Effects of Method of Incineration on Rice Husk Ash Blended Concrete

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Abstract

Rice Husk Ash (RHA) produced in a charcoal fired incinerator was milled and characterized using Back Scatter Electron (BSE) imaging and X-ray Diffraction (XRD) methods. Compressive and tensile strengths development of Normal Strength Concrete (NSC) containing the RHA was investigated in the laboratory at different ages. Split tensile strength of the concrete mixes containing RHA was tested after 28 days of curing. The RHA used for the study as Ordinary Portland Cement (OPC) replacement by weight in concrete was in the range of 0 - 25%; the water/ binder (w/b) ratio used was 0.45, 0.50 and 0.55. The total binder content in the mixes was kept constant. The results show that the RHA could be used to replace 25% of OPC in NSC at w/b ratio of 0.55 without compressive strength loss. The results also show increased tensile strength for the mix containing RHA over the control.

Introduction

The milling of paddy rice (Oryza sativa) produces husk as an agricultural waste that is difficult to dispose of in an environmentally friendly way, and in Nigeria 748,000 - 990,000 tons of rice husk was projected to have been produced in 2010 based on estimated paddy rice production figure of 3.4 - 4.5 million tonnes (FAO, 2008; Flake and David, 2009). Rice husk produced in Nigeria is currently disposed of by uncontrolled burning since rice husk is considered as agricultural waste because it has low nutrition value. The rice being produced could potentially produce 720,000 tonnes of RHA that can generate economic activity for rice farming communities and equally empower such communities to use this material for cheaper building construction.

Rice husk contains silica and if this silica is concentrated by burning it leaves residual ash that has high silica content. However, rice husk with typical thermal conductivity of 0.024Watts/m-K, high thermal resistance (Bhatti, 2009) and a low heating value of 13-15MJ/kg that is lower than most biomass fuels (Bharadwaj et al., 2004) presents peculiar difficulties to ash by thermal process.

Methods of incinerating rice husk varies from simple open air burning that produces RHA with high carbon content to fluidized bed and Torbed technologies that produce RHA with lower carbon content.

Fluidized bed combustion is used for industrial production of RHA; the technology for industrial production of RHA is adopted from existing technologies for solid fuel combustion. The term 'fluidized bed' encompasses a range of combustion combinations where combustion of the rice husk takes place within a bed of inert material that is kept “fluid” by an upward draught of air. The inert material is usually silica sand with particle sizes in the range of Ø0.3 - 0.5mm. The combustion chamber is similar to conventional boilers, except that the floor of the boiler is covered with numerous air nozzles and some ash removal outlets. Primary combustion air enters the boiler through the nozzles and in so doing causes the mix of rice husk and inert material to mix continuously in a manner similar to a fluid. The fuel is fed from apertures located some distance above the bed. The mixing caused by fluidization produces a relatively uniform combustion temperature and avoids the extremes in temperature that occur in other types of combustion. Industrial combustion of rice husk tends to produce RHA of variable quality (Howlett, 2003). High carbon content ashes usually produced by industrial boilers are used mainly by the steel industry.

Another method of RHA production adopted from boiler technology with a high output that uses liquefied natural gas (LNG) is the stand-alone conical fluidized bed combustor. Silica sand is used as inert bed at the bottom of the cone through which air passes. LNG is introduced within the cone and the rice husk charge is introduced at a slightly higher level in the conical part. A cyclone is used to separate the RHA from flue gases. A typical incinerator has output of 15kg/hr (Janvijitsakul et al., 2004).

A Torbed reactor could be used to produce RHA but the output is usually smaller than that of a fluidized bed reactor. In a Torbed reactor rice husk particles are held in cyclonic motion in high velocity air stream. Rice husk particles are conveyed to the outer reactor walls where spinning downward airflow carry them to the base of the reactor. Nehdi (2003) reported that the use of this reactor technology has advantages over circulating fluidised bed technology as it is a smaller and a more economic reactor and the particles of rice husk undergo more thorough processing due to improved retention of rice husk particles. The use of this reactor has been reported to eliminate the need for external cyclones for separating and re-injecting rice husk particles. A Torbed reactor operates with gas velocities in the range of 3-12m/s compared to operating gas velocities of 0.1-0.6m/s for fluidized beds. A Torbed reactor operated at 750°C can produce RHA with loss on ignition (LOI) of 1.8-3.7% whereas fluidized bed can produce RHA with LOI of 7.0% (Nehdi 2003). Though different incineration methods have different peak temperatures, incinerating rice husk at temperatures of 750°C and 830°C has been proven to produce reactive RHA (Nehdi et al. 2003). The study of Nehdi et al. (2003) also show that at 12.5% RHA replacement, RHA produced using a Torbed reactor operated at 750°C produced higher compressive strength at 28 days in concrete than RHA produced using fluidized bed technology.

In the work of Chindaprasirt et al. (2007) using RHA with LOI of 11.2% sourced from power plants using fluidized burners, optimum 20% cement replacement with RHA recorded compressive strength increase at 28 and 90 days. The RHA was milled to a median particle size of 10.2µm.

The use of RHA in concrete as cement replacement is known to improve tensile and compressive strengths, and durability properties of concrete (Ganesan et al., 2008; Giannotti da Silva et al., 2008; Saraswathy and Song, 2007; Rodrý´guez de Sensale, 2006).

Local studies showed that rice husks of Enyong Creek (Akwa Ibom state) wetland rice incinerated using the open heap method yielded RHA with 94.47% total silica (SiO_2) content and LOI of 2.11% (Essien, 2006). The RHA did not result in compressive strength increase for all the mix proportions tested after 7, 14, and 28 days of wet curing.

The burning of rice husks from Minna metropolis using the perforated drum incinerator produced RHA with 67.3% total SiO_2 and LOI of 17.78 % (Abalaka et al., 2007). In concrete the maximum compressive strength increase recorded was 39.05% at 28 days at 5% cement replacement.

The works of Nehdi et al. (2003) and Rodrý´guez de Sensale (2006) indicate that country of origin, incineration technology and conditions of rice husk effect composition of RHA and its reactivity in concrete. Different methods of incineration therefore tend to produce RHA with different characteristics.

Whatever the method of RHA production, the challenge is in producing RHA that satisfies the standard requirements of either the ASTM standard with maximum permissible LOI of 6% or the Indian specification with maximum permissible LOI of 3%. Moreover the use of Torbed reactor or fluidized bed incinerator to produce quality RHA would require the use of costly LNG as fuel; hence the need for an incinerator that uses a cheaper source of energy like charcoal.

The aim of this work was to study the effects of RHA produced using a charcoal fired incinerator on compressive strength development of NSC to determine optimum cement replacement level.

Materials and Method

Materials

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

The incinerator used for producing the RHA was powered using charcoal as solid fuel. The incinerator used for this study was based on the design principles of Allen (2008) and Loo et al. (1984). The incinerator consists of two concentric 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 and contained in an expanded steel metal basket placed inside the small steel mesh basket and allowed to burn out. (Figures 1-3 show the incinerator in use). 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. For the quantitative determination of the mineral phases of the RHA, ground samples were subjected to XRD analysis. A laser diffraction particle size analyzer was used to determine the particle size distribution of the RHA. Figure 4 shows the BSE image of the raw RHA; the cellular structures of the RHA particles are visible.

Natural river bed quartzite sand with specific gravity of 2.73 was used as fine aggregate; crushed granite of 20mm maximum size with specific gravity of 2.63 was used as coarse aggregate. The fine and coarse aggregates particle size distributions are given in Table 1. The concrete mix proportions are given in Table 2. The cement used is a commercial brand of OPC available in Nigeria. The composition of the OPC by X-ray florescence (XRF) is given in Table 3.

Table 1: 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	-	-	96.5	94	68.60	37.40	13.80	4
Coarse aggregates	95.00	40.62	0.80	-	-	-	-	-

Table 2: 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 3: 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

Figure 1. Filling the incinerator with rice husk

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

Figure 3. The incinerator converting rice husk into RHA

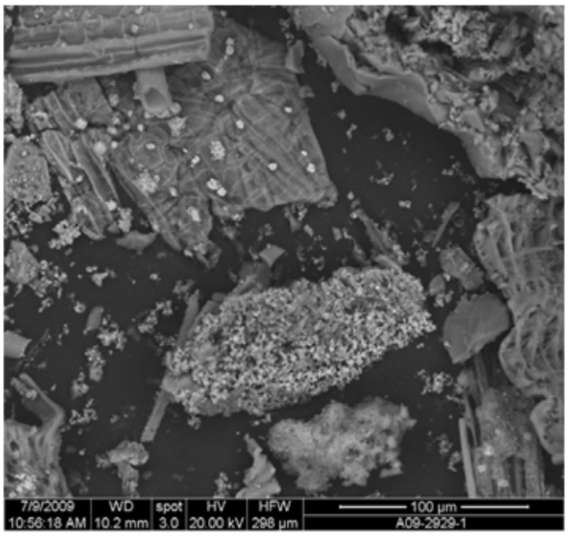

Figure 4. BSE Photomicrographs of the raw RHA showing siliceous particles (X1000)

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 corundum added as internal standard. The amount of the amorphous silica was estimated as the difference to 100%. The 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.

Compressive Strength

The concrete was mixed in a tilting drum mixer for 3 minutes, and manually compacted in two layers in 100mm steel moulds. After 24 hrs in the moulds, the cubes were demolded and cured in water. At the end of curing days the cubes were removed from water and excess surface water wiped off and the compressive strength determined. A constant binder content of 267kg/m^3 was used for all the mixes. Since no water reducing admixture was used for the study, the lowest w/b ratio that could produce workable concrete was 0.45. Since the concrete mixes became stiff and difficult to work for each w/b ratio as the RHA content increased; the maximum RHA content for each w/b ratio represents the limit that could be worked. The compressive strength test of the cubes were done using ELE ADR 3000 digital compression machine at a loading rate of 3.00kN/s. Concrete cubes containing 0% RHA were used as control. Three samples were cast for each parameter investigated.

Split Tensile Strength

For determining split tensile strength of the concretes, concrete cylinders were cast using 150 mm×300mm steel moulds, demolded after 24hrs and cured in water. The cylinders were tested after 28days of wet curing. The split tensile test of the concrete cylinders were done using ELE ADR 3000 digital compression machine at a loading rate of 2.10kN/s. The results of the tests given in Tables 6-8 represent an average of three samples.

Water Absorption

Percentage of water absorption is a measure of the pore volume or porosity in hardened concrete, which is occupied by water in a saturated condition. Water absorption values of concrete specimens were measured as per ASTM C 642 (2003) standard procedure after 28 days of moisture curing.

Results and Discussion

Physical and Chemical Characteristics of RHA

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%. Table 5 shows that 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 (3 hours). 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 requirement of 6% (max.) and the Indian standard (IS: 1727:1967) of 3% (max.) for pozzolans used in concrete. The milled RHA used had a specific surface of 235m^2/kg. The particle size distribution of then RHA by laser diffraction is given in Fig. 5.

Table 4: Oxide Composition of RHA by XRF

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Mn_2O_3	P_2O_5	TiO_2	Cl-
95.41%	0.00%	0.82%	0.00%	1.24%	0.07%	1.65%	0.22%	0.19%	3.97%	0.03%	0%

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%

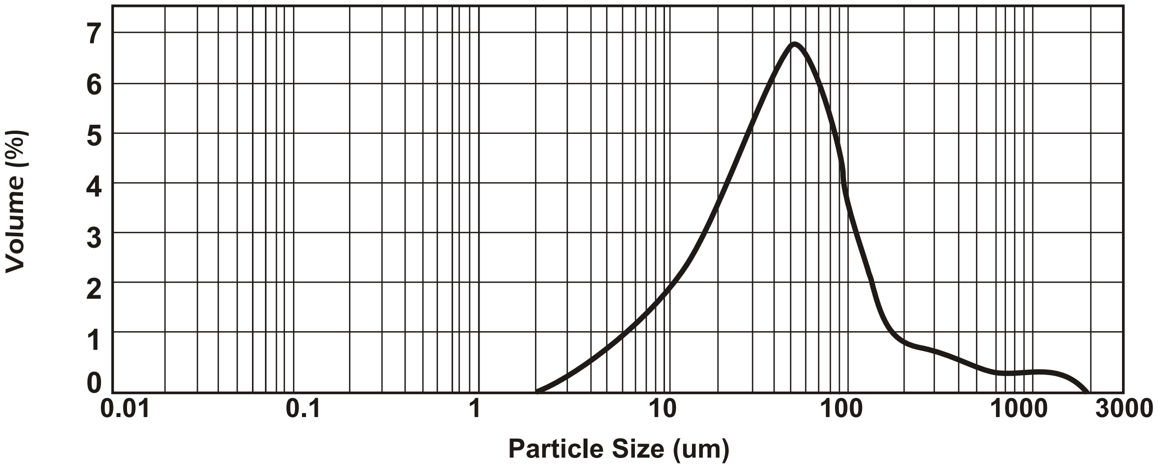

Figure 5. Particle size distribution of ground RHA

Compressive Strength

From Table 6, at a w/b ratio of 0.45, compressive strength of concrete cubes containing 5% RHA were less than control for all the wet curing ages. However concrete cubes containing 10% RHA had compressive strength that is greater than control at 90 day.

Table 7 show the effect of the RHA in concrete at w/b ratio of 0.50 at different ages of wet curing. The results show that at 3, 7, 14 and 21days, all the cubes containing RHA had compressive strength less than control, except the cubes containing 10% at 14 days. At 28 and 90 days all the concrete cubes containing 10%, 15%, and 20% RHA had compressive strength greater than control.

The effects of RHA on compressive strength of concrete at w/b ratio of 0.55 are shown in Table 8. Early age compressive strength increases over control were recorded at this w/b ratio, particularly at 15% and 20% RHA content. At 14 and 21days all the cubes containing RHA had compressive strength gains over control with the exception of cubes containing 5% RHA. At 28 and 90 days all the concrete cubes containing RHA had compressive strength higher than control. These results indicate that early compressive strength increase or early age reactivity of the RHA in concrete tends to depend on w/b ratio. As shown in Fig. 4, the RHA has high specific surface that causes increase in water demand (Abalaka et al. 2011); and, as has been observed, this causes water retaining effect in the mesopore structure (Salas et al., 2009). RHA is known to derive its strength improving properties by mechanical filler effect of the fine particles in concrete and from chemical reaction of the amorphous silica with lime liberated by cement hydration to produce more calcium silicate hydrate (CSH) gel (Feng et al., 2004; Qijun et al., 1999). However, since the specific surface of the RHA used is low, the strength increasing properties recorded in this study could be understood to be mainly due to the pozzolanic reaction of the RHA. The median particle diameter of the RHA was 46.548μm.

Split Tensile Strength

From Table 6, at w/b ratio of 0.45, tensile strength of concrete cylinders containing 5% and 10% RHA were higher than control at 28 days.

From the results in Table 7, the split tensile strength of concrete cylinders containing 5% and 10% RHA were higher than control at 28 days. At 15% RHA content the tensile strength was less than control and at 20% RHA content it was marginally higher than control.

From Table 8 split tensile strength increases over control were recorded at 15%, 20% and 25% RHA content, indicating that tensile strength increase in concrete containing RHA also depend on the w/b ratio of the concrete mix. Tensile strength increases in concrete containing

RHA have been reported in other investigations (Ganesan, 2008; Nehdi et al., 2003). The tensile strength increases recorded in this study are mainly due to the formation of more CSH gel resulting from the reaction of RHA with lime liberated by cement hydration. The amorphous silica that is mainly responsible for RHA reactivity in concrete was measured to be 90% by weight in the RHA.

Table 6: Effects of RHA on properties of NSC (free w/b=0.45)

RHA replacement (%)	Slump (mm)	Average compressive strength (N/mm^2)						Split tensile strength (N/mm^2)	Saturated water absorption (%)
		3 days	**7 days**	**14 days**	**21 days**	**28 days**	**90 days**	**28 days**	**28 days**
0	3	23.73	28.99	31.99	32.07	32.11	35.92	2.636	4.95
5	3	17.56	18.44	21.57	24.24	26.90	28.54	3.451	5.45
10	0	20.29	23.25	25.82	26.02	31.07	38.43	3.325	6.08

Table 7: Effects of RHA on properties of NSC (free w/b=0.50)

RHA replacement (%)	Slump (mm)	Average compressive strength (N/mm^2)						Split tensile strength (N/mm^2)	Saturated water absorption (%)
		3 days	**7 days**	**14 days**	**21 days**	**28 days**	**90 days**	**28 days**	**28 days**
0	5	22.07	22.07	30.96	32.52	31.34	38.74	3.247	6.08
5	10	21.25	21.25	27.69	26.60	26.97	37.00	3.322	5.58
10	3	20.60	20.60	31.00	31.25	33.03	39.58	3.376	5.95
15	2	14.92	14.92	27.21	29.75	32.54	39.51	3.218	6.60
20	1	14.90	14.90	24.98	30.66	32.11	39.37	3.255	5.62

Table 8: Effects of RHA on properties of NSC (free w/b=0.55)

RHA replacement (%)	Slump (mm)	Average compressive strength (N/mm^2)						Split tensile strength (N/mm^2)	Saturated water absorption (%)
		3 days	**7 days**	**14 days**	**21 days**	**28 days**	**90 days**	**28 days**	**28 days**
0	7	15.75	19.91	21.82	24.20	24.83	28.84	2.709	6.08
5	12	15.26	18.80	21.46	24.02	26.56	30.75	2.486	6.72
10	5	16.29	19.72	23.24	26.09	28.36	32.28	2.683	6.47
15	4	17.56	22.58	25.71	28.26	30.77	34.34	3.221	7.20
20	2	17.54	20.68	26.29	28.31	32.28	37.20	3.463	7.11
25	0	15.65	17.19	23.69	25.47	25.61	30.19	3.146	6.52

Saturated Water Absorption

From Table 6, the saturated water absorption of concrete cubes containing RHA after 28 days of curing was higher than that of control. Recorded increase in saturated water absorption was due to the hygroscopic nature of RHA. At a higher w/b ratio of 0.50 as shown in Table 7, the saturated water absorption of concrete cubes containing RHA was lower than control with the exception of cubes containing 15% RHA. Recorded reduction in saturated water absorption at this w/b ratio could be attributed to reduction in permeable voids as a result of RHA addition. In Table 8 all the concrete cubes containing RHA had higher saturated water absorption compared to control due to the hygroscopic nature of RHA.

Slump

At w/b ratio of 0.45 the slump value of the concrete containing 5% RHA was the same compared to control, and at 10% RHA replacement no slump was measured for the concrete. At higher w/b ratio of 0.50 and 0.55, the effect of the RHA on concrete slump indicated slump increase at 5% content, and subsequent increase in RHA content resulted in slump reduction.

The higher slump recorded at 5% content was due to the effect of reduction in cement flocculation resulting from RHA addition. This effect is similar to the effect of plasticizers in concrete; where the compounds by attaching to cement grains and imparting negative charge causes cement grains to disperse more effectively. This effectively avoids the formation of 'flocs' that tend to trap mixing water (Taylor, 2000). It does appear therefore that 5% RHA replacement would result in better workability in concrete.

The reduction in the slump as RHA content increased was due to water absorption of the RHA particles because of the cellular structure of the particles. There had been reported linear increase in water demand as RHA content increased in cement mortar at standard consistence (Abalaka et al., 2011).

Conclusion

This study has shown that it is possible to use charcoal as solid fuel in an incinerator to produce RHA of acceptable quality that could be used in concrete. From the results of this study, RHA at a low specific surface of 235m^2/kg was reactive in NSC thus indicating that commercial mill could be used to produce RHA for concreting. At a w/b ratio of 0.55 the RHA used activated early day's reaction in NSC that led to improved compressive strength at these early days. In all the mixes used for this study, 5%

OPC replacement with RHA caused increased concrete slump. The use of this RHA in concrete in the range of w/b ratio presented in the recorded improved split tensile strength of concrete. The RHA could be used to replace OPC at 25% by weight at w/b ratio of 0.55 without compressive strength loss in NSC.

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