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Variation Of Opc-Rice Husk Ash Composites Strength Under Prolonged Curing

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ABSTRACT

This work investigated the variation of OPC-Rice Husk Ash (RHA) composites strength under prolonged curing. 165 concrete cubes,165 sandcrete cubes, and 165 soilcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with RHA of 0% (control), 5%, 10%, 15%, and 20% and crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, 90, 120, 150, 180, and 210 days of curing. The compressive strength values of the OPC-RHA blended cement compositesat all percentage replacement of OPC with RHA were much lower than the control values at 3-14 days.For concrete, the control strength values rose to 23.50N/mm^2 at 28 days and 30.50N/mm^2 at 210 days. The strength values for 10% and 15% replacement of OPC with RHA were respectively 23.00N/mm^2 and 21.30N/mm^2 at 28 days and 31.80N/mm^2 and 31.00N/mm^2 at 210 days. Thus, whereas the control concrete attained 130% of its 28-day strength at 210 days, 10% OPC replacement with RHA attained 138% of its 28-day strength at 210 days and 15% OPC replacement with RHA attained 146% of its 28-day strength at 210 days. Sandcrete and soilcrete strength variations were similar to but more pronounced than that of concrete. The continued more rapid increase in strength of OPC-RHA composites compared to purely OPC composites between 28 and 210 days suggests that OPC-RHA blended cement structural members could be designed using some suitably higher strength values than the 28-day strength if they would not be fully loaded for some reasonable period after construction.

Key words: Blended cement, composites, compressive strength, concrete, prolonged curing, rice husk ash, sandcrete, soilcrete.

INTRODUCTION

Attempts are continuously being made to reduce the cost of cement due to its great role in physical infrastructural development. Researchers have particularly focused on formulating blended cements by obtainingsuitablepozzolanicagricultural by-products such as rice husk ash that could partially replace OPC in making cement composites. During hydration of Portland cement, calcium hydroxide [$Ca(OH)_2$] is obtained as one of the hydration products. It is responsible for deterioration of concrete. When a pozzolanic material is blended with Portland cement it reacts with the $Ca(OH)_2$ to produce additional calcium-silicate-hydrate (C-S-H), which is the main cementing component. Thus the pozzolanic material reduces the quantity of the deleterious $Ca(OH)_2$ and increases the quantity of the beneficial C-S-H. Therefore, the cementing quality is enhanced if a good pozzolanic material is blended in suitable quantity with Portland cement (Padney et al., 2003; Dwivedia et al., 2006).

Industrial waste pozzolans such as fly ash (FA) and silica fume (SF) are already widely used in many countries (Cisse and Laquerbe, 2000) and attempts are currently being made to produce and use pozzolanic rice husk ash (RHA) commercially. Malhotra and Mehta (2004) found that ground RHA with finer particle size than OPC improves concrete properties, including that higher substitution amounts results in lower water absorption values and the addition of RHA causes an increment in the compressive strength.Mehta and Pirtz (2000) investigated the use of RHA to reduce temperature in high strength mass concrete and found that RHA is very effective in reducing the temperature of mass concrete compared to OPC concrete.Sakr (2006) investigated the effects of silica fume (SF) and RHA on the properties of heavy weight concrete and found that these pozzolans gave higher concrete strengths than OPC concrete at curing ages of 28 days and above. Cordeiro, Filho, and Fairbairn (2009) carried elaborate studies of Brazilian RHA and rice straw ash (RSA) and demonstrated that grinding increases the pozzolanicity of RHA and that high strength of RHA, RSA concrete makes production of blocks with good bearing strength in a rural setting possible. Their study showed that combination of RHA or RSA with lime produces a weak cementitious material which could however be used to stabilize laterite and improve the bearing strength of the material. They also investigated the influence of different grinding times on the particle size distribution and pozzolanic activity of RHA obtained by uncontrolled combustion in order to improve the performance of the RHA. The study revealed the possibility of using ultrafine residual RHA containing high-carbon content in high-performance concrete.

Wada et al. (2000) demonstrated that RHA mortar and concrete exhibited higher compressive strength than the control mortar and concrete. Rukzon and Chindaprasirt (2006)investigated the strength development of mortars made with ternary blends of OPC, ground RHA, and classified fly ash (FA). The results showed that the strength at the age of 28 and 90 days of the binary blended cement mortar containing 10 and 20% RHA were slightly higher than those of the control, but less than those of FA. The researchers concluded that 30% of OPC could be replaced with the combined FA and RHA pozzolan without significantly lowering the strength of the mixes. Fadzil et al. (2008)also studied the properties of ternary blended cementitious (TBC) systems containing OPC, groundRHA, and FA. They found that at long-term period, the compressive strength of TBC concrete was comparable to the control mixes even at OPC replacement of up to 40% with the pozzolanic materials. Agbede and Obam (2008) investigated the strength properties of OPC-RHA blended sandcrete blocks. They replaced various percentages of OPC with RHA and found that up to 17.5% of OPC can be replaced with RHA to produce good quality sandcrete blocks.

Recent studies by Ettu et al. (2013a), Ettu et al. (2013b), Ettu et al. (2013c), and Ettu et al. (2013d) have confirmed the suitability of Nigerian RHA as a pozzolanic material for producing cement composites. What remains is to investigate the effects of some key factors on the strengths of OPC-RHA cement composites. The effect of curing age on the strength of OPC composites is well known. For example, so long as the hydration of anhydrous cement particles goes on, concrete strength increases with increase in the moist curing period (Mehta and Monteiro (2006).This is so because the strength of concrete depends on the amount of gel (the C-S-H which is the essential cementing compound) in the cement paste at any time, and this itself is a function of age. The amount of gel produced at any given time also depends on the type of cement because different cements require a different length of time to produce the same quantity of gel (Neville, 2008). This work investigated the variation of strength of OPC-RHA cement composites under prolonged curing. The knowledge of this variation would be of great importance when a structure is to be subjected to full loading at a later age in which case the gain in the strength after the age of 28 days could be taken into account in design.

METHODOLOGY

Rice husk was obtained from rice milling factories in Afikpo, Ebonyi State, Nigeria, air-dried, and calcined into ashes in a locally fabricated combustion chamber at temperatures generally below 650^{o}C. The ash was sieved and large particles retained on the 600μm sieve were discarded while those passing the sieve were used for this work. No grinding or any special treatment to improve the ash quality and enhance its pozzolanicity was applied because the researchers wanted to utilize simple processes that can be easily replicated by local community dwellers. The resultant rice husk ash (RHA) had a bulk density of 770 Kg/m^3, specific gravity of 1.85, and fineness modulus of 1.45. Other materials used for the work are Ibeto brand of Ordinary Portland Cement (OPC) with a bulk density of 1650 Kg/m^3 and specific gravity of 3.13; river sand free from debris and organic materials with a bulk density of 1590 Kg/m^3, specific gravity of 2.80, and fineness modulus of 2.90; crushed granite of 20 mm nominal size free from impurities with a bulk density of 1550 Kg/m^3, specific gravity of 3.00, and fineness modulus of 3.70; laterite free from debris and organic materials with a bulk density of 1470 Kg/m^3, specific gravity of 2.40, and fineness modulus of 3.35;and water free from organic impurities.

A simple form of pozzolanicity test was carried out for the RHA. It consists of mixing a given mass of the ash with a given volume of Calcium hydroxide solution [$Ca(OH)_2$] of known concentration and titrating samples of the mixture against hydrochloric acid solution of known concentration at time intervals of 30, 60, 90, and 120 minutes using phenolphthalein as indicator at normal temperature. The titre value (volume of acid required to neutralize the constant volume of calcium hydroxide-ash mixture) continuously reduced with time, confirming the ash as a pozzolan that fixed more and more of the calcium hydroxide, thereby reducing the alkalinity of the mixture (The amount of lime fixed by the pozzolan could be computed.). The chemical analysis of the ash showed it satisfied the ASTM requirement that the sum of SiO_2, Al_2O_3, and Fe_2O_3 should be not less than 70% for pozzolans.

A standard mix ratio of 1:2:4 (blended cement: sand: granite) was used for concrete, 1:6 (blended cement: sand) for sandcrete, and 1:6 (blended cement: laterite) for sandcrete. Batching was by weight and a constant water/cement ratio of 0.6 was used. Mixing was done manually on a smooth concrete pavement. The RHA was first thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with the fine aggregate-coarse aggregate mix(or fine aggregate only for sandcrete and soilcrete), also at the required proportions. Water was then added gradually and the entire concrete, sandcrete, or soilcrete heap was mixed thoroughly to ensure homogeneity. One hundred and sixty-five (165) granite concrete cubes, one hundred and sixty-five (165) sandcrete cubes, and one hundred and sixty-five (165) soilcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with RHA of 0% (control), 5%, 10%, 15%, and 20%. All the concrete cubes were cured by immersion while the sandcreteand soilcretecubes were cured by water sprinkling twice daily in a shed. Three concrete cubes, three sandcrete cubes,and three soilcrete cubes for each percentage replacement of OPC with RHA were tested for saturated surface dry bulk density and crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, 90, 120, 150, 180, and 210 days of curing.

RESULTS AND DISCUSSION

The particle size analysis showed that the RHA was much coarser than OPC, the reason being that the ash was not ground to finer particles. Therefore, the compressive strength values obtained using it can still be improved upon when the ash is ground to finer particles. The pozzolanicity test confirmed the RHA as pozzolanic since it fixed some quantities of lime over time. The variation of the compressive strengths of the OPC-RHA cement compositesunder prolonged curing is shown in Tables 1, 2, and 3 for concrete, sandcrete, and soilcrete respectively.

Table 1. Compressive strength of OPC-RHA cement concrete

Age (days)	Compressive Strength (N/mm^2) for				
	0 % RHA	5 % RHA	10 % RHA	15 % RHA	20 % RHA
3	8.20	5.50	5.00	4.50	3.80
7	14.30	10.00	9.50	8.40	7.90
14	21.90	18.40	18.10	15.90	14.00
21	22.50	22.40	21.80	19.30	17.40
28	23.50	25.80	23.00	21.30	19.10
50	25.80	28.50	25.40	24.80	22.10
90	27.40	29.70	28.00	26.30	24.60
120	28.20	30.20	29.10	28.00	27.30
150	29.30	30.60	30.00	29.20	28.90
180	30.00	30.90	31.00	30.10	29.40
210	30.50	31.40	31.80	31.00	29.90

Table 2. Compressive strength of OPC-RHA cement sandcrete

Age (days)	Compressive Strength (N/mm^2) for				
	0 % RHA	5 % RHA	10 % RHA	15 % RHA	20 % RHA
3	2.90	2.10	2.00	1.80	1.70
7	5.20	3.20	3.10	2.70	2.50
14	7.40	4.70	4.30	3.80	3.50
21	8.30	5.50	5.10	4.90	4.10
28	9.70	8.00	7.50	6.80	5.80
50	10.60	10.20	9.90	9.10	8.50
90	11.30	11.60	11.50	11.00	10.00
120	11.60	12.10	11.80	11.40	10.60
150	12.10	12.50	12.30	12.20	11.30
180	12.40	12.80	12.70	12.50	11.70
210	12.60	13.00	13.20	12.90	12.00

Table 3. Compressive strength of OPC-RHA cement soilcrete

Age (days)	Compressive Strength (N/mm^2) for				
	0 % RHA	**5 % RHA**	**10 % RHA**	**15 % RHA**	**20 % RHA**
3	2.80	2.00	1.80	1.60	1.50
7	4.20	3.00	2.90	2.60	2.40
14	6.00	4.50	4.10	3.50	3.30
21	6.60	5.20	5.00	4.10	3.90
28	8.40	7.50	7.00	6.60	5.60
50	9.20	9.20	9.10	8.90	8.30
90	9.80	10.40	10.10	9.90	9.70
120	10.00	11.10	10.80	10.40	10.10
150	10.50	11.60	11.70	11.20	10.90
180	10.70	12.00	12.20	11.80	11.50
210	10.90	12.40	12.60	12.00	11.80

It can be seen from Tables1, 2, and 3 that the compressive strength values of the OPC-RHA blended cement composites at all percentage replacement of OPC with RHA were much lower than the control values at 3-14 days, but increased to become comparable to and even greater than the control values at some later days of curing.This consistent pattern for all the composites has been explained by Ettu et al. (2013e) and Ettu et al. (2013f) as being a result of the low rate of pozzolanic reaction at those early ages. The silica from the pozzolans reacts with lime produced as by-product of hydration of OPC to form additional calcium-silicate-hydrate (C-S-H) that increases the binder efficiency and the corresponding strength values at later days of curing.

For concrete, the control strength values rose to 23.50N/mm^2 at 28 days, 28.20N/mm^2 at 120 days, and 30.50N/mm^2 at 210 days. The strength values for 10% and 15% replacement of OPC with RHA were respectively 23.00N/mm^2 and 21.30N/mm^2 at 28 days, 29.10N/mm^2 and 28.00N/mm^2 at 120 days, and 31.80N/mm^2 and 31.00N/mm^2 at 210 days. Thus, whereas the control attained 120% and 130% of its 28-day strength at 120 and 210 days respectively, 10% OPC replacement with RHA attained 127% and 138% of its 28-day strength at 120 and 210 days respectively, and 15% OPC replacement with RHA attained 130% and 146% of its 28-day strength at 120 and 210 days respectively.

For sandcrete, the control strength values rose to 9.70N/mm^2 at 28 days, 11.60N/mm^2 at 120 days, and 12.60N/mm^2 at 210 days. The strength values for 10% and 15% replacement of OPC with RHA were respectively 7.50N/mm^2 and 6.80N/mm^2 at 28 days, 11.80N/mm^2 and 11.40N/mm^2 at 120 days, and 13.20N/mm^2 and 12.90N/mm^2 at 210 days. Thus, whereas the control attained 120% and 130% of its 28-day strength at 120 and 210 days respectively, 10% OPC replacement with RHA attained 157% and 176% of its 28-day strength at 120 and 210 days respectively, and 15% OPC replacement with RHA attained 167% and 190% of its 28-day strength at 120 and 210 days respectively.

For soilcrete, the control strength values rose to 8.40N/mm^2 at 28 days, 10.00N/mm^2 at 120 days, and 10.90N/mm^2 at 210 days. The strength values for 10% and 15% replacement of OPC with RHA were respectively 7.00N/mm^2 and 6.60N/mm^2 at 28 days, 10.80N/mm^2 and

10.40N/mm^2 at 120 days, and 12.60N/mm^2 and 12.00N/mm^2 at 210 days. Thus, whereas the control attained 119% and 130% of its 28-day strength at 120 and 210 days respectively, 10% OPC replacement with RHA attained 154% and 180% of its 28-day strength at 120 and 210 days respectively, and 15% OPC replacement with RHA attained 158% and 182% of its 28-day strength at 120 and 210 days respectively.

These results indicate that the variation of OPC-RHA composites strength under prolonged curing is different from that of OPC composites and depends on the percentage OPC replacement with RHA. The continued more rapid increase in strength of OPC-RHA composites compared to purely OPC composites (with 0% RHA) between 28 and 210 days also suggests that some pozzolanic activity could still be going on at such later curing ages. This observation is particularly useful in that designers of structures that would not be fully loaded until some months after construction could use more suitable design strengths of OPC-RHA blended cement composites higher than those attainable at 28 days of curing.

CONCLUSIONS

i. The compressive strength values of the OPC-RHA blended cement composites at all percentage replacement of OPC with RHA were much lower than the control values at 3-14 days, but increased to become comparable to and even greater than the control values at some later days of curing.

ii. Whereas the control concrete attained 120% and 130% of its 28-day strength at 120 and 210 days respectively, 10% OPC replacement with RHA attained 127% and 138% of its 28-day strength at 120 and 210 days respectively, and 15% OPC replacement with RHA attained 130% and 146% of its 28-day strength at 120 and 210 days respectively.

iii. Similarly, whereas the controlsandcrete attained 120% and 130% of its 28-day strength at 120 and 210 days respectively, 10% OPC replacement with RHA attained 157% and 176% of its 28-day strength at 120 and 210 days respectively, and 15% OPC replacement with RHA attained 167% and 190% of its 28-day strength at 120 and 210 days respectively.

iv. In like pattern, whereas the control soilcreteattained 119% and 130% of its 28-day strength at 120 and 210 days respectively, 10% OPC replacement with RHA attained 154% and 180% of its 28-day strength at 120 and 210 days respectively, and 15% OPC replacement with RHA attained 158% and 182% of its 28-day strength at 120 and 210 days respectively.

v. The continued more rapid increase in strength of OPC-RHA composites compared to purely OPC composites (with 0% RHA) between 28 and 210 days suggests that some pozzolanic activity could still be going on at such later curing ages. Thus, OPC-RHA blended cement structural members could be designed using some suitably higher strength values than the 28-day strength if they would not be fully loaded for some reasonable period after construction.

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