Strength of Binary Blended Cement Composites Containing Afikpo Rice Husk Ash

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Abstract:

This work investigated the strength characteristics of binary blended cement composites made with Ordinary Portland Cement (OPC) and Afikpo Rice Husk Ash (RHA). 105 concrete cubes and 105 sandcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with Afikpo RHA of 5%, 10%, 15%, 20%, and 25% and crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, and 90 days of curing. The 3-14 day compressive strength values of OPC-Afikpo RHA binary blended cement concrete were found to be much lower than the control values; the 21-28 day strengths were comparable to the control values; while the 50-90 day strengths were higher than the control valuesespecially at 5-10% replacements of OPC with Afikpo RHA, ranging from 26.80N/mm^2 for 10% replacement of OPC to 29.30N/mm^2 for 5% replacement of OPC compared with the control value of 23.60N/mm^2. This same trend was observed for OPC-Afikpo RHA binary blended cement sandcrete. The variation in density was not significant. Mathematical models were developed for predicting compressive strengths of OPC-Afikpo RHA binary blended cement composites using polynomial regression analysis. The model values of compressive strengths obtained from the various model equations were found to be either exactly the same as those of the equivalent laboratory values or very close to them, especially at ages 28-90 days, with percentage differences ranging from 0 to 0.05. Thus, OPC-Afikpo RHA binary blended cement composites would be good for civil engineering works and the developed model equations can be easily used to estimate their strengths for various curing ages and percentage OPC replacement with Afikpo RHA.

Key words: *Binary blended cement, composites, concrete, pozzolan, rice husk ash, sandcrete.*

I. INTRODUCTION

The high cost of Ordinary Portland cementin Nigeriaand many other parts of Africahas resulted in extremely high cost of building thereby rendering many persons “homeless.” Thus, so long as the cement industry continues to play a cardinal role in physical infrastructural development, attempts should continuously be made to (i) reduce the cost of production of Portland cement, (ii) reduce the consumption of the raw materials, (iii) protect the environment, and (iv) enhance the quality of cement. One way is to use suitable low-cost, sustainable, and environmentally friendly materials as partial replacement of Portland cement. Major materials used in this regard are industrial and agricultural by-products, otherwise regarded as wastes in technologically disadvantaged communities. Researchers have especially more recently intensified work on substitute materials for cement in makingcement composites such as concrete and sandcrete (Olugbenga et al., 2007). Blended cements are currently used in many parts of the world (Bakar, Putrajaya, and Abdulaziz, 2010). 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 cementit 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 $Ca(OH)_2$ and increases the quantity of 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).The incorporation of agricultural by-product pozzolans calcined at high temperatures has been studied with positive results in the manufacture and application of blended cements (Malhotra and Mehta, 2004). Ezeh and Ibearugbulem (2009) found good prospect in partially replacing cement with periwinkle shell ash in river stone aggregate concrete.

Adewuyi and Ola (2005) successfully applied waterworks sludge as partial replacement for cement in concrete production. Elinwa and Awari (2001) investigated the potentials of groundnut husk ash concrete by partially replacing Ordinary Portland Cement with groundnut husk ash.Many other researchers have also confirmed rice husk ash (RHA) a pozzolanic material that can be used to partially replace OPC in making cement composites (Ikpong and Okpala, 1992; Cisse and Laquerbe, 2000; Wada et al., 2000; Rukzon and Chindaprasirt, 2006; Cordeiro, Filho, and Fairbairn, 2009; Fadzil et al., 2008; Poon, Kou, and Lam, 2006; De Sensale, 2006; Saraswathy and Song, 2007; Agbede and Obam, 2008; Habeeb and Fayyadh, 2009; Rukzon, Chindaprasirt, and Mahachai, 2009.). However, studies by Chandrasekar et al. (2003) have shown that the physical and chemical properties of RHA are dependent on a number of factors, including the soil chemistry, paddy variety, climatic and geographical conditions, and fertilizers applied during rice cultivation.

Efforts to intensify food production and local economic ventures in many Nigerian communities lead to increased agricultural wastes such as rice husk.The problem is worse in places like Afikpo district of Ebonyi State where farming in general and massive cultivation of rice in particular is the predominant business of many community dwellers, leading to the generation of some thousands of tons of rice husk annually.There is therefore a need to specifically investigate the suitability of using Afikpo rice husk ash as possible cement replacement in making cement composites.Its utilization as pozzolanic material would both reduce the problem of solid waste management (Elinwa and Ejeh, 2004)and add commercial value to the otherwise waste product. This would serve as a boost to intensive cultivation of the product and ultimately lead to increased food, more jobs for people, and more peaceful society through the elimination of various vices related to poverty and idleness.

II. 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 760 Kg/m^3, specific gravity of 1.81, and fineness modulus of 1.40. 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 witha bulk density of 1580 Kg/m^3, specific gravity of 2.70, and fineness modulus of 2.84; Crushed granite of 20 mm nominal size free from impurities with a bulk density of 1510 Kg/m^3, specific gravity of 2.94, and fineness modulus of 3.65; 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 and 1:6 (blended cement: sand) 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, also at the required proportions. Water was then added gradually and the entire concrete heap was mixed thoroughly to ensure homogeneity. The workability of the fresh concrete was measured by slump test, and the wet density was also determined.One hundred and five (105) granite concrete cubes and one hundred and five (105) sandcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with RHA of 5%, 10%, 15%, 20%, and 25%. Twenty one concrete cubes and twenty one sandcrete cubes with 100% OPC were also produced to serve as controls. This gives a total of 126concrete cubes and 126 sandcrete cubes. All the concrete cubes were cured by immersion while the sandcrete cubes were cured by water sprinkling twice daily in a shed. Three concrete cubes and three sandcrete cubes for each percentage replacement of OPC with RHA and the control were tested for saturated surface dry bulk density and crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, and 90 days of curing.

Average values of concrete and sandcretecompressive strengths and densities for the various curing ages and percentages of OPC replacement with RHA were obtained and presented in tables and graphs. Mathematical models were developed in form of equations through polynomial regression analysis of the data showing the variation of concrete and sandcretecompressive strengths with curing age and percentage replacement of OPC with RHA. Suitable analytical tools in Microsoft Excel were used to plot appropriate polynomial curves, generate the corresponding mathematical equations, and obtain model values of compressive strengths for comparison with corresponding laboratory values.

2.1 Results and Discussion

The particle size analysis showed that the RHA was much coarser than OPC, the reason being that it was not ground to finer particles. The implication of this is that whatever compressive strength values obtained using it can still be improved upon when the ash is ground to finer particles. The pozzolanicity test confirmed Afikpo rice husk ash as a pozzolan since it fixed some quantities of lime over time, thereby reducing the alkalinity of the mixture as reflected in the smaller titre value over time compared to the blank titre.The compressive strengths of the binary blended cement concrete and sandcrete produced with OPC and Afikpo RHA are shown in tables 1 and 2 respectively.

Table1.Compressive strength of blended OPC-RHA cement concrete

Age (days)	Compressive Strength (N/mm^2) for					
	0 % RHA	5 % RHA	10 % RHA	15 % RHA	20 % RHA	25 % RHA
3	7.90	5.20	4.70	4.20	3.50	3.30
7	14.00	9.70	9.20	8.10	7.20	7.00
14	21.50	18.00	17.70	15.50	11.70	11.00
21	22.10	22.00	21.40	18.90	16.00	14.00
28	23.00	25.30	22.50	20.80	17.90	16.00
50	23.50	28.00	24.70	23.80	21.60	20.00
90	23.60	29.30	26.80	25.90	23.20	22.00

Table2.Compressive strength of blended OPC-RHA cement sandcrete

Age (days)	Compressive Strength (N/mm^2) for					
	0 % RHA	5 % RHA	10 % RHA	15 % RHA	20 % RHA	25 % RHA
3	2.70	1.90	1.80	1.60	1.50	1.50
7	5.00	3.00	3.00	2.50	2.30	2.20
14	7.10	4.40	4.00	3.50	3.20	2.80
21	8.00	5.20	4.80	4.00	3.80	3.20
28	9.30	7.60	6.40	5.80	5.00	4.10
50	9.70	9.80	8.90	8.00	7.10	6.20
90	10.30	11.30	10.80	10.10	9.50	8.80

It can be seen from table 1 that the compressive strength values of binary blended cement concrete consistently decrease with increase in percentage replacement of OPC with Afikpo RHA. The 3-14 day compressive strength values are much lower than the control values for all percentage replacements of OPC with Afikpo RHA. The 3-day strengths range from 3.30N/mm^2 at 25% replacement of OPC to 5.20N/mm^2 at 5% replacement of OPC compared with the control value of 7.9 N/mm^2. The 7-day strengths range from 7.00N/mm^2 at 25% replacement of OPC to 9.70N/mm^2 at 5% replacement of OPC compared with the control value of 14N/mm^2. The 14-day strengths range from 11.00N/mm^2 at 25% replacement of OPC to 18.00N/mm^2 at 5% replacement of OPC compared with the control value of 21.50N/mm^2. However, the 90-day strength at 5-15% replacement of OPC with Afikpo RHAis higher than that of the control, ranging from 25.90 N/mm^2 for 15% replacement of OPC to 29.30N/mm^2 for 5% replacement of OPC compared with the control value of 23.60N/mm^2. This same trend of binary blended cement concrete strength variation with age and percentage replacement of OPC with Afikpo RHArelative to the control values is noticeable for blended cement sandcrete as shown in table 2. The 3-14 day low strength values compared to the control can be attributed to the low rate of pozzolanic reaction at those 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.

The density results suggests that although the saturated surface dry bulk densities of OPC-Afikpo RHAblended cement concrete and sandcrete reduce slightly with both curing age and percentage replacement of OPC with Afikpo RHA, the variations are of no significance for engineering purposes as they all still fall within the range for normal weight composites.

As should be expected, the results show that the strength of 100% OPC concrete (the control) increases steeply with age until about 14 days. The strength still increases steadily but less steeply between 14 and 28 days, after which the strength increases much more slowly such that the strength at 90 days is not much greater than the strength at 50 days. The variation in strength with age for the binary blended OPC-Afikpo RHA cement concrete is different from the control, especially at high percentages of OPC replacement with Afikpo RHA. The results show that the variation for 5% OPC replacement with Afikpo RHA is not much different from that of the control, although, unlike the control, the binary blended cement concrete continues to attain much higher strength values up to 90 days. The variation for 10% and 15% OPC replacement with Afikpo RHA is significantly different from that of the control. The binary blended cement concrete strength picks up more slowly up to 21 days, after which it begins to increase rapidly until 90 days and beyond. At 20% and 25% OPC replacement with Afikpo RHA the strength picks up even more gradually during the early ages of up to 21 days than at 10-15% replacement levels. However the increase in strength continues more steeply at the later ages of 50 days and above.

Mathematical Models for Predicting Compressive Strength of Opc-Afikpo Rha Cement Composites

The mathematical equations for predicting compressive strength of OPC-Afikpo RHA cement concrete and sandcrete obtained from the results of polynomial regression analysis are presented in this section.

Variation of OPC-Afikpo RHA concrete strength with percentage RHA

$$Y_3 = 0.00009667X^4 - 0.00550741X^3 + 0.10786111X^2 - 0.94846561X + 7.89563492 \text{ ------ } (1)$$

Where Y_3 is the 3-day compressive strength in N/mm^2 of the binary blended OPC-Afikpo RHA concrete and X is the percentage replacement of OPC with AfikpoRHA.

$$Y_7 = -0.00001467X^5 + 0.00108000X^4 - 0.02910000X^3 + 0.35100000X^2 - 2.01333333X + 14.00000000 \text{ ------------ } (2)$$

$$Y_{14} = 0.00032667X^4 - 0.01630370X^3 + 0.24972222X^2 - 1.57708995X + 21.49603175 \text{ -- } (3)$$

$$Y_{21} = 0.00009000X^4 - 0.00364815X^3 + 0.02380556X^2 - 0.04431217X + 22.08769841 \text{ --- } (4)$$

$$Y_{28} = -0.00013333X^4 + 0.00841481X^3 - 0.18322222X^2 + 1.12050265X + 23.05158730 \text{ -- } (5)$$

$$Y_{50} = 0.00005200X^5 - 0.00352667X^4 + 0.08690000X^3 - 0.93983333X^2 + 3.83500000X + 23.50000000 \text{ ------------ } (6)$$

$$Y_{90} = 0.00005307X^5 - 0.00353333X^4 + 0.08590000X^3 - 0.93366667X^2 + 4.06933333X + 23.60000000 \text{ ------------ } (7)$$

Model values of OPC-Afikpo RHA concrete strength from equations (1) to (7) together with their equivalent laboratory values are shown in table 3.

Variation of OPC-Afikpo RHA sandcrete strength with percentage Afikpo RHA

$$Y_3 = 0.00002667X^4 - 0.00151111X^3 + 0.03000000X^2 - 0.26984127X + 2.69523810 \text{ ------ } (8)$$

$$Y_7 = -0.00001147X^5 + 0.00079333X^4 - 0.01996667X^3 + 0.22216667X^2 - 1.10366667X + 5.00000000 \text{ ------------ } (9)$$

$$Y_{14} = -0.00000880X^5 + 0.00062000X^4 - 0.01630000X^3 + 0.19850000X^2 - 1.19700000X + 7.10000000 \text{ ------------ } (10)$$

$$Y_{21} = 0.00006000X^4 - 0.00381481X^3 + 0.08505556X^2 - 0.86978836X + 7.97698413 \text{ -- } (11)$$

$$Y_{28} = 0.00000480X^5 - 0.00030000X^4 + 0.00613333X^3 - 0.03850000X^2 - 0.26633333X + 9.30000000 \text{ -- } \quad (12)$$

$$Y_{50} = -0.00003333X^4 + 0.00203704X^3 - 0.04305556X^2 + 0.18375661X + 9.70396825 \text{ ---}(13)$$

$$Y_{90} = 0.00000133X^5 - 0.00013333X^4 + 0.00490000X^3 - 0.08266667X^2 + 0.50666667X + 10.30000000 \text{ --- } \quad (14)$$

Model values of OPC-Afikpo RHA sandcrete strength from equations (8) to (14) together with their equivalent laboratory values are shown in table 4.

Table 3. Model and laboratory values of OPC-Afikpo RHA concrete strength

Age (days)	Compressive Strength in N/mm^2 for					
	0 % RHA	**5 % RHA**	**10 % RHA**	**15 % RHA**	**20 % RHA**	**25 % RHA**
L3	7.9	5.2	4.7	4.2	3.5	3.3
M3	7.9	5.2	4.7	4.2	3.5	3.3
L7	14	9.7	9.2	8.1	7.2	7
M7	14.0	9.7	9.2	8.1	7.2	7.0
L14	21.5	18	17.7	15.5	11.7	11
M14	21.5	18.0	17.7	15.5	11.7	11.0
L21	22.1	22	21.4	18.9	16	14
M 21	22.1	22.1	21.3	19.0	15.9	14.0
L28	23	25.3	22.5	20.8	17.9	16
M 28	23.1	25.0	23.0	20.3	18.2	15.9
L50	23.5	28	24.7	23.8	21.6	20
M50	23.5	28.0	24.7	23.8	21.6	20.0
L90	23.6	29.3	26.8	25.9	23.2	22
M90	23.6	29.3	26.8	25.9	23.2	22.0
L3 = Laboratory value at 3 days; M3 = Model value at 3 days.						

Table 4. Model and laboratory values of OPC-Afikpo RHA sandcrete strength

Age (days)	Compressive Strength in N/mm^2 for % RHA of					
	0	**5**	**10**	**15**	**20**	**25**
L3	2.7	1.9	1.8	1.6	1.5	1.5
M3	2.7	1.9	1.8	1.6	1.5	1.5
L7	5	3	3	2.5	2.3	2.2
M7	5.0	3.0	3.0	2.5	2.3	2.2
L14	7.1	4.4	4	3.5	3.2	2.8
M14	7.1	4.4	4	3.5	3.2	2.8
L21	8	5.2	4.8	4	3.8	3.2
M 21	8.0	5.3	4.6	4.2	3.7	3.2
L28	9.3	7.6	6.4	5.8	5	4.1
M 28	9.3	7.6	6.4	5.8	5.0	4.1
L50	9.7	9.8	8.9	8	7.1	6.2
M50	9.7	9.8	8.9	8.0	7.1	6.2
L90	10.3	11.3	10.8	10.1	9.5	8.8
M90	10.3	11.3	10.8	10.1	9.5	8.8
L3 = Laboratory value at 3 days; M3 = Model value at 3 days.						

It can be seen from tables 3 and 4 that the model values of compressive strengths obtained from the various model equations 1 to 14 are either exactly the same as those of the equivalent laboratory values or very close to them, especially at ages 28-150 days, with percentage differences ranging from 0 to 0.05. Therefore, the respective model equations are all suitable for determining the compressive strength values of OPC-Afikpo RHA binary blended cement concrete and sandcrete for various curing ages and percentage replacement of OPC with Afikpo RHA.

III. CONCLUSIONS

The strength of OPC-Afikpo RHA binary blended cement concrete gets comparable to that of the control at 21 days of curing. The strength of the binary blended cement concrete at 5 to 15% replacement is higher than that of the control at 28, 50, and 90 days of curing. This clearly shows that OPC-Afikpo RHA binary blended cement concrete can be used for high strength requirements at curing ages greater than 28 days.

There is similarity in the pattern of variation of OPC-Afikpo RHA binary blended cement sandcrete strength with that of OPC-Afikpo RHA binary blended cement concrete for different percentage replacements of OPC with Afikpo RHA at 3 to 90 days of curing. Just as for concrete, OPC-Afikpo RHA binary blended cement sandcrete has very low strength compared to the control at early ages up to 14 days. The strength improves greatly thereafter and increases to become greater than that of the control at ages above 50 days. Thus OPC-Afikpo RHA binary blended cement sandcrete could also be used in civil engineering works where early strength is not a major requirement.The mathematical models/equations developed for predicting compressive strength of OPC-Afikpo RHA binary blended cement composites can be used as guide in determining appropriate percentage replacement and minimum curing age to use for required strength values since the model values of compressive strengths obtained from the equations are either exactly the same as those of the equivalent laboratory values or very close to them, especially at ages 28-150 days.

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