

Strength Development and Durability Properties of Concrete Containing Pre-Soaked Rice Husk Ash

Akogu Elijah Abalaka, *Federal University of Technology*, Obumneme Godwin Okoli, *Ahmadu Bello University*

Abstract: Concrete at water-cement (w/c) ratio of 0.30 and 0.35 containing rice husk ash (RHA) at a low specific surface presoaked with equal weight of water was cured in water and ambient air (uncured). The RHA was presoaked in equal mass of water prior to mixing to reduce water demand in fresh concrete usually associated with concrete containing RHA. The aim was to determine the optimum ordinary Portland cement (OPC) replacement with RHA resulting from the reactivity of presoaked RHA and the effects of presoaked RHA on durability properties (coefficient of water absorption and sorptivity) of concrete at the age of 90 days. At w/c ratio of 0.30, OPC replacement with 20% RHA resulted in higher compressive strength compared to control for both water cured and uncured cubes. Improvements in durability properties of concrete resulting from the use of presoaked RHA were recorded.

Keywords: presoaked RHA, compressive strength, tensile strength, curing, durability properties

I. INTRODUCTION

The milling of paddy rice (*Oryza sativa*) produces husk as an agricultural waste with a low nutrition value. The disposal of rice husk has been very difficult globally because of the large ash residue resulting from improper incineration. Nigeria has the potential for ample quality RHA production suitable for use in the construction industry; it is the second largest rice producing country in Africa, and it has been estimated that 748,000– 990,000 metric tonnes of rice husk have been produced based on paddy rice production in 2010 [1,2].

Amorphous silica in RHA reacts with Ca^{2+} , OH^- ions and $\text{Ca}(\text{OH})_2$ (lime) liberated as a result of cement hydration to form a calcium silicate hydrate (CSH) gel that improves concrete strength [3-6]. It is known that reactivity of amorphous silica in RHA is influenced by the surface area of the particles [7-11]. However, the work of Cordeiro et al. [12] suggest that particle size distributions are more important in influencing reactivity when the cellular pore structure of the RHA is intact compared to a specific surface when the cellular structures break down as a result of grinding. The fine particles of RHA in concrete contribute to increased strength by improving the microstructure of the cement paste in the aggregate-cement zone in concrete [11, 13].

The works of earlier researchers indicate that the effect of RHA in concrete depends on the country of origin, methods of incineration and chemical treatment of rice husk before incineration [3, 14, 6, 15, 16]. Studies on the optimum

amount of cement replacement with RHA in both high strength concrete (HSC) and normal strength concrete (NSC) indicate that the replacement levels depend on cement content and w/c ratio [11, 17].

The use of RHA in concrete causes an increase in water demand due to the hygroscopic nature of RHA and high specific surface of the particles [18]. This effect has been observed to be linear in cement mortars; the higher the RHA content, the higher the water demand [19]. The demand for water as RHA level increases in concrete leads to a lower slump of fresh concrete and plasticizer must be used to improve workability; this is particularly pronounced when cement replacement with RHA exceeds 10% [11, 17, 20, 21].

Once the cement in concrete sets, it is important to provide external water to concrete to compensate for moisture loss to the atmosphere and aid cement hydration by curing. Curing enables the control of temperature and moisture movement from and into concrete for a definite period of time [22, 23, 24]. Since cement hydration takes place only in water filled capillaries it is important to keep concrete saturated or as nearly saturated as possible until the water filled pores in the fresh cement paste are filled to the desired extent by hydrating CSH gels and other solid hydration products [23, 25]. Hydration of cement can be defined as the combination of all chemical and physical processes that take place after contact of the anhydrous solid with water [26]. However, site concrete, being the exception, is hardly cured sufficiently for long for practical reasons.

The objective of this study was to determine the effects of presoaked RHA in concrete in terms of slump, compressive strength development, tensile strength and durability properties. By mixing RHA at a low specific surface in equal weight of water, the cellular pores of the RHA are saturated with water and the RHA is in the saturated surface dry condition. The extra water should achieve two things in concrete: First, it will reduce the water demand in concrete resulting in lower dose of plasticizer, particularly at high levels of cement replacement. Secondly, this pore water at a microscopic level would be available for hydration as calcium silicate hydrate gels develop in concrete; in this regard, the extent to which this water is available and for how long it is available for hydration should influence the compressive strength development of concrete.

II. MATERIALS AND METHOD

A. Materials

The RHA used for this study was produced from rice husk sourced from local rice mills in Minna town, Nigeria using a charcoal fired incinerator. Minna is a small-sized state capital of Niger state; a major rice producing state in the middle belt region of Nigeria.

The incinerator used for producing the RHA was fired using charcoal as solid fuel. The incinerator used for this study was based on the design principles of Allen [27] and Loo et al. [28]. The incinerator consists of two concentric fine steel mesh baskets. The small steel basket was placed inside the bigger basket with the top level and the space between the two baskets filled with rice husk. Red hot charcoal was poured into the small steel mesh basket acting as the receptacle and allowed to burn out. Plates 1-3 show the incinerator in use. Temperature measurements in the incinerator using type k thermocouples recorded maximum temperature of 758oC in the rice husk for less than 4 hours; the maximum temperature recorded in the hot charcoal interior was 838oC and the duration was less than 4 hours.



Fig.1. The incinerator with rice husk



Fig. 2. Inner steel mesh basket charged with red hot charcoal



Fig.3. The incinerator converting rice husk into RHA

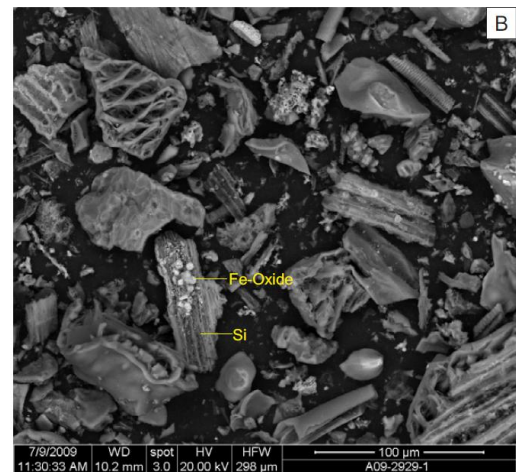


Fig.4. Cellular microstructure of milled RHA siliceous particles (X1000)

After production, the RHA was ground using a commercial hammer mill. The RHA had a specific gravity of 1.13. For the quantitative determination of the mineral phases of RHA, ground samples were subjected to X-ray diffraction (XRD) analysis. A laser diffraction particle size analyzer, Mastersizer 2000 by Malvern Instruments (UK), was used to determine the particle size distribution of the milled RHA. Plate 4 shows the BSE image of the milled RHA; the cellular structures of the RHA particles are visible in the photomicrograph.

Natural river bed quartzite sand with specific gravity of 2.73 was used as fine aggregates; crushed granite of 20mm maximum size with specific gravity of 2.63 was used as coarse aggregate. The particle size distributions of the fine aggregates correspond to zone 2 sand by the BS 882: 1983 [29] classification. The particle size distributions of fine and coarse aggregates are provided in Table 1. The concrete mix proportions are given in Table 2. The cement used is a commercial brand of OPC (Type 1) available in Nigeria. The composition of the OPC by X-ray fluorescence (XRF) is given in Table 3.

TABLE I
PARTICLE SIZE DISTRIBUTION OF AGGREGATES AS PERCENTAGE BY WEIGHT PASSING SIEVE SIZES

		Sieve size (mm)							
		20	10	5	2.36	1.18	0.60	0.30	0.15
Fine aggregates		-	-	92.4	81.6	61	38.3	14.5	5.3
Coarse aggregates		95.00	40.62	0.80	-	-	-	-	-

TABLE II
CONCRETE MIX PROPORTIONS

Cement content	Sand	Coarse aggregates	Free w/c ratio
530kg/m ³	458kg/m ³	1,302kg/m ³	0.30,0.35

TABLE III
COMPOSITION OF OPC BY XRF

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O
24.79%	6.35%	0.92%	58.50%	2.87%	4.91%	0.80%
Na ₂ O	Mn ₂ O ₃	P ₂ O ₅	TiO ₂	Cl-	SR	AR
0.65%	0.0%	0.15%	0.06%	0%	3.41	6.88

SR: silica ratio= $\text{SiO}_2 / (\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$, AR=alumina ratio= $\text{Al}_2\text{O}_3 / \text{Fe}_2\text{O}_3$

B. Characterization of RHA

For the quantitative determination of the mineral phases, 0.9g of sample was mixed with 0.1g corundum used as an internal standard. The amounts of the crystalline phases in the samples were estimated using the integrated peak intensities of the strongest peak for each compound. The intensities were normalized with values of $k=I/I_{\text{cor}}$ from Powder Diffraction File database. Normalization factor k for a compound is the ratio of its strongest peak intensity to the intensity of the strongest peak of corundum in a sample containing 50% of the compound and 50% of corundum. The amounts of the crystalline phases were recalculated based on 10% weight corundum added as an internal standard. The amount of the amorphous silica was estimated as the difference to 100%. The XRD analysis was performed using Philips X'Pert Pro diffractometer equipped with Cu X-ray operated at 40kV and

a current of 50mA in a range of 3-80 deg 2 θ at a sample rotation of 1rev/sec.

Tables 4 and 5 show the composition of the RHA used for this study. Table 4 shows that the total silica content of the RHA determined by XRF was 95.41%. From Table 5, the amorphous silica content of the RHA was 90% with a LOI of 0.77% at 800oC (6 minutes) and 3.88% at 1050oC (3hours). The LOI is a measure of the quantity of unburnt carbon in the RHA. The values of the loss of ignition satisfied the ASTM C618-03 [30] requirement of 6% (max.) for pozzolans used in concrete. The milled RHA used had a low specific surface of 235m²/kg; at this specific surface the cellular structures of the RHA weremaintained. Fifty percent of the RHA particles are less than 46.451 μm in diameter and ninety percent of the particles are less than 178.521 μm in diameter. The particle size distributions of the RHA determined by laser diffraction are given in Fig. 5.

TABLE IV
OXIDE COMPOSITION OF RHA BY XRF

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O
95.41%	0.00%	0.82%	0.00%	1.24%	0.07%	1.65%
Na ₂ O	Mn ₂ O ₃	P ₂ O ₅	TiO ₂	Cl-		
0.22%	0.19%	3.97%	0.03%	0%		

TABLE V
PHYSICAL PROPERTIES OF RHA

Specific surface	Loss of ignition (LOI)		Amorphous (opal-SiO ₂ nH ₂ O)	Crystalline (cristobalite SiO ₂)	Quartz (SiO ₂)	Langbeinite KBaFe ₂ (PO ₄) ₃	Fairchild (K ₂ Ca(CO ₃)) and Phosphates in trace amounts
	800°C (6 min.)	1050°C (2 hrs)					
235m ² /kg	0.77%	3.88%	90%	1%	6%	2%	1%

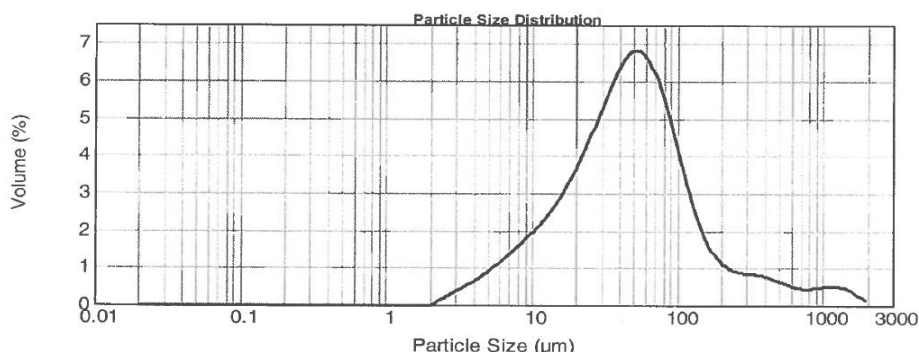


Fig. 5. Particle size distribution of milled RHA

C. Mixing Process and Strength Determination

Weighed RHA was mixed with equal weight of water to produce a soft cake ten minutes before mixing. Half of the weight of coarse aggregates was poured into the rotating mixer; the RHA cake was added and mixed for two minutes before the remaining weight of coarse aggregates was then poured into the mixer. Thereafter, half the weight of the mixing water containing the plasticizer was added to the mixer followed by cement and fine aggregates. The remaining water was then finally added. The concrete mixing in the tilting drum mixer was carried out for three minutes after the final addition of water. The concrete was manually compacted in two layers in 100mm steel moulds.

The slump of the fresh concrete mixes was measured by standard sump cone using standard procedures in BS EN12350-2:2009[31].

A chloride free lignosulphonate based plasticizer (Fosroc’s ConplastP505) complying with BS EN 934 [32] standard was used to increase the slump of the mixes. After 24hrs in the moulds, the cubes to be continuously cured in water were demolded and cured in water in compliance with BS 1881. P111:1997 [33] standard.

The cubes that were designated uncured were removed from the moulds after 24hours and stored in the open air on the laboratory floor. The average daytime temperature recorded was 23oC at an average daily relative humidity of 44%. Two sets of cubes were cast for each mix proportion; one set of cubes was continuously cured in water while another set was stored in the open air on the laboratory floor. At predetermined ages, the cubes were removed and their compressive strength was determined. Since the RHA used was presoaked with equal weight of water prior to mixing, the

weight of water used for the concrete mix was determined on the basis of cement content only. Concrete cubes without RHA cured in water were used as control.

The compressive strength of the cubes (100mm) was determined in compliance with BS 1881: part 4:1970 [34] standard using ELE ADR 3000 digital compression machine at a loading rate of 3.00kN/s; the split tensile strength of concrete cylinders (150mm×300mm) was determined in compliance with BS 1881: Part 117: 1983[35] standard using the same machine at a loading rate of 2.10kN/s. The tensile test results are average of three specimen tests.

D. Coefficient of Water Absorption

Coefficient of water absorption is a measure of permeability of concrete [5, 14]. This is determined by measuring water uptake in dry concrete within 1 hour. The concrete specimens were heated in an oven at 98oC until a constant weight was attained at ten days and the cubes were allowed to cool gradually to room temperature for 24hrs. Four sides of 100mm cube samples were sealed with 1mm thick silicone sealant to a height of 30mm to allow for water absorption on only one surface of the cube. The samples were immersed to a depth of 10mm in water as shown in Fig. 6. After immersion in water for one hour, the cubes were taken out and the wet surface was wiped of excess water and weighed. The coefficient of water absorption of the specimens at 90 days was calculated from the formula,

$K_a = \frac{Q}{A} \times \frac{1}{t}$, where K_a is the coefficient of water absorption (m²/s), Q is the quantity of water absorbed (m³) by the oven dry specimen in the time (t), t=3600 seconds and A is the surface area (m²), through which water was absorbed [5].

E. Sorptivity

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material [5, 36]. The concrete specimens were heated in an oven at 98oC until a constant weight was attained within ten days and then allowed to cool to room temperature for 24hrs. The sides of the cubes were coated with silicone sealant to allow for the flow of water on only one surface of the cube specimen. The cube specimens were immersed to a depth of 10mm in water on only one surface. The initial mass of the cube was taken at time 0 and at time intervals of 1, 2, 4, 8, 10, 20, 30, 60 and 90 minutes, the samples were removed from water and excess water blotted off and the sample weighed. It was then placed back in water and the process was repeated at the same selected time intervals. The sorptivity value of the specimens at 90 days was calculated using the formula,

$i = S / \bar{t}$, where i is the cumulative water absorption per unit area of the surface (m³/m²); S is the sorptivity (m/ \bar{t}) and t is the elapsed time (s) [37].

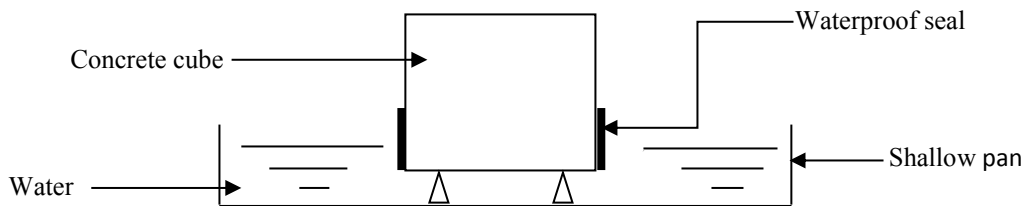


Fig. 6. Coefficient of water absorption and sorptivity test

III. RESULTS

The results of the compressive strength tests on uncured and water cured concrete cubes containing different OPC replacement with RHA by weight at different ages are shown in Table 6. The compressive strength of uncured and water cured specimens at different test ages at w/c ratio of 0.30 is shown in Figures 7 and 8. The results are the average of three specimen tests. The percentage differences between the compressive strength of uncured and water cured specimens are given in Table 7.

The tensile strength of concrete cylinders, sorptivity and coefficient of water absorption at 90 days for water cured and uncured cube specimens are shown in Table 8 and Table 9.

IV. DISCUSSION

A. Compressive Strength

The results of compressive strength tests in Table 6 show that at a w/c ratio of 0.30 at 90 days, 20% OPC replacement with RHA was attained without strength reduction for both water cured and uncured cubes. The results indicate that the presoaked RHA in uncured cubes was not only most reactive at the 5% replacement, but also the cubes had higher compressive strength than water cured specimens at 3, 7, and 14 days. The results in Table 7 show that uncured cubes containing RHA had lower compressive strength losses at 90 days compared to cubes without RHA. This is attributable to the effect of presoaking the RHA with water. It does appear

that the effect of presoaking the RHA mitigated the effects of moisture loss and self-desiccations in concrete. By presoaking the RHA pores with water, marginal improved early age hydration appeared to have been recorded.

Furthermore, the results show that presoaking the RHA did not interfere with the reactivity of the RHA at this w/c ratio. The use of presoaked RHA enabled the simultaneous reduction in plasticizer content and increase in slump at the

same time. Usually, when dry RHA is used in concrete production, rapid water absorption by the RHA particles (due to the high specific surface and the hygroscopic nature of the particles) results in water demand. This effectively results in the lowering of slump, thus necessitating the use of plasticizers in order to produce concrete with acceptable slump. By presoaking the RHA with water, the demand for water occasioned by the use of dry RHA is eliminated.

TABLE VI
EFFECTS OF WATER AND AIR CURING ON COMPRESSIVE STRENGTH OF CONCRETE CONTAINING PRE-SOAKED RHA

Free w/c ratio	RHA replacement	Plasticizer (l/m ³)	Slump (mm)	Uncured Compressive strength (N/mm ²)					Water cured Compressive strength (N/mm ²)				
				3days	7days	14days	28days	90days	3days	7days	14days	28days	90days
0.30	0%	8.3	30	29.43	30.85	31.91	32.84	32.95	36.04	40.02	47.38	49.49	49.95
	5%	6.7	20	44.11	46.43	50.66	52.82	55.73	42.70	43.54	48.14	55.52	59.04
	10%	7.0	65	37.74	38.28	44.40	47.90	49.39	35.09	43.88	48.55	52.95	60.04
	15%	7.2	88	28.54	38.28	42.13	45.75	44.89	31.90	41.66	49.16	54.28	57.74
	20%	7.0	55	28.84	34.82	37.07	37.97	39.04	24.14	32.83	42.18	48.33	51.20
0.35	0%	6.7	73	29.03	34.24	36.64	38.86	39.50	35.42	41.68	45.73	52.71	61.71
	5%	6.7	200	35.66	39.76	43.33	49.74	48.26	39.86	46.21	53.01	59.89	66.52
	10%	6.5	390	24.68	29.94	34.84	35.15	34.59	27.16	37.39	43.25	51.90	56.35
	15%	5.0	125	23.90	29.14	32.28	32.71	35.30	32.45	38.04	42.38	50.34	55.92
	20%	5.0	100	21.58	28.66	29.80	28.50	29.73	21.12	27.20	33.72	38.16	40.57

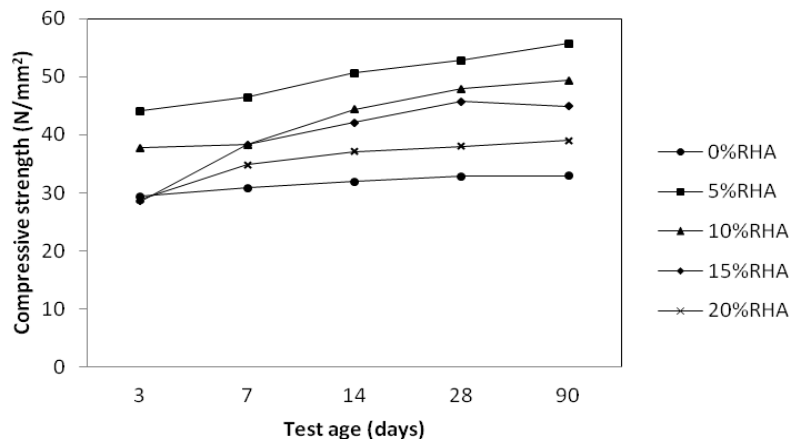


Fig. 7. Compressive strength of uncured concrete cubes at free w/c ratio of 0.30

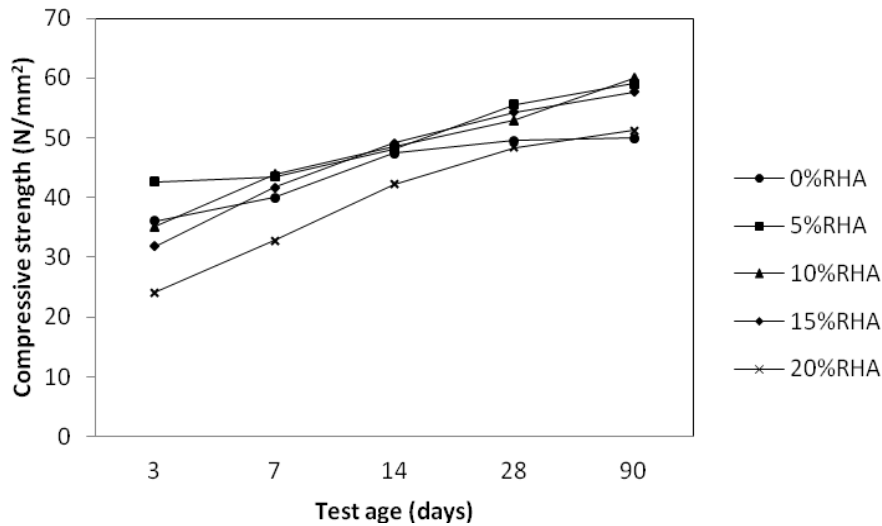


Fig. 8. Compressive strength of water cured concrete cubes at free w/c ratio of 0.30

TABLE VII
PERCENTAGE COMPRESSIVE STRENGTH LOSSES OF UNCURED CUBES RELATIVE TO CONTROL

Free w/c ratio	RHA replacement	Percentage compressive strength losses of uncured cubes compared to control				
		3days	7days	14days	28days	90days
0.30	0%	-18.34	-22.91	-32.65	-33.64	-34.03
	5%	+3.30	+6.64	+5.23	-4.86	-5.61
	10%	+7.55	-12.76	-8.55	-9.54	-17.74
	15%	-10.53	-8.11	-14.30	-15.71	-22.25
	20%	+19.39	+6.06	-6.31	-16.35	-23.75
0.35	0%	-18.04	-17.85	-19.88	-26.28	-35.99
	5%	-10.54	-13.96	-18.26	-16.95	-27.45
	10%	-9.13	-19.93	-19.45	-32.27	-38.62
	15%	-26.35	-23.40	-23.83	-35.02	-36.87
	20%	+2.18	+5.37	-10.44	-20.23	-26.72

At a higher w/c ratio of 0.35, 5% RHA content was recorded to have resulted in the maximum compressive strength increase at 90 days for both uncured and water cured cubes. From the results in Table 7, no appreciable mitigation of compressive strength losses due to moisture loss was recorded for uncured cubes containing presoaked RHA at 90days. However, the compressive strength loss at 90 days and other ages for uncured cubes containing 5% RHA was lower than that of cubes without RHA. The extra water from presoaking would account for this. The early compressive

strength gains recorded at 20% RHA content could be attributed to extra water available for cement hydration sourced from the water in the RHA pores.

The use of presoaked RHA resulted in lower plasticizer dose and higher slump for mixes containing RHA. The lower compressive strength recorded at the w/c ratio of 0.30 for specimens without RHA compared to compressive of specimens without RHA at w/c ratio of 0.35 was due to the quantity of plasticizer used at this low w/c ratio.

TABLE VIII
DURABILITY PROPERTIES AND TENSILE STRENGTH OF WATER CURED CONCRETE AT 90DAYS

Free w/c ratio	0.30					0.35				
RHA content (%)	0	5	10	15	20	0	5	10	15	20
Tensile strength (N/mm ²)	4.276	4.317	4.305	4.512	3.853	3.978	4.678	4.293	4.577	3.619
Sorptivity $s(m \times \sqrt{t})$	0.906	0.905	1.068	1.620	1.333	0.920	1.141	1.414	1.636	1.546
Coefficient of water absorption Ka (m ² /s) $\times 10^{-8}$	4.016	2.845	4.713	7.501	5.945	4.134	6.275	4.869	7.275	6.275

TABLE IX
DURABILITY PROPERTIES AND TENSILE STRENGTH OF UNCURED CONCRETE AT 90DAYS

Free w/c ratio	0.30					0.35				
RHA content (%)	0	5	10	15	20	0	5	10	15	20
Tensile strength (N/mm ²)	3.074	3.261	3.381	3.268	3.058	3.153	3.300	2.575	2.921	2.336
Sorptivity $s(m \times \sqrt{t})$	1.524	1.509	1.767	2.283	2.054	1.605	1.600	1.847	2.717	1.973
Coefficient of water absorption Ka (m ² /s) $\times 10^{-8}$	8.837	7.229	8.444	19.586	8.155	11.412	10.068	16.741	19.638	13.254

B. Tensile Strength

The results of tensile strength tests in Table 8 and Table 9 show that the use of presoaked RHA resulted in slight increases in value as the RHA content increased for both water cured and uncured cylinders. However, in all the specimens, 20% RHA content resulted in lower tensile strength compared to cylinders without RHA. Concrete is generally known to be weak in tensile strength. Though no adequate theory exists to explain the source of strength or bonding for CSH gels, it is accepted that CSH is responsible for the compressive strength properties of concrete. CSH is also known to be weak in tensile strength possibly due to bond break in silicate chains at the atomic scale [38]. The growth of more CSH gels as a result of RHA reactions in concrete contributed to the tensile strength increase recorded.

C. Sorptivity and Coefficient of Water Absorption

The sorptivity measurements of the uncured and water cured specimens in Table 8 and Table 9 show that the water cured specimens had better compact microstructure than uncured specimens. Also the lower w/c ratio mixes had a more compact microstructure than higher w/c ratio mixes. The growth of more solid hydration products as a result of water curing attributed to this. Furthermore, high w/c ratio mixes are known to have more and bigger micro pores resulting from water not used in hydration [39]. However, as the RHA content increased the hygroscopic nature of the RHA contributed to an increase in sorptivity.

The permeability of concrete as indicated in the coefficient of water absorption measurements in Table 8 and Table 9 at

90 days reduced as the w/c decreased due to a reduction in microscopic pores at lower w/c ratio. It also reduced as more hydration is promoted in water cured specimens. Due to the hygroscopic nature of RHA, the permeability of specimens increased as RHA content increased, with the exception of 5% RHA content. This could be understood to be due to the filler effect of the RHA at this content that improved the microstructure without the counter hygroscopic effect of the RHA.

V. CONCLUSIONS

The results have shown that presoaked RHA is not only reactive in concrete, but that 20% of cement can be replaced by the presoaked RHA at low specific surface. The optimum percentage OPC replacement with presoaked RHA recorded in this study generally agrees with other studies using dry RHA. It also shows that the percentage RHA replacement content without strength loss is also dependent on the w/c ratio of the concrete mix. The results have also shown that the slump of fresh concrete can be increased without an increase in plasticizer content by using presoaked RHA. Furthermore, the results have demonstrated that the usual reduction of slump of fresh concrete associated with the use of RHA in concrete can be drastically reduced by presoaking RHA in equal mass of water prior to mixing. Improvements in durability properties of concrete at 5% RHA content have also been shown.

REFERENCES

- [1] FAO (FAO rice market monitor), vol. 13, no 2, 2010. [Accessed 20.06.2011.]. Available: <http://www.fao.org/docrep/012/al307e/al307e00.pdf>
- [2] L. Flake, M. David. (2009.). Nigeria, Grain. USDA foreign agricultural service report. [Accessed 20.08.2012.]. Available: <http://www.globaltrade.net/international-trade-import-exports/f/market-research/pdf/Nigeria/Crops-and-Support-Services-Rice-Grain-and-Feed-Annual-in-Nigeria.html>
- [3] Q. Feng, H. Yamamichi, M. Shoya, S. Sugita, "Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment," *Cement and concrete research*, vol.34 (3), pp.521-526, 2004.
- [4] Y. Qijun, K. Sawayama, S. Sugita, M. Shoya, Y. Isojima, "The reaction between rice husk ash and Ca(OH)₂ solution and the nature of its product," *Cement and concrete research*, vol.29 (1), pp.37-43, 1999.
- [5] K. Ganesan, K. Rajagopal, K. Thangavel, "Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete," *Construction and Building Materials*, vol. 22(8), pp.1675-1683, 2008.
- [6] M. Nehdi, J. Duquette, A. El Damatty, "Performance of rice husk ash produced using a new technology as a mineral admixture in concrete," *Cement and concrete research*, vol. 33(8), pp.1203-1210, 2003.
- [7] K. Kraiwood, J. Chai, S. Smith, C. Seksun, "A study of ground coarse fly ashes with different finenesses from various sources as pozzolanic materials," *Cement and concrete composite*, vol.23, pp.335-343, 2001.
- [8] J. Paya, J. Monzo, E. Peris-Mora, M.V. Borrachero, R. Tercero, C. Pinillos, "Early-strength development of Portland cement mortars containing air classified fly ashes," *Cement and concrete research*, vol. 25(2), pp. 449-456. 1995.
- [9] J. Paya, J. Monzo, M.V. Borrachero, E. Peris, E. Gonzalez-Lopez, "Mechanical treatment of fly ashes. Part III: studies on strength development on ground fly ash cement mortars," *Cement and concrete research*, vol. 27(9), pp.1365-1377, 1997.
- [10] A. N. Givi, S. A. Rashid, F. N. A. Aziz, M. A. M. Salleh. (2010.) Contribution of rice husk ash to the properties of mortar and concrete: A review, *Journal of American science*. [Online]. 6 (3), pp.157-165, Available: <http://www.americanscience.org>. [Accessed 21.08.2012.].
- [11] D. D. Bui, J. Hu, P. Stroeven, "Particle size effect on the strength of rice husk ash blended gap-graded Portland cement concrete," *Cement and concrete composites*, vol.27(3), pp.357-366, 2005.
- [12] G. C. Cordeiro, R. D. T. Filho, L. M. Tavares, E. M. R. Fairbairn, S. Hempel, "Influence of particle size and specific surface area on the pozzolanic activity of residual rice husk ash," *Cement and Concrete Composites*, vol.33(5), pp.529-534, 2011.
- [13] G. Giaccio, G. Rodri'guez de Sensale, R. Zerbino, "Failure mechanism of normal and high-strength concrete with rice-husk ash," *Cement and concrete composites*, vol.29 (7), pp.566-574, 2007.
- [14] F. Giannotti da Silva, J. B. L. Liborio, P. Helene. (2008.). Improvement of physical and chemical properties of concrete with Brazilian silica rice husk (SRH), *Revista Ingenieria de Construcción*. [Online]. 23(1), pp.18-25. Available: <http://www.scielo.cl/pdf/ric/v23n1/art02.pdf>.
- [15] G. Rodriguez de Sensale, "Strength development of concrete with rice-husk ash," *Cement and concrete composites*, vol. 28(2), pp.158-160, 2006.
- [16] A. Salas, S. Delvasto, R. Mejía de Gutierrez, D. Lange, "Comparison of two processes for treating rice husk ash for use in high performance concrete," *Cement and concrete research*, vol. 39(9), pp.773-778, 2009.
- [17] M. S. Ismail, A. M. Waliuddin, "Effect of rice husk ash on high strength concrete," *Construction and building materials*, vol. 10(7), pp.521-526, 1996.
- [18] H. Chao-Lung, B. Le Anh-Tuan, C. Chun-Tsun, "Effect of rice husk ash on the strength and durability characteristics of concrete," *Construction and building materials*, vol. 25(9), pp.3768-3772, 2011.
- [19] A. E. Abalaka, O. G. Okoli, M. M. Garba, I. K. Zubairu, "Effects of Nigerian rice husk ash produced using a charcoal fired incinerator on properties of cement mortar and concrete: preliminary results," In: *Proceedings of 3RD West Africa Built Environment Research (WABER) Conference*, Accra, Ghana. 19th-21st, vol. 1, July 2011. pp. 336-346.
- [20] A. L. G. Gastaldini, G. C. Isaia, N. S. Gomes, J. E. K. Sperb, "Chloride penetration and carbonation in concrete with rice husk ash and chemical activators," *Cement and concrete composites*, vol.29 (3), pp.176-180, 2007.
- [21] A. L. G. Gastaldini, G. C. Isaia, T. F. Hoppe, F. Missau, A. P. Saciloto, "Influence of the use of rice husk ash on the electrical resistivity of concrete: A technical and economic feasibility study," *Construction and building materials*, vol. 23(11), pp.4311-3419, 2009.
- [22] M. S. Mamlouk, J. P. Zaniewski, *Materials for Civil and Construction Engineers*, Third Edition. Pearson Education, Inc New Jersey, 2011, pp. 292-297.
- [23] A. M. Neville, *Properties of concrete*, Third edition, Longman scientific & technical. England, 1981, pp. 307-318.
- [24] A.M. Neville, J.J. Brooks, *Concrete technology*, Pearson educational ltd, England, 2008.
- [25] G.D. Taylor, *Materials in construction, an introduction*, Third edition. Pearson education limited. England. U.K, 2000, pp. 50-51.
- [26] J. Stark, "Recent advances in the field of cement hydration and microstructure analysis," *Cement and concrete research*, vol. 41, pp. 666-678, 2011.
- [27] M.L. Allen, "The manufacture of a cement extender from rice-husks using a basket-burner," [Online]. Available: http://www.journeytoforever.org/farm_library/RiceHusks.pdf 2008.
- [28] Y. C. Loo, P. Nimityongskul, P. Karasudhi, "Economical rice husk ash concrete," *Building Research and practice*, vol 12, pp.233-238, 1984.
- [29] British Standards Institution. *Specification for aggregates from natural sources for concrete*. BS 822, London. UK. 1983.
- [30] American Society for Testing and Materials Standard (ASTM C618-08). *Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete*.
- [31] British Standards Institution. *Methods of testing concrete; methods of testing fresh concrete. Testing fresh concrete*. BS EN 12350-2:2009. Slump-test. London. UK. 2009.
- [32] British Standards Institution. *Admixtures for concrete, mortar and grout. Concrete admixtures. Definitions, requirements, conformity, marking and labeling*. BS EN 934-2:2001. London. UK. 2001.
- [33] British Standards Institution. *Methods of normal curing of test specimens. (20 degree C method)*. BS 1881. P111. London. UK. 1997.
- [34] British Standards Institution. *Methods of testing concrete for strength*. BS 1881: Part 4. London. UK. 1970.
- [35] British Standards Institution. *Splitting tensile (indirect) strength of cylindrical concrete specimens*. BS 1881: Part 117. London. UK. 1983.
- [36] C. Hall. Water sorptivity of mortars and concretes: a review. *Magazine of concrete research*, 1989, vol. 41(14), pp.51-61.
- [37] K.D. Stanish, R.D., Hooton, M.D.A. Thomas, "Testing the chloride penetration resistance of concrete: a literature review," FHWA contract DTFH61 1997, Department of civil engineering, University of Toronto, Canada. 1997, pp. 19-22.
- [38] J. S. Murray, V. J. Subramani, R. P. Selvam, K. D. Hall, "Molecular dynamics to understand the mechanical behavior of cement paste," *Transportation Research Record. Journal of the Transportation Research Board*, vol. 21(42), pp.75-82, 2010.
- [39] K. Friedemann, F. Stallmach, J. Kärger, NMR diffusion and relaxation studies during cement hydration – A non-destructive approach for clarification of the mechanism of internal post curing of cementitious materials. *Cement and concrete research*, vol. 36, pp. 817-826, 2006.

Akogu Elijah Abalaka. Builder. Senior Lecturer. PhD, 2012. Research interests: pozzolans, concrete materials and structures. Publications: over 30 publications and methodological papers. Department of Building, Federal University of Technology, Minna, Nigeria. Email: aabalaka@gmail.com

Obumneme Godwin Okoli. Civil Engineer. Professor. PhD, 1994. Research interests: materials and structures. Publications: over 30 publications and methodological papers. Department of Building, Ahmadu Bello University, Zaria, Nigeria. Email: okolygody02@yahoo.com