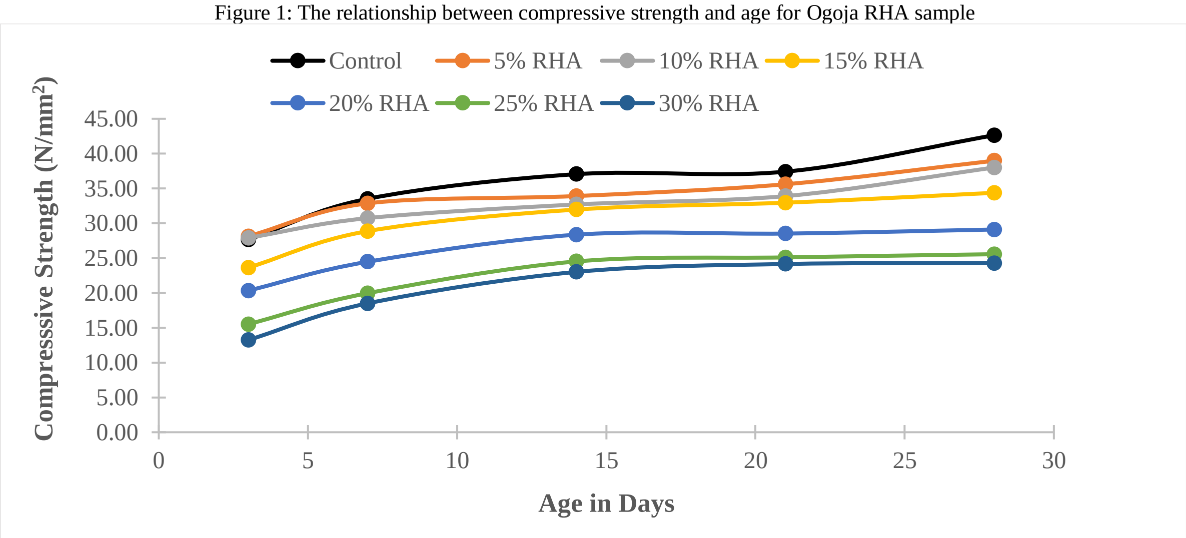

Figure 2: The relationship between compressive strength and age for Abakaliki RHA sample

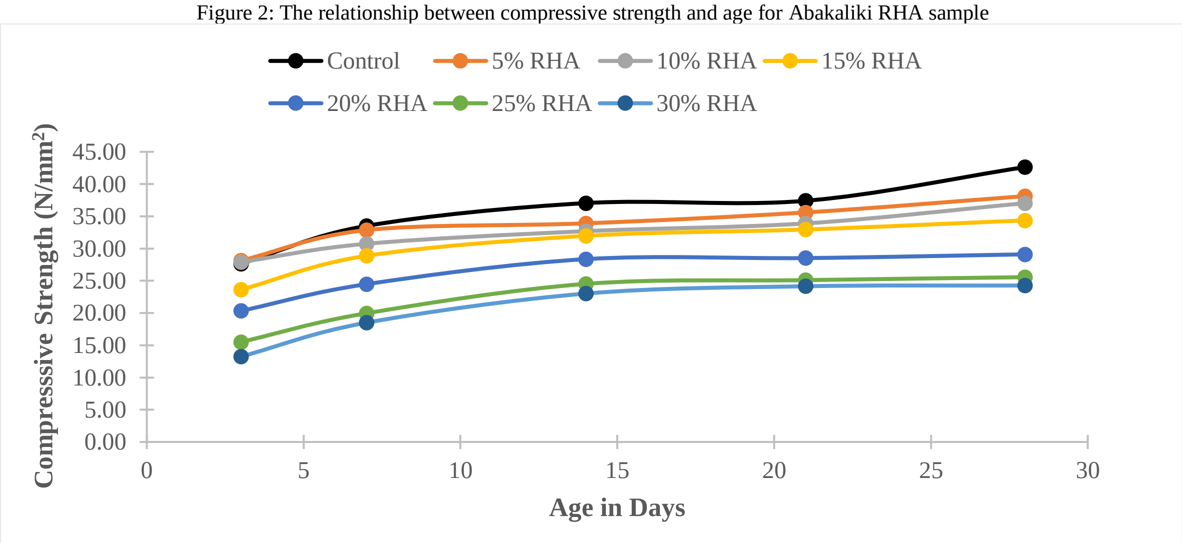

Figure 3: The relationship between compressive strength and age for Adani RHA sample

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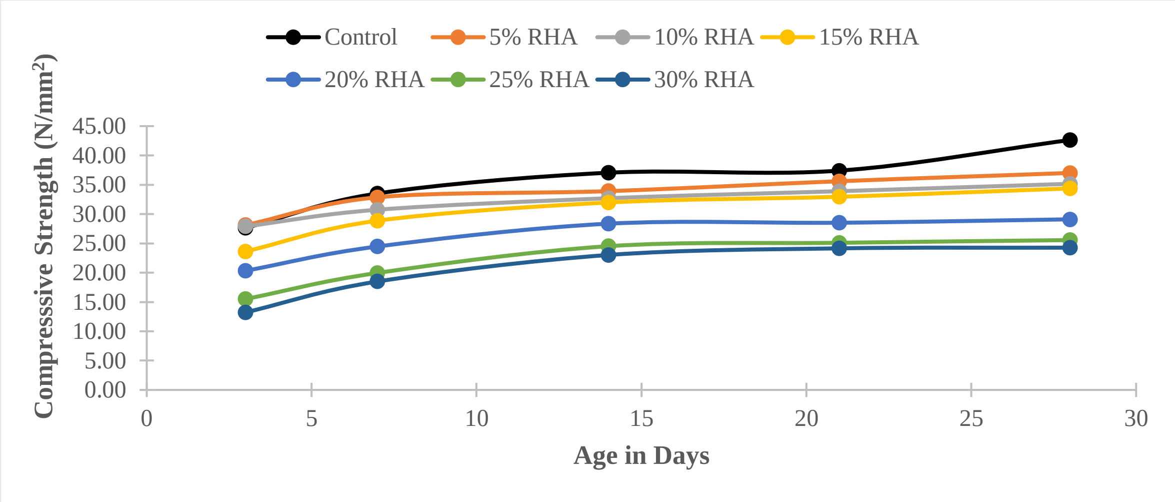

Figure 4: The relationship between compressive strength and age for Adikpo RHA sample

3.4. Water absorption and permeability

Due to the exposed environment, the most prevalent difficulty with durability is the penetration and absorption of liquids, ions, and gasses by the concrete. This leads to the deterioration of concrete in core structures, as well as the degradation of physical and chemical bonding. The porosity of concrete determines how well liquid penetrates and absorbs. The results of the water absorption test are presented in figure 6 to 9. The results showed that RHA concrete has a low water absorption and permeability at 5 to 15% replacements and the values are lower than that of the control sample, they range from 0.15 to 0.40 and 0.41 to 0.89 for 20 to 30% replacements. Concrete porosity can be decreased by up to 30% RHA [45], which also reduces water penetration and absorption. RHA has been found to reduce water penetration and absorption in concrete [73-75]. However, the water absorption rate is about the same for 0 to 15% RHA-added concrete. According to Venkatanarayanan and Rangaraju [76], when the ground RHA was 7% and 15%, respectively, there was a 13% and 12% decrease in water absorption compared to the concrete without RHA. The most important factor, however, is the fineness of RHA and its pozzolanic reactivity, which are critical requirements for producing concrete with the lowest porosity. Water penetration can aid in the development of concrete strength by boosting long-term curing at an early stage. However, exceeding the saturation limit and being damped for an extended period of time can impair the strength and durability of concrete, as well as induce chemical leaching and efflorescence.

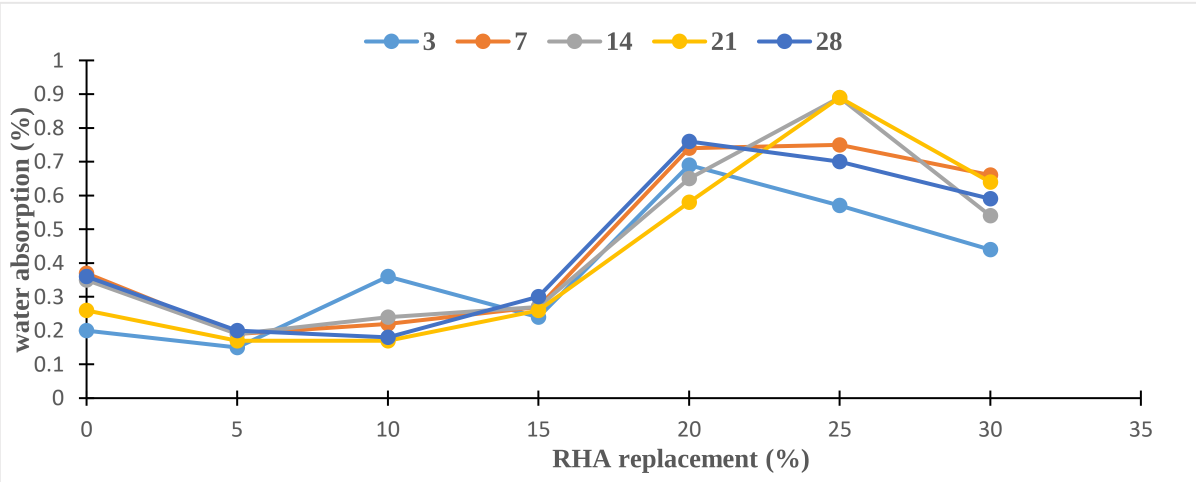

Figure 5: Water absorption for concrete from Ogoja RHA sample

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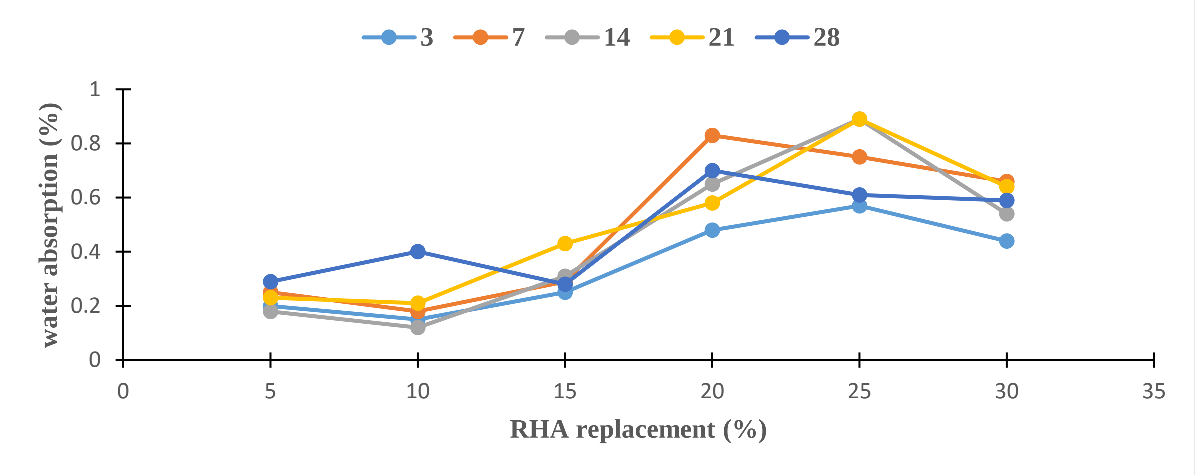

Figure 6: Water absorption for concrete from Abakaliki RHA sample

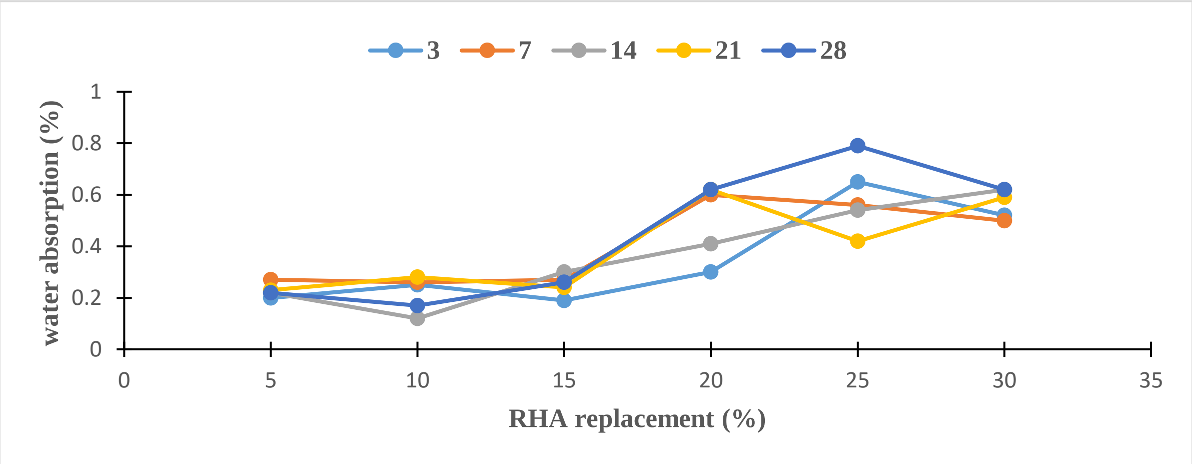

Figure 7: Water absorption for concrete from Adani RHA sample

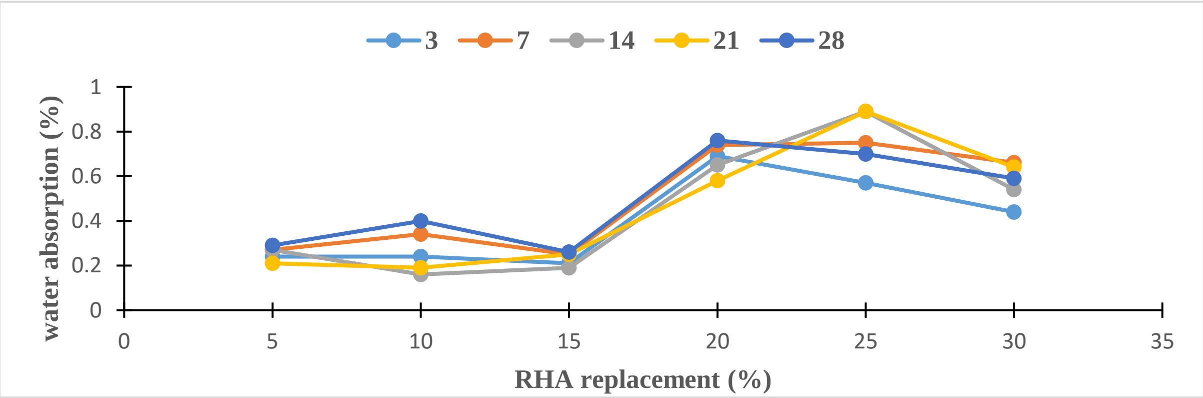

Figure 8: Water absorption for concrete from Adikpo RHA sample

3.5 Analysis of Variance

The observed data were then subjected to analysis of variance (ANOVA) to determine the contributing variable in the improvement of RHA concrete produced from different RHA-cement replacement levels. The calculated F-value at 0.05 level of significance for curing days is 114.3 which is much greater than the critical F value of 2.8 (Table 8). This confirms that the strength increases with respect to curing days is significant. Similarly, the calculated F-value for the strength increment of RHA concrete due to RHA-cement replacement up to 30% is 146.5 which is far greater than the critical F-value of 2.5. This shows that the strength property of concrete is dependents on RHA replacement and also the main contributing strength factor since it calculated F-value is greater than that of curing days.

Table 8: Analysis of variance for compressive strength

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing days	589.2771	4	147.3193	114.2721	2.95E-15	2.776289
RHA	1133.037	6	188.8396	146.4784	1.08E-17	2.508189
Error	30.94073	24	1.289197			
Total	1753.255	34				

Table 9 shows the density improvement in concretes produced at varying RHA-cement replacement levels and cured for 28 days. The density improvement is significant because the calculated F-values of 6.2 and 16.96 are greater than the critical F value of 2.9 and 2.7 respectively at 0.05 confidence level.

Table 9: Analysis of variance for density

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing days	8314.653	4	2078.663	6.155761	0.002132	2.866081
RHA	28632.39	5	5726.478	16.95841	1.37E-06	2.71089
Error	6753.554	20	337.6777			
Total	43700.6	29				

In table 10, the calculated F-value at 0.05 level of significance for curing days is 1.09 which is less than the critical F value of 2.78. This confirms that the water absorption rate in RHA concrete is independent of curing duration. On the contrary, the calculated F-value for the water absorption rate for RHA concrete owing to RHA-cement replacement up to 30% is 45.5 which is greater than the critical F-value of 2.5. This shows that the water absorption rate in RHA concrete is dependent on RHA replacement. and also the main contributing factor since it calculated F-value is greater than that of curing days.

Table 10: Analysis of variance for water absorption

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
RHA	1.680977	6	0.280163	45.53907	5.99E-12	2.508189
Curing days	0.026869	4	0.006717	1.091838	0.382975	2.776289
Error	0.147651	24	0.006152			
Total	1.855497	34				

4.0 CONCLUSION

RHA has a high concentration of amorphous reactive silica. The chemical composition of RHA varies depending on the production process. The variability in the chemical or pozzolanic properties of RHA will also affects the strength properties of concrete. Concrete with compressive strength of 24.27 to 41.48N/mm2 was achieved in 28 days when mixed with Portland limestone cement at percentage replacements of 5, 10, 15, 20, 25, and 30. These results are more than the minimum standard compressive strength requirement of 20N/mm^2 (IS 4098-1967). In this study, the addition of RHA up to 30% of the cement replacement level densifies the concrete matrix and reduces the volume of voids, resulting in a reduced rate of water absorption and chemical ion penetration into the concrete. Surprisingly, the progress made by partial replacement of cement containing uncontrolled burnt and non-ground RHA of variable chemical composition is comparable to RHA produced under control conditions. Based on the test of adequacy, analysis of variance (ANOVA) test at 95% confidence level was applied to check the adequacy of the models and from the results, the p-values for the ANOVA indicates a very strong correlation between the RHA/curing age and the concrete properties.

The use of RHA in concrete innovation has elevated RHA to the status of a construction material rather than a complete and utter waste. As a result, RHA has proven its capacity to increase the strength and durability properties of concrete, as well as reduce construction costs and carbon emissions. As a result, this process may be considered a positive phase for the environment, building sector, and economy.

5.0 DECLARATIONS

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Declaration of Competing Interest

The authors state that they have no known conflicting financial interests or deep connections that may seem to have influenced the work described in this publication.

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