

Comparative Effects of Air and Water Curing on Concrete Containing Optimum Rice Husk Ash Replacement

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Abstract

Concrete cubes and cylinders containing optimum cement replacement with rice husk ash (RHA) at low specific surface were cured in water and ambient air. The RHA was thermally produced using a charcoal fired incinerator. The characterizations of the RHA show that it was predominantly composed of amorphous silica with minor traces of cristobalite. The relative effects of air and water curing regimes on the physical properties of the concrete specimens containing the RHA and control were determined at different ages and water/cement (w/c) ratios. The results of compressive strength tests show that at 90 days, concrete cube specimens containing RHA recorded higher compressive strength losses compared to cube specimens without RHA.

Keywords: concrete, curing, RHA, compressive strength, hydration.

INTRODUCTION

The incineration of rice husk produces high volume ash residue that could be used as a pozzolan to improve properties of concrete (Nair et al., 2008). When incinerated at the right temperature, RHA is primarily composed of amorphous silica (Ganesan et al., 2008). Though numerous studies have shown that RHA at low carbon content can improve physical properties of concrete, the optimum replacement level depends on the specific surface and the w/c ratio of the concrete (Givi et al., 2010; Ganesan et al., 2008; Ferraro and Nanni, 2012; Chao-Lung et al., 2011). However, the works of Rodríguez de Sensale (2006), Chao-Lung et al. (2011) and Cordeiro et al. (2011) indicates the possible use of high carbon RHA after considerable grinding.

The uses of RHA in concrete results in the growth of more calcium silicate hydrate (CSH) gels that improve the strength of concrete (Feng et al., 2004; Yu et al., 1999). In addition, the filler effects of the fine RHA particles also results in improvement in mechanical properties of concrete containing RHA (Bui et al., 2005).

The process of cement hydration starts as soon as water is added to cement and complex silicates are formed in addition to other products. CSH is the major hydration product responsible for the strength properties of concrete. Though the mechanism of how it contributes to the high compressive strength of concrete is not firmly established, current theory is that it develops its strength properties from the electrostatic and bond forces in the silicate chains at

the atomic level, and the packing of its diverse range of sizes at various scales (Masoero et al. 2012; Murray et al. 2010).

The curing of concrete is important in promoting cement hydration by reducing moisture loss from the concrete to the atmosphere and providing water needed for the hydration of CSH gels. Curing should be a long term process since short period of early drying could result in potential strength gain reduction (Carrier, 1983). For curing to be beneficial in concrete it should start as soon as concrete hardens since the detrimental effect of early improper curing are irreversible (ACI, 1991). In addition to increasing the strength of concrete, proper curing reduces the porosity and provides a fine pore size distribution in concrete microstructure (Alamri, 1988). However, when a mineral admixture like RHA is added to concrete, curing conditions could affect strength and concrete microstructures differently. Mineral admixtures have been shown to cause more compressive strength losses in uncured concrete specimens than normal concrete mixes (Ramezani-pour and Malhotra, 1995; Ozer and Ozkul, 2004).

In this study, the effects of water curing and air curing of concrete cube and cylinder specimens containing RHA on mechanical properties of concrete at optimum replacement levels were established. An understanding of the effects of curing conditions on strength development of concrete containing RHA is very important in the concrete production. The optimum levels of OPC replacement with RHA were

determined from literature and other previous works (Abalaka, 2012).

MATERIALS AND METHOD

The cement used is a commercial brand of ordinary Portland cement (OPC) available in Nigeria. The composition of the OPC by X-ray florescence (XRF) analysis is given in Table 1.

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 classification. The particle size distributions of the aggregates are given in Table 2.

The concrete mix proportions are given in Table 3. The concrete was mixed in a tilting drum mixer for 3minutes, and manually compacted in two layers in 100mm steel moulds. The milled RHA was weighed and added dry to the cement before mixing. A chloride free lignosulphonate based plasticizer (Fosroc’s *Conplast P505*) complying with BS EN 934 standard was used to increase the slump of the mixes. Two sets of cubes were cast for each mix proportion; one set of cubes were continuously cured in water while another set were stored in the open on the laboratory floor. After 24hrs in the moulds, the cubes and cylinders (150mm×300mm) to be continuously cured in water were de-molded and cured in water in compliance to BS 1881. P111:1997 standard. The cubes and cylinders that were designated uncured were de-molded and stored on the laboratory floor and at specific ages, the strength determined. Concrete cubes without RHA cured in water were used as control.

The RHA used for this study was produced from rice husks sourced from local rice mills in Minna town, Nigeria using a charcoal fired incinerator. Minna is the 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 consists of two concentric fine steel mesh baskets. The small steel basket was placed inside the bigger basket with the tops level and the space between the two baskets filled with rice husk. Red hot charcoal was poured into the small fine steel mesh basket acting as the receptacle and allowed to burn out. Temperature measurements in the incinerator using type k thermocouples recorded maximum temperature of 758°C in the rice husk for less than 4 hours duration.

After production, the RHA was ground using a commercial hammer mill. The hammer mill was

chosen for its availability, high milling output and affordability. A laser diffraction particle size analyzer, *Mastersizer 2000* by Malvern Instruments U.K., was used to determine the particle size distribution of the milled RHA.

Table 1. 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=SiO₂/ (Al₂O₃+Fe₂O₃), AR=alumina ratio= Al₂O₃/Fe₂O₃

Table 2. 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 3. Concrete mix proportions.

Cement content	Sand	Coarse aggregates	Free w/c ratio
530kg/m ³	458kg/m ³	1,302kg/m ³	0.30-0.55

The compressive strength of the cube specimens were determined in compliance to BS 1881: part 4:1970 standard using *ELE ADR 3000* digital compression machine at a loading rate of 3.00kN/s; split tensile strength of concrete cylinders specimens were determined in compliance to BS 1881: Part 117: 1983 standard using the same machine at a loading rate of 2.10kN/s. The results of strength tests are averages of three specimen tests.

RHA Quality

For the quantitative determination of the mineral phases, 0.9g of sample was mixed with 0.1g corundum used as 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 $k=I/I_{cor}$ 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 internal standard. The amount of the amorphous silica was estimated as the difference to 100%. The X-ray diffraction (XRD) analysis was done 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 2θ at a sample rotation of 1rev/sec.

Tables 4 and 5 show the composition of the RHA used for this study. Table 4 shows the total silica content of the RHA determined by XRF to be 95.41%. From Table 5, the amorphous silica content of the RHA was 90% with a LOI of 0.77% at 800°C (6 minutes) and 3.88% at 1050°C (3hours). The LOI is a measure of the quantity of un-burnt carbon in the RHA. The values of the loss of ignition satisfied the ASTM C618-03 requirement of 6% (max.) for pozzolans used in concrete. In addition to low reactivity of RHA with high carbon content, the use of RHA with high carbon content results in dark coloration of concrete and interferes with the action of surfactants by absorbing them (Hurt et al. 2003; Ferraro and Nanni, 2012), thus reducing the effects of

surfactants in concrete. The milled RHA used had a low specific surface of 235m²/kg. Fifty percent of the RHA particles are less than 46.451µm in diameter and ninety percent of the particles are less than 178.521µm in diameter. The measured median particle size of the milled RHA was 46.451µm. Figure 1 shows the back scatter electron (BSE) photo of raw RHA sample. The external surface of the RHA fragments is covered by collomorph silica. The interior of the fragments shows preserved cellular texture. Figure 2 shows the BSE photo of the milled RHA, the internal cellular structures of the RHA particles are visible.

Table 4. Oxide Composition of RHA by XRF.

SiO₂	Al₂O₃	Fe₂O₃	CaO	MgO	SO₃	K₂O
95.41%	0.00%	082%	0.00%	1.24%	0.07%	1.65%
Na₂O	Mn₂O₃	P₂O₅	TiO₂	Cl-		
0.22%	0.19%	3.97%	0.03%	0%		

Table 5. 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 K ₂ BaFe 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%

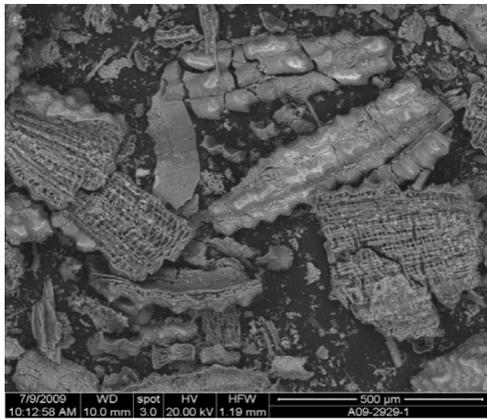


Figure 1. BSE photomicrograph of raw RHA(x250)

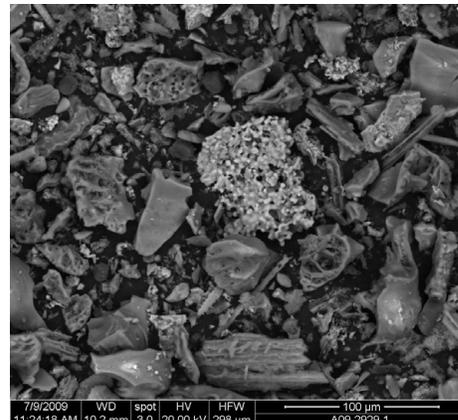


Figure 2. BSE photomicrograph of milled RHA sample (x1000)

Coefficient of Water Absorption

Coefficient of water absorption is a measure of permeability of concrete (Ganesan et al., 2008; Giannotti da Silva et al., 2008). This is determined by measuring water uptake in dry concrete in a time of 1 hour. The concrete specimens were heated in an oven at 98°C 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 water absorption on only one surface of the cube. The samples were immersed to a depth of 10mm in water.

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,

$$K_a = \left[\frac{Q}{A} \right]^2 \times \frac{1}{t}$$

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 (Ganesan et al., 2008).

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 (Ganesan et al., 2008; Hall 1989). The concrete specimens were heated in an oven at 98°C until a constant weight was attained at ten days and then allowed to cool to room temperature for 24hrs. The sides of the cubes were coated with silicone sealant to allow 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 repeated at the same selected time intervals. The sorptivity value of the specimens at 90 days were calculated using the formula,

$i = S/\sqrt{t}$, where i is the cumulative water absorption per unit area of the surface (m^3/m^2); S is the sorptivity (m/\sqrt{t}) and t is the elapsed time (s) (Stanish et al.1997).

RESULTS

The effects of air and water curing conditions on compressive strength of concrete specimens containing RHA at optimum replacement at different ages are given in Table 6. The effects of water and air curing on split tensile strength, coefficient of water absorption and sorptivity at 90 days are given in Tables 7 and 8.

Table 6. Effects of curing conditions on compressive strength of concrete containing optimum RHA replacement

Free w/c	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%	10.3	7	21.13	23.83	22.69	27.14	27.19	30.93	38.43	41.39	44.12	50.42
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%	7.2	106	37.63	41.60	48.25	48.33	49.08	22.55	37.97	38.64	50.84	51.98
0.40	0%	2.5	120	28.79	30.36	33.60	34.78	35.01	32.49	34.95	40.42	44.53	49.96
	5%	2.7	137	28.45	32.71	33.13	35.51	38.75	30.39	35.93	39.04	40.72	45.01
0.45	0%	1.2	200	22.13	29.96	31.00	33.40	33.34	23.82	27.68	33.69	33.94	40.11
	10%	1.7	130	23.42	28.93	31.55	34.30	34.60	28.30	34.24	37.51	41.06	46.09
0.50	0%	0	200	19.19	20.45	25.54	25.79	26.75	20.89	24.18	28.13	30.39	34.85
	15%	0	20	20.32	22.99	25.47	29.94	31.38	22.10	27.58	30.05	35.85	42.42
0.55	0%	0	200	13.29	16.25	18.56	20.39	21.21	15.20	16.99	21.01	21.34	26.37
	5%	0	200	13.55	16.34	20.70	23.28	22.15	15.57	17.91	22.85	25.33	28.39

Table 7. Tensile strength and durability properties of water cured concrete containing RHA.

Free w/c ratio	0.30		0.35		0.40		0.45		0.50		0.55	
RHA content (%)	0	5	0	5	0	5	0	10	0	15	0	5
Tensile strength (N/mm^2)	4.274	4.024	3.978	2.823	3.557	4.200	3.760	4.267	3.516	3.567	2.953	2.749
Sorptivity $s(m/\sqrt{t})$	0.906	0.994	0.920	1.296	1.274	0.876	1.657	1.458	1.951	1.620	2.393	1.841
Coefficient of water absorption $K_a (m^2/s) \times 10^{-8}$	4.016	4.358	4.134	4.016	4.786	5.466	9.036	6.875	11.950	9.545	11.955	9.649

Table 8. Tensile strength and durability properties of air cured concrete containing RHA.

Free w/c ratio	0.30		0.35		0.40		0.45		0.50		0.55	
RHA content (%)	0	5	0	5	0	5	0	10	0	15	0	5
Tensile strength (N/mm^2)	3.074	2.125	3.153	2.272	2.911	2.830	2.994	2.764	2.238	2.406	1.845	1.844
Sorptivity $s(m/\sqrt{t})$	1.524	2.099	1.605	1.465	2.209	1.296	2.319	2.135	3.829	3.284	5.449	5.431
Coefficient of water absorption $K_a (m^2/s) \times 10^{-8}$	8.837	13.376	11.412	6.275	20.332	10.068	25.101	20.031	46.883	36.145	78.047	78.024

DISCUSSION

Compressive Strength

The results of compressive tests in Table 6 shows that at a w/c ratio of 0.30, the compressive strength of uncured specimens containing 0% and 5% RHA was less than control. Compressive strength loss of uncured cubes here is attributable to moisture loss and self desiccation in the concrete; cubes containing 5% RHA that were water cured at 90 days had

compressive strength higher than control. At 90 days, compared to the control, the compressive strength losses of uncured cubes containing 0% and 5% RHA are -34.03% and -46.07% respectively.

At a w/c ratio of 0.35 and 0.40, all the specimens had compressive strength lower than control at 90 days; though the compressive strength of the water cured specimens containing 5% RHA were higher than that

of uncured specimens containing 0% and 5% RHA as a result of improved hydration. At 90 days, at w/c ratio of 0.35, compressive strength losses of uncured cubes containing 0% and 5% RHA compared to control, are -35.99% and -5.58%. At a w/c ratio of 0.40 at 90 days, the compressive strength losses of uncured specimens containing 0% and 5% RHA are -29.92% and -13.90% relative to control. Since pozzolanic reactions of RHA causes the production of additional CSH gels that requires water to hydrate, it does appear that lower demand for additional water of hydration occasioned by low reactivity resulted in lower compressive strength losses of these mixes containing RHA.

Though the compressive strength of uncured cubes containing 0%, 10%, 15%, and 5% RHA at a w/c ratio of 0.45, 0.50 and 0.55 were less than control, water cured cubes had compressive strength higher than control. At a w/c ratio of 0.45, compressive strength losses of uncured cubes containing 0% and 10% RHA relative to control were recorded to be -16.88% and -24.93% at 90 days. At the w/c ratio of 0.50 the losses of uncured specimens containing 0% and 15% were recorded as -23.24% and -26.03% compared to control at 90 days. At a w/c ratio of 0.55, uncured cubes containing 0% and 5% RHA had compressive strength losses of -19.57% and -21.94% respectively at 90 days. Since the pozzolanic reactions in concrete results in the formation of more CSH gels that requires more water to hydrate, these reactions inevitably resulted in higher demand for hydration water. This water was supplied by curing, hence the higher compressive losses recorded for uncured specimens containing RHA when compared to specimens uncured without RHA.

Tensile Strength

The results shown in Table 7 for split tensile strength indicates only marginal increase for cylinders containing RHA at w/c ratio of 0.40, 0.45 and 0.50. For uncured cylinders marginal tensile strength increase was recorded at w/c ratio of 0.50 only. However, tensile strength of water cured cylinders was recorded to be generally higher than that of uncured cylinders, due to improved hydration. Higher w/c ratio mixes generally recorded lower tensile strength compared to lower w/c ratio mixes. Higher w/c ratio mixes are known to develop more and larger micro pores that are responsible for lower strength properties of high w/c ratio concrete mixes (Friedemann et al., 2006).

Sorptivity and Coefficient of Water Absorption

The sorptivity and coefficient of water absorption of water cured specimens were lower than that of uncured specimens at the entire w/c ratio investigated. As curing improves hydration, in addition to CSH gels other solid hydration products develop in concrete that tends to produce a more

compact microstructure for water cured specimens compared to uncured specimens. For both the water cured and the uncured specimens, significant reductions in sorptivity and coefficient of water absorption were recorded for cubes containing RHA at higher w/c ratio mixes. It does appear that the filler effect of the RHA particles and the growth of additional CSH gels were more pronounced in improving durability properties of the high w/c ratio specimens than at the lower w/c ratios.

CONCLUSIONS

The results in this work have shown that the RHA used in this study was reactive at low specific surface. Specimens that were uncured containing RHA were shown to have recorded higher compressive strength losses at 90 days compared to specimens that did not contain RHA. The results also show that compressive strength gains above control of RHA specimens were only achieved when they were cured in water. It is therefore important that concrete containing RHA are properly cured to achieve optimum strength development since the effects of improper curing would be more pronounced when this is not done.

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