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Strength and Some Durability Properties of Concrete Containing Rice Husk Ash Produced in a Charcoal Incinerator at Low Specific Surface

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Abstract: Strength and some durability properties of concrete containing rice husk ash (RHA) predominantly composed of amorphous silica at a specific surface of 235 m^2/kg produced using a charcoal incinerator were determined. The maximum ordinary Portland cement (OPC) replacement with the RHA increased with increase in water/binder (w/b) ratio of the concrete mixes. The results show that 15 % OPC could be substituted by the RHA without strength loss at w/b ratio of 0.50. The split tensile strength generally increased with increase in RHA content for the mixes.

Keywords: RHA, incinerator, strength, concrete, pozzolanic reactions.

1. Introduction

Controlled incineration of rice husks at a temperature below 800 °C produces RHA that is predominantly composed of amorphous silica (Howlett 2003). Though different incinerators produce different temperature profiles that may affect the amount of amorphous silica in RHA, the change from amorphous to crystalline silica starts at 800 °C and transition to crystalline silica is complete at 900 °C (Howlett 2003).

The hydration of cement produces calcium silicate hydrate (CSH) gels known to give strength and cohesion to concrete. Though there are other solid hydration products in cement paste, CSH constitute 60 % of hydrated cement paste volume (Peled et al. 2013). The amorphous silica in RHA reacts with lime liberated as a result of cement hydration to produce additional CSH gels that improves concrete strength and durability properties (Yu et al. 1999). The reactivity of RHA in concrete is influenced by the ash properties. Previous studies on RHA suggest that incinerating conditions, pre-incinerating treatment of the rice husk, geographical location and specific surface affects the reactivity of RHA in concrete (Salas et al. 2009; Nehdi et al. 2003; Bui et al. 2005; Givi et al. 2010; Paya et al. 1995, 1997; Kraiwood et al. 2001; Ganesan et al. 2008; Ferraro and Nanni 2012). In addition to the pozzolanic reactions of the amorphous silica, the filler effect of the fine RHA particles in the concrete also improves strength at the interfacial transition zone (ITZ) between aggregate and the cement paste (Bui et al. 2005; Giaccio et al. 2007). In addition to the amorphous silica content, the specific surface is one significant factor that influences the reactivity of RHA. Literature on optimum ordinary Portland cement (OPC) replacement with RHA show that the RHA used in these studies had high specific surface. e.g. (Ferraro and Nanni 2012) achieved 15 % cement replacement with RHA at a specific surface of 430 m^2/kg and w/c ratio 0.44; (Ganesan et al. 2008) reported 30 % cement replacement with RHA with specific surface of 36.47 m^2/g in concrete at w/b ratio 0.53. Though RHA containing high loss on ignition (LOI) milled to high specific surface have been reported to be reactive in concrete (Hwang et al. 2011), it is however important that the un-burnt carbon in RHA should be kept low to prevent coloration in concrete and reduce anti surfactant effect of the un-burnt carbon in concrete.

2. Materials and Methods

The RHA used for this study was produced from rice husk sourced from a local rice mill in Minna, using a charcoal incinerator. Minna is a small sized state capital and a university town located in Niger state; a major rice producing state in the middle belt region of Nigeria. After production, the RHA was milled using a commercial hammer mill. Though the level of fineness that could be attained by the commercial mill is lower than laboratory mills, it was chosen for its affordability, rapid milling and accessibility and to determine the extent of cement replacement with the low specific surface RHA produced.

The incinerator for producing the RHA used charcoal as solid fuel. The incinerator consists of two concentric fine steel wire baskets of very small apertures; the smaller and shorter steel basket was placed inside the bigger steel basket and the space between the two filled with rice husk. The

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Fig. 1 The incinerator with rice husk.

Fig. 2 The incinerator charged with *red* hot charcoal.

inner steel basket was then charged with red hot charcoal and allowed to burnout. The resulting RHA was allowed to gradually cool to ambient temperature, collected and milled. Using thermocouples, the maximum temperature of the RHA recorded was 758 °C at less than 4 h duration and that of the charcoal interior was 838 °C and less than 4 h duration. Figures 1 and 2 show the incinerator in use.

River sand [specific gravity (SG) = 2.73, Cc = 1.82, Cu = 6] was used as fine aggregate; crushed granite of 20 mm maximum size with specific gravity of 2.63 was used as coarse aggregate. The fine and coarse aggregate particle size distributions are given in Fig. 3. The concrete mix proportions are given in Table 1. The cement used is a commercial brand of OPC in Nigeria. The composition of the OPC by X-ray florescence (XRF) is shown in Table 2. The compositions of the RHA are given in Table 3.

The concrete was mixed in a drum mixer for 3 min. All samples were demoulded after 24 h and cured in water at 21 °C in compliance to BS EN 12390-2 standard (2000). In determining the compressive strength of the concrete, cubes were cast in 100 mm steel moulds and manually compacted in two layers and tested at determined ages. In determining split tensile strength of the concrete mixes, concrete cylinders were cast in 150 × 300 mm steel moulds.

Milled RHA was used dry as percentage cement replacement in the concrete mixes. A laser diffraction particle size analyzer *Mastersizer 2000* by Malvern Instruments U.K. was used to determine the specific surface of the RHA.

The compressive strength of the cubes were determined in compliance to BS EN 12390-3 standard (2002) using *ELE*

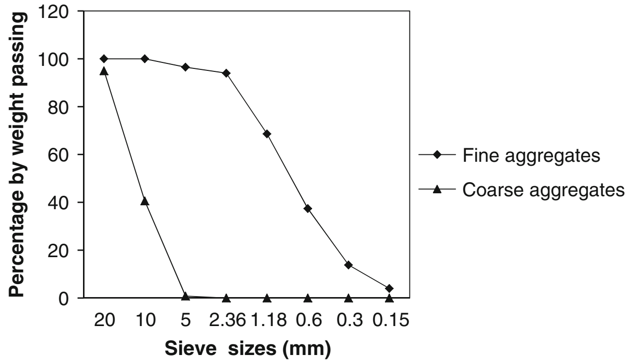

Fig. 3 Particle size distribution of aggregates as percentage by weight passing sieve sizes.

ADR 3000 digital compression machine at a loading rate of 3.00 kN/s; split tensile strength of concrete cylinders were determined in compliance to BS EN 12390-6 standard (2009) using the same machine at a loading rate of 2.10 kN/s. Concrete cubes containing 0 % RHA were used as control.

2.1 Experimental Methods

2.1.1 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 10 days and then allowed to cool gradually to room temperature for 24 h. 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 in water in a shallow pan to a depth of 5 mm on one surface. The initial mass of the cube was taken; subsequent mass measurement was taken at 4, 8, 10, 20, 30, 60 and 90 min. The sorptivity of the specimens were calculated by using the formula suggested by Stanish et al. (1997).

$$i = \frac{S}{\sqrt{t}} \quad (1)$$

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). The sorptivity of the specimens were determined after 28 and 90 days of water curing. The setup for the measurement of sorptivity values of the concrete cubes is shown in Fig. 4.

2.1.2 Saturated Water Absorption

Percentage water absorption by saturated concrete cubes is a measure of the pore volume or porosity occupied by water. The water absorption values of the concrete cubes were measured as per ASTM C 642 after 28, 90 and 180 days of water curing of the cubes (ASTM 2006).

3. Results

Tables 4, 5, 6, 7 and 8 show the effects of OPC replacement with RHA on compressive and split tensile strength of

Table 1 Concrete mix proportions.

Cement content	Sand	Coarse aggregates	Free w/b ratio
425 kg/m^3	446 kg/m^3	1,419 kg/m^3	0.35, 0.40, 0.45, 0.50, 0.55

Table 2 Composition of OPC by mass using XRF.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
24.79 %	6.35 %	0.92 %	58.50 %	2.87 %	4.91 %	0.80 %

Na_2O	Mn_2O_3	P_2O_5	TiO_2	Cl–	SR	AR
0.65 %	0.0 %	0.15 %	0.06 %	0 %	3.41	6.88

SR: silica ratio = $SiO_2/(Al_2O_3+Fe_2O_3)$, AR = alumina ratio = Al_2O_3/Fe_2O_3.

Table 3 Composition of RHA.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
95.41 %	0.00 %	0.82 %	0.00 %	1.24 %	0.07 %	1.65 %

Na_2O	Mn_2O_3	P_2O_5	Specific surface	LOI	Amorphous silica
0.22 %	0.19 %	3.97 %	235 m^2/kg	0.77 %	90 %

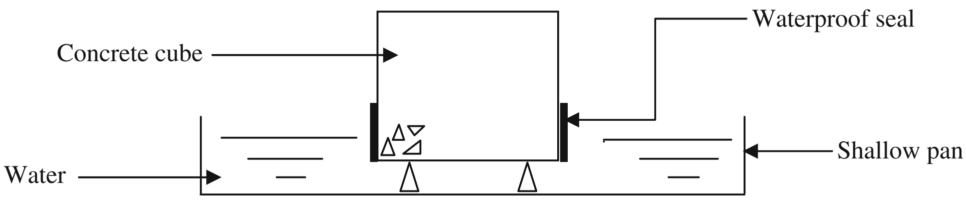

Fig. 4 Sorptivity test.

Table 4 Effects of RHA on strength properties of concrete (free w/b = 0.35).

RHA replacement (%)	Average compressive strength (N/mm^2)							Tensile strength (N/mm^2)
	3 days	7 days	14 days	21 days	28 days	90 days	180 days	28 days
0	44.40	45.51	52.13	54.24	55.63	65.11	66.25	3.709
5	27.38	37.13	39.54	40.23	46.50	49.46	54.91	3.812

concrete specimens. The effects of RHA on slump, saturated water absorption and sorptivity properties of concrete at different w/b ratio are given in Tables 9, 10, 11, 12 and 13.

4. Discussions

The results in Tables 4, 5, 6, 7 and 8 show that as the w/b ratio increased, the amounts of maximum RHA replacements increased, e.g. at a w/b ratio of 0.35 the maximum OPC replacement that could produce a workable concrete was 5 %. At a w/b ratio of 0.40, it increased to 10 % and at w/b ratio of 0.45 it increased to 15 %. At the w/b ratio of 0.55, the maximum RHA replacement was 25 %. The increase in maximum RHA replacement as the w/b ratio increased was as a result of the hygroscopic nature of RHA and its cellular microstructure. Lower w/b ratio mixes resulted in lower maximum RHA replacements as less water was available for absorption by the RHA particles. In high w/b ratio mixes more water was available for absorption by the RHA particles resulting in higher replacement levels.

4.1 Effects of RHA on Strength Properties of Concrete

The results of compressive strength tests in Tables 4 show that though specimens containing 5 % RHA progressively gained strength with age, specimens containing RHA did not record strength higher than control for all the test ages. The results in Tables 5 and 6 show that compressive strength increases above the control were recorded at 5 % RHA content at w/b ratio of 0.40 and 0.45 at the age of 180 days. At a w/b ratio of 0.40 the strength increase recorded above control was 13.27 % at 180 days and at w/b ratio of 0.45 strength increase recorded above the control was 2.15 % at 180 days. The

Table 5 Effects of RHA on strength properties of concrete (free w/b = 0.40).

RHA replacement (%)	Average compressive strength (N/mm^2)							Tensile strength (N/mm^2)
	3 days	7 days	14 days	21 days	28 days	90 days	180 days	28 days
0	29.28	35.35	41.71	42.78	47.93	56.14	57.79	3.553
5	35.78	42.85	45.29	51.21	52.81	63.19	65.46	4.097
10	33.71	38.20	44.28	44.24	49.87	53.44	55.02	3.669

Table 6 Effects of RHA on strength properties of concrete (free w/b = 0.45).

RHA replacement (%)	Average compressive strength (N/mm^2)							Tensile strength (N/mm^2)
	3 days	7 days	14 days	21 days	28 days	90 days	180 days	28 days
0	30.18	30.16	37.73	40.59	40.71	50.04	51.07	3.517
5	30.60	31.52	37.92	41.95	45.11	51.65	52.17	3.591
10	26.91	34.38	37.05	39.29	44.83	49.07	50.48	3.230
15	21.70	27.15	26.75	36.48	42.84	44.15	45.08	3.228

Table 7 Effects of RHA on strength properties of concrete (free w/b = 0.50).

RHA replacement (%)	Average compressive strength (N/mm^2)							Tensile strength (N/mm^2)
	3 days	7 days	14 days	21 days	28 days	90 days	180 days	28 days
0	23.36	26.47	34.93	33.61	37.57	39.33	45.98	2.618
5	24.90	27.62	33.60	34.68	38.80	45.18	46.85	3.476
10	25.17	30.53	30.01	35.86	44.90	44.00	49.42	3.389
15	25.19	31.06	37.11	36.22	41.33	39.89	46.66	3.694
20	19.91	26.02	29.83	37.90	32.81	36.89	39.11	3.294

Table 8 Effects of RHA on strength properties of concrete (free w/b = 0.55).

RHA replacement (%)	Average compressive strength (N/mm^2)							Tensile strength (N/mm^2)
	3 days	7 days	14 days	21 days	28 days	90 days	180 days	28 days
0	21.24	25.75	31.47	30.71	34.86	40.27	42.95	3.297
5	21.34	27.28	32.94	34.82	37.72	41.08	44.10	3.812
10	19.09	29.57	29.05	34.13	35.53	38.75	42.88	3.834
15	18.96	24.53	29.19	34.40	34.13	37.75	41.61	3.483
20	18.07	24.06	28.33	32.73	32.84	35.81	38.82	3.182
25	17.01	21.07	26.29	30.60	29.38	33.45	34.71	3.176

Table 9 Effects of RHA on slump, saturated water absorption and sorptivity properties of concrete (free w/b ratio = 0.35).

RHA replacement (%)	Slump (mm)	Saturated water absorption (%)			Sorptivity $i(m/\sqrt{t}) \times 10^{-5}$	
		28 days	90 days	180 days	28 days	90 days
0	1	4.7	4.4	3.3	2.04	1.46
5	2	5.0	5.8	5.6	2.45	2.25

Table 10 Effects of RHA on slump, saturated water absorption and sorptivity properties of concrete (free w/b ratio = 0.40).

RHA replacement (%)	Slump (mm)	Saturated water absorption (%)			Sorptivity $i(m/\sqrt{t}) \times 10^{-5}$	
		28 days	90 days	180 days	28 days	90 days
0	3	5.8	5.3	5.0	2.86	2.18
5	5	5.9	5.6	5.5	2.59	2.11
10	2	6.0	5.7	5.0	2.45	1.67

Table 11 Effects of RHA on slump, saturated water absorption and sorptivity properties of concrete (free w/b ratio = 0.45).

RHA replacement (%)	Slump (mm)	Saturated water absorption (%)			Sorptivity $i(m/\sqrt{t}) \times 10^{-5}$	
		28 days	90 days	180 days	28 days	90 days
0	3	5.8	5.7	5.6	2.45	2.18
5	30	6.0	6.4	6.4	2.10	2.05
10	3	6.7	6.7	6.2	2.00	1.91
15	0	7.0	6.9	6.2	1.50	0.90

Table 12 Effects of RHA on slump, saturated water absorption and durability properties of concrete (free w/b ratio = 0.50).

RHA replacement (%)	Slump (mm)	Saturated water absorption (%)			Sorptivity $i(m/\sqrt{t}) \times 10^{-5}$	
		28 days	90 days	180 days	28 days	90 days
0	24	6.8	6.7	6.4	1.88	1.23
5	90	6.6	7.0	6.9	1.74	1.19
10	23	6.7	7.0	6.5	3.81	1.33
15	3	7.4	7.7	6.6	2.86	1.17
20	1	8.0	8.8	6.7	3.13	3.12

Table 13 Effects of RHA on slump, saturated water absorption and sorptivity properties of concrete (free w/b ratio = 0.55).

RHA replacement (%)	Slump (mm)	Saturated water absorption (%)			Sorptivity $i(m/\sqrt{t}) \times 10^{-5}$	
		28 days	90 days	180 days	28 days	90 days
0	35	6.3	6.6	6.3	2.59	2.49
5	100	6.5	7.4	6.8	1.75	1.38
10	55	7.9	7.8	7.5	3.81	2.31
15	35	8.0	8.0	6.2	3.67	2.03
20	27	8.1	9.7	6.8	3.61	3.54
25	2	8.5	9.7	7.5	3.54	3.00

compressive strength of specimens containing 15 % RHA was recorded to be higher than control at w/b ratio of 0.50 at all the test days; at 180 days, the compressive strength increase recorded was 1.48 % higher than control. At a w/b ratio of 0.55, compressive strength higher than control was recorded for all the test days at 5 % RHA content; at 180 days, the strength increase above control was 2.68 %. Water appears to play an important role in RHA reactivity in concrete as strength increase was not recorded at low w/b ratio of 0.35. The results at a w/b ratio of 0.35 and 0.55 suggests that optimum free water is needed for the activation of pozzolanic activity of the RHA particles; where the free water was low, no reactivity was recorded and where it was high no strength gains were recorded.

The results generally indicate that the RHA at a low specific surface was reactive in concrete and 15 % of OPC could be replaced by the RHA without strength loss at a w/b ratio of 0.50. The optimum replacement level recorded in this study agrees with other studies that used RHA at a higher specific surface. The results also suggest that at the cement content used for this study, there is an optimum w/b ratio that would give maximum reactivity of the RHA in concrete that result in optimum replacement level. The compressive strength gains that were recorded for this study suggests that the reactivity that resulted in compressive strength increases were mainly due to the amorphous silica content of the RHA since the specific surface was low.

The test results in Tables 4, 5, 6, 7 and 8 show that OPC replacement with RHA that resulted in maximum compressive increase also recorded tensile strength increase above that of the control. Tensile strength increases above the control were relatively marginal compared to compressive strength increases for specimens containing RHA at the different w/b ratio tested. Though the high compressive strength of concrete is known to be due to the strength and cohesion of CSH gels, it is also known to be weak in tension. The work of Murray et al. (Murray et al. 2010) suggests that electrostatic and bond forces at the atomic level of silicate chains as the main reason for the compressive strength of concrete and that its weak tensile strength is due to breaks in silicate chains at the atomic level. The growth of more CSH gels resulting from the pozzolanic reactions of the RHA would have contributed to the tensile strength increase recorded for cylinders containing RHA.

4.2 Sorptivity

The results of sorptivity test in Table 9 show that specimens containing RHA had sorptivity values higher than control. The RHA particles at this w/b ratio did not result in pozzolanic reactions that could improve the packing of particles but resulted in increased water absorption. The sorptivity of the specimens reduced at lower w/b ratio mixes and RHA content, but increased as the RHA content increased at higher w/b ratio mixes; due to the hygroscopic nature of RHA. The RHA addition would have reduced the capillary of the concrete due to the filler effects and the growth of more CSH gels from pozzolanic reactions. At 90 days as hydration continued, the permeability further reduced resulting in reductions in sorptivity recorded at 90 days compared to 28 days. Tables 12 and 13 show that at 28 days, as the RHA content increased, the permeability of the concrete increased above the control due to the hygroscopic nature of the RHA.

4.3 Saturated Water Absorption and Slump

The saturated water absorption of the specimens containing RHA at w/b ratio of 0.35 was recorded to have increased above the control; the RHA particles that were not used in pozzolanic reactions absorbed water that resulted in increased water intake. Marginal reductions in water absorption of specimens were recorded at 180 days compared to 90 and 28 days.

The slump of the fresh concrete recorded show that higher RHA content resulted in lower slumps for all the mixes except 5 % RHA content. The rapid water absorption of RHA particles due to the cellular microstructure of the particles and the hygroscopic nature resulted in lower slumps recorded. The 5 % RHA content however appeared to have had a different effect on the slump of the fresh concrete as the slumps were higher than that of the control mixes. The 5 % RHA content appeared to have improved the dispersion of the cement particles resulting in higher slumps recorded.

5. Conclusions

The results have also shown that the optimum OPC replacement with RHA was dependent on the w/b ratio of the concrete mix. The results show that low w/b mixes tended to lower optimum RHA replacement levels. The RHA used has been shown to have improved the tensile strength of the concrete. The results of this study have further shown that, the low specific surface RHA used could replace 15 % of OPC at w/b ratio of 0.50 without reduction in both compressive and tensile strength of concrete.

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