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Influence of water-binder ratio on normal strength concrete with rice husk ash

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Abstract: The effects of rice husk ash (RHA) produced using a charcoal fired incinerator on properties of normal strength concrete at water /binder (w/b) ratio of 0.45, 0.50 and 0.55 was investigated. Characterization of the RHA by X-ray diffraction (XRD), X-ray florescence (XRF) and energy dispersive X-ray (EDS) spectroscopy methods of analysis showed that the RHA was predominantly composed of amorphous silica with traces of cristobilite. The results further show that the RHA with a low specific surface could be used to replace 25% of ordinary Portland cement (OPC) in concrete at a w/b ratio of 0.55. Improvements in split tensile strength and pore structure of the concrete were also recorded.

Introduction

With paddy rice production estimate of 3.4-4.5 million tonnes for 2010 harvest season (FAO 2010; Flake and David, 2009), Nigeria rice husk generation could be estimated at 748,000-990,000 tonnes. Since there is no commercial RHA production in the country, this quantity of rice husk is mostly disposed of by open air burning that poses environmental hazard. The quantity of rice husk currently generated in Nigeria could supplement clinker cement consumption through production of quality RHA.

Rice husk is composed of silica fibers in a matrix consisting largely of cellulose and hemi cellulose and lignin (Bharadwaj *et al*., 2004) and when incinerated at the right temperature produces RHA that contains reactive amorphous silica. Incinerating rice husk burns off the volatiles, producing about 18-20% silica ash by weight.

Amorphous silica in RHA is known to react with $Ca(OH)_2$ in the presence of water to form a calcium silicate hydrate (CSH) gel that improves concrete strength (Yu *et al*., 1999). The presence of water is very important in pozzolanic reactions in concrete (Neville, 2006; Lea, 1988; Wansom *et al*., 2010). The work of Saraswathy and Song (2007) on NSC shows that at w/c ratio of 0.53 up to 25% replacement of OPC with RHA could lead to increase in compressive strength and decrease in effective porosity and coefficient of waster absorption in concrete at 28 days.
RHA is also known to reduce the porosity of concrete at the interface between cement paste and aggregate and improve strength in this zone (Bui *et al*., 2005, Giaccio *et al*., 2007). The use of RHA as a mineral admixture is known to improve mechanical and durability properties of concrete (Saraswathy and Song, 2007). Though amorphous silica is the most reactive form, grinding RHA containing crystalline silica to very fine particles can activate pozzolanic reaction in concrete (Rodríguez de Sensale *et al*., 2008). Reactivity of RHA in concrete is also improved by increased fineness of the particles, but the cellular structures of the RHA particles must not break down (Kraiwood 2001; Paya *et al*., 1995; Paya *et al*., 1997); RHA with specific surface varying from 97,530m^2/kg to 274,000m^2/kg have been reported to be reactive in concrete (Giannotti da Silva *et al*., 2008, Salas *et al*., 2009).
The concrete used for this work could be considered as normal strength concrete (NSC). Concrete with compressive strength less than 40N/mm^2 at 28 days are considered NSC (Long, 2008). NSC differs from a class of concrete that are classified high strength concrete (HSC); cement content of NSC are usually lower than 300kg/m^3 and their internal structure is more porous with a less uniform internal structure compared to HSC (Giaccio *et al*., 2007). The NSC grade used for this work is the most common grade used for general construction in Nigeria.
The aim of this study was to determine the effects of w/b ratio of the physical properties of NSC containing RHA with low specific surface produced using a charcoal fired incinerator.

Materials

The RHA used for this study was produced from rice husk sourced from local rice mills in Minna, Niger

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state Nigeria. Minna is a state capital located in the middle belt rice producing region of Nigeria.

The incinerator used for producing the RHA used for this study used charcoal as solid fuel. The incinerator consists of two concentric fine mesh steel mesh baskets of different heights and diameter; the smaller steel basket was placed inside the bigger steel basket. The top of the two steel baskets were brought to the same level by filling the bottom of the bigger steel basket with a 16cm thick layer of rice husk. The smaller steel basket was concentrically placed on this layer and the space between the two steel baskets was filled with rice husk. Red hot charcoal was poured in the inner smaller steel basket and allowed to burn out; the rice husk surrounding the inner core was incinerated by thermal energy provided by the charcoal fuel. Type K thermocouple was used to monitor the temperature of the incinerator. The maximum temperature in the RHA recorded was 758^{o}C for duration less than 4hrs and that of the charcoal chamber was 838^{o}C for less than 4hrs duration. After the charcoal was allowed to burn out, the RHA cooled to ambient temperature and was collected and milled using a commercial mill. Though the resulting particle fineness when a commercial mill is used is usually lower than laboratory mills, it was chosen for its availability, high output and affordability in Nigeria. Plates 1, 2 and 3, show the prototype incinerator being used to produce the RHA. Plate 4 shows the back scatter electron (BSE) photomicrograph of the milled RHA sample. The cellular microstructures of the milled RHA particles are visible.

Plate 1. Filling the incinerator with rice husk.

Plate 2. Rice husk incinerator charged with red hot Charcoal.

Plate 3. A close view of the incinerator converting rice husk to RHA.

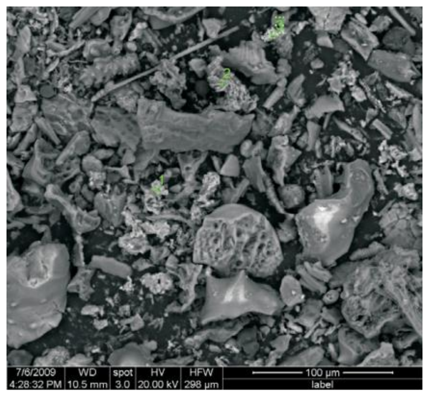

Plate 4. Cellular siliceous particles of milled RHA(x1000).

The composition of the RHA determined by XRF analysis is given in Table 1. The particle size distribution of the milled RHA was determined by laser particle size analyzer *Mastersizer 2000* by Malvern Instruments, UK. The ground RHA used had specific surface area of 235m^2/kg, with a median diameter of 46.451µm. Particle sizes range from 30-100µm.

The OPC used is commercial brand sold in Nigeria. The composition of the OPC determined by XRF is given in Table 2.

Crushed granite of 20mm maximum size with specific gravity of 2.63 was used as coarse aggregates. Natural river bed quartzite sand with specific gravity of 2.73 was used as fine aggregates; the sand is zone 2 type by BS 882: 1973 classification. The particle size distributions of fine and coarse aggregates are given in Table 3. The concrete mix proportions used are given in Table 4.

Table 1. Oxide composition of RHA by XRF.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
95.41%	0.00%	082%	0.00%	1.24%	0.07%	1.65%
Na_2O	**Mn_2O_3**	**P_2O_5**	**TiO_2**	**Cl-**		
0.22%	0.19%	3.97%	0.03%	0%		

Table 2. Composition of OPC by 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. Particle size distribution of aggregates as percentage by weight passing sieve sizes.

	Sieve size (mm)							
	20	**10**	**5**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**
Fine aggregates	-	-	96.5	94	68.60	37.40	13.80	4
Coarse aggregates	95.00	40.62	0.80	-	-	-	-	-

Table 4. Concrete mix proportions.

Cement content	Sand	Coarse aggregates	Free w/c ratio
267kg/m^3	486kg/m^3	1,537kg/m^3	0.45-0.55

Table 5. Composition of RHA.

Specific surface	Loss of ignition (LOI)		Amorphous (opal-SiO_2nH_2O)	Crystalline (cristobalite SiO_2)	Quartz (SiO_2)	Langbeinite $KBaFe_2(PO_4)_3$)	Fairchild ($K_2Ca(CO_3)$)) 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%

Methodology

The RHA was weighed and used in the dry state as percentage replacement OPC replacement. The concrete was mixed in a rotary drum mixer for three minutes and cast in 100mm steel moulds after manual compaction in two layers. A constant binder content of 267kg/m^3 was maintained for all the mixes. After 24hrs in the moulds, the cubes were de-molded and cured in water at 21^{o}C using BS 1881. P111, 1997 procedures; at the end of curing, the cubes were removed from water and excess surface water wiped off and the compressive strength determined using BS 1881: Part 4 procedures.
In determining split tensile strength, concrete cylinders were cast in 150 mm ×300mm steel moulds and de-molded after 24hrs and cured in water at 21^{o}C. Using BS 1881: Part 117 procedures, the cylinders were tested at 28 days at a loading rate of 2.10kN/s using *ELE ADR 3000* digital compression machine. Three samples were cast for each parameter investigated.
The split tensile and compressive strength test of the cylinders and cubes were done using *ELE ADR 3000* digital compression machine. The concrete cubes were tested at a loading rate of 3.00kN/s and the cylinders were tested at a loading rate of 2.10kN/s.
Concrete cubes containing 0% RHA were used as control.

3.1. *Characterization of RHA*

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 of corundum added as internal standard. The amount of 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 source operated at 40kV and a current of 50mA in a range of 3-80 deg 2θ at a sample rotation of 1rev/sec. The results of the analysis of the RHA in Table 5 show that the RHA was predominantly composed of amorphous silica with low loss of ignition.

3.2. 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 for 7days at 98^{o}C until a constant weight was attained and allowed to cool to ambient temperature for two days. The sides of the concrete cube samples were sealed with 2mm thick silicone sealant to a height of 30mm on the four faces to allow water absorption on only one face of the cubes. The samples were immersed to a depth of 5mm in water in a shallow pan, exposing the other sides of the cube to air. After immersion in water for one hour, the cubes were taken out and the face was wiped of excess water and weighed. The coefficient of water absorption of the specimens at 28 days were 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 (m^2/s), Q is the quantity of water absorbed (m^3) by the oven dry specimen in the time (t), t=3600 seconds and A is the surface area (m^2) through which water is absorbed.

3.3. *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^{o}C for 7days and cooled to ambient temperature for two days. The sides of the cubes were coated with silicone sealant to allow the flow of water on only one face of the cube. After the initial mass of the cube was taken, it was immersed to a depth of 5mm in water on one face in a shallow pan. At time intervals of 1, 2, 4, 8, 10, 20, 30, 60, and 90 minutes the samples were removed from the water and excess water blotted off and the sample weighed. It was then placed back in water and the process repeated at selected time intervals. The sorptivity value of the specimens at 28 days were calculated by using the formula (Stanish *et al*., 1997),

$i = S \times \sqrt{t}$, 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). The sorptivity values were calculated at the time of 90 minutes (5400 sec.).

3.4. *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 28days of moisture curing of the cubes.

Results

The effects of w/b ratio on compressive and split tensile strength of NSC at different ages are given in Tables 6-8. In Tables 9-11 the effects of RHA on slump, sorptivity, saturated water absorption and coefficient of water absorption of cube specimens at 28days are shown.

Discussion

5.1. Compressive strength

From Table 6, 5% RHA replacement did not result in compressive strength increase over control at all the ages tested. At 10% RHA replacement compressive strength decrease was recorded for all the samples except at 90 days when strength increase of 7% over control was recorded.

From Table 7 at w/b ratio of 0.50 no compressive strength increases above control were recorded at 3 days. Compressive strength increase over control started at 28 days for all the cubes except for cubes containing 5% RHA. At 28 and 90 days concrete cubes containing 20% RHA were higher than control. Marginal compressive strength increase of 1.6% was recorded at 20% RHA content at 90 days. At 90 days, the maximum compressive strength increase recorded at this w/b ratio was at 10% RHA replacement; the strength increase over control was 2.2%.

The results in Table 8 show that the maximum compressive strength was recorded at 20% RHA content. The same results also show that at 25% OPC replacement with RHA the compressive strength at 90 days was higher than control.

The results of the compressive strength tests shown in Tables 6-8 indicates that the higher w/b ratio mixes had higher RHA replacements that resulted in compressive strength increase over control. These results indicate that the water content in the cement matrix is important in pozzolanic reaction in concrete. In addition to the pozzolanic reactions, it appears that the filler effect of the fine RHA particles were more pronounced in the higher w/b ratio mixes. Since it is known that increase in w/c ratio leads to increases in porosity of the transition zone in concrete that result in strength reduction (Elrahman et al. 2011, Prokopski and Langier 2000), and higher w/c ratio is associated with larger pore size in cement hydration (Friedemann et al. 2006); the combined pozzolanic reaction and filler effect of the fine RHA particles would result in better compressive strength improvements with higher w/b ratio mixes. Furthermore, the compressive strength increases recorded could be mainly attributable to the pozzolanic reaction of the RHA since the specific surface of the RHA used was low.

5.2. *Split tensile strength*

From Tables 6-8 at w/b ratio of 0.45, 0.50 split tensile strength increases were generally recorded in all the mixes containing RHA. At a w/b ratio of 0.55 split tensile strength increases were recorded for specimens containing higher RHA content.

Table 6. Effects of RHA on strength properties of NSC at w/b = 0.45.

RHA (%)	Average compressive strength (N/mm^2)						Tensile strength (N/mm^2)
	3 days	**7 days**	**14 days**	**21 days**	**28 days**	**90 days**	**28 days**
0	23.73	28.99	31.99	32.07	32.11	35.92	2.636
5	17.56	18.44	21.57	24.24	26.90	28.54	3.451
10	20.29	23.25	25.82	26.02	31.07	38.43	3.325

Table 7. Effects of RHA on strength properties of NSC at w/b = 0.50.

RHA (%)	Average compressive strength (N/mm^2)						Tensile strength (N/mm^2)
	3 days	**7 days**	**14 days**	**21 days**	**28 days**	**90 days**	**28 days**
0	22.07	22.07	30.96	32.52	32.53	38.74	3.247
5	21.25	23.65	27.69	26.60	26.97	37.00	3.322
10	20.60	25.38	31.00	31.25	33.03	39.58	3.376
15	14.92	21.76	27.21	29.75	32.54	39.51	3.218
20	14.90	21.76	24.98	30.66	32.11	39.37	3.255

Table 8. Effects of RHA on strength properties of NSC at w/b = 0.55.

RHA (%)	Average compressive strength (N/mm^2)						Tensile strength (N/mm^2)
	3 days	**7 days**	**14 days**	**21 days**	**28 days**	**90 days**	**28 days**
0	15.75	19.91	21.82	24.20	24.83	28.84	2.709
5	15.26	18.80	21.46	24.02	26.56	30.75	2.486
10	16.29	19.72	23.24	26.09	28.36	32.28	2.683
15	17.56	22.58	25.71	28.26	30.77	34.34	3.221
20	17.54	20.68	26.29	28.31	32.28	37.20	3.463
25	15.65	17.19	23.69	25.47	25.61	30.19	3.146

The CSH gel that is mainly responsible for the compressive strength and cohesion of cement paste in concrete is low in tensile strength; though the breakage in silicate chains at the atomic level is responsible for low tensile strength in concrete (Murray *et al*., 2010), the reasons are not certain.

5.3. Effects of RHA on durability properties and slump of NSC

Tables 9-11 show the effects of RHA on durability properties of saturated water absorption, coefficient of water absorption and sorptivity of NSC at 28days. The results show increase in saturated water absorption over control for all the cubes containing RHA that is attributable to the hygroscopic nature of the RHA.

Table 9. Effects of RHA on durability properties of NSC at w/b ratio =0.45

RHA (%)	Slump (mm)	Saturated water absorption (%)	Coefficient of water absorption **Ka** (m^2/s)	Sorptivity $i\ (m/\sqrt{t})$
		28days	**28 days**	**28 days**
0	3	4.95	3.36×10^{-10}	2.18×10^{-5}
5	3	5.45	7.11×10^{-10}	2.45×10^{-5}
10	0	6.08	2.78×10^{-10}	2.11×10^{-5}

Table 10. Effects of RHA on durability properties of NSC at w/b ratio =0.50

RHA (%)	Slump (mm)	Saturated water absorption (%)	Coefficient of water absorption **Ka** (m^2/s)	Sorptivity $i\ (m/\sqrt{t})$
		28days	**28 days**	**28 days**
0	5	5.08	4.45×10^{-10}	2.45×10^{-5}
5	10	5.58	4.34×10^{-10}	2.59×10^{-5}
10	3	5.95	3.06×10^{-10}	1.99×10^{-5}
15	2	6.60	4.55×10^{-10}	2.59×10^{-5}
20	1	5.62	5.40×10^{-10}	2.57×10^{-5}

Table 11. Effects of RHA on durability properties of NSC at w/b ratio =0.55

RHA (%)	Slump (mm)	Saturated water absorption (%)	Coefficient of water absorption **Ka** (m^2/s)	Sorptivity $i\ (m/\sqrt{t})$
		28 days	**28 days**	**28 days**
0	7	6.08	5.98×10^{-10}	3.06×10^{-5}
5	12	6.72	3.36×10^{-10}	3.40×10^{-5}
10	5	6.47	3.67×10^{-10}	1.77×10^{-5}
15	4	7.20	1.91×10^{-10}	1.69×10^{-5}
20	2	7.11	4.00×10^{-10}	2.20×10^{-5}
25	0	6.52	10.00×10^{-10}	2.71×10^{-5}

Compared to the control, coefficient of water absorption for concrete cubes containing RHA generally decreased at lower RHA content and then increased as RHA content increased due to the hygroscopic nature of RHA. Increases in coefficient of water absorption and sorptivity are attributable to the hygroscopic nature of the RHA and higher increases in these values were recorded at higher RHA replacements. Significant reductions in sorptivity were only recorded for specimens containing RHA at the w/b ratio of 0.55. As microscopic pore sizes and numbers increased as a result of free water molecules that were not associated with cement reactions in high w/b ratio mixes, the filler effects of fine RHA particles in the concrete become more pronounced.

The slump of fresh concrete mixes containing 5% RHA were higher than that of control at w/b ratio of 0.50 and 0.55. The result indicates that RHA content at this level resulted in better dispersion of cement particles thus causing increase in slump of the fresh concrete.

6.0 Conclusion

This work has shown that it is possible to produce RHA that is reactive in concrete using a charcoal fired incinerator. The use of RHA with low specific surface of $235m^2/kg$ produced using a commercial mill in concrete could lead to improved strength, and durability properties of NSC. The results presented in this study have shown that optimum OPC replacement with RHA at 25% by weight could be attained without strength reduction in NSC at w/b ratio of 0.55. The results have also shown that w/b ratio is important in achieving both early strength gains and the optimum cement replacement level with RHA.

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