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Suitability of Nigerian Agricultural By-Products as Cement Replacement for Concrete Making

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Abstract: *This work investigated the strength characteristics of binary blended cement concrete made with Ordinary Portland Cement (OPC) and each of eight agricultural by-products in South Eastern Nigeria, namely Rice Husk Ash (RHA), Saw Dust Ash (SDA), Oil Palm Bunch Ash (OPBA), Cassava Waste Ash (CWA), Coconut Husk Ash (CHA), Corn Cob Ash (CCA), Plantain Leaf Ash (PLA), and Paw-Paw Leaf Ash (PPLA). 105 concrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with each of the eight ashes of 5%, 10%, 15%, 20%, and 25%. Three concrete cubes for each percentage replacement of OPC with each ash 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. The compressive strengths of binary blended cement concrete increased with curing age and decreased with increase in percentage replacement of OPC with pozzolans. The 3-14 day compressive strength values were much lower than the control values for all percentage replacements of OPC with pozzolan. However, the 90-day strength at 5-10% replacement of OPC in binary blending with each of the eight pozzolans was higher than that of the control, ranging from 24.50N/mm^2 for 10% replacement of OPC with coconut husk ash (CHA) to 30.2N/mm^2 for 5% replacement of OPC with RHA compared with the control value of 23.8N/mm^2. Thus, all the eight agricultural by-products investigated in this work could be good for binary blending with OPC in making structural concrete. However, since blended cement concrete take a longer time to attain adequate strength than 100% OPC concrete, major structural elements constructed with blended cement concrete should be allowed a longer time before loading, say 28-50 days for 5-15% replacement of OPC with agricultural by-product pozzolans and 50-90 days for 15-25% replacement of OPC.*

Key Words: *Blended cement, binary, composites, compressive strength, concrete, curing method, mix ratio, pozzolan, sandcrete.*

I. Introduction

Gross inadequacy of accommodation for the densely populated areas ofSouth Eastern Nigeria and many other parts of Africa has constrained researchers to continue to seek ways of reducing the cost of building projects. Agricultural by-products regarded as wastes in technologically underdeveloped societiescould be used as partial replacement of Portland cement to achieve this purpose. Efforts have recently been focused on such substitute materials in making cement 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). Calcium hydroxide [Ca $(OH)_2$] is one of the hydration products of Portland cement and it greatly contributes toward the deterioration of cement composites. When a pozzolan is blended with Portland cement it reacts with the lime to produce additional calcium-silicate-hydrate (C-S-H), which is the main cementing compound. Thus the pozzolanic material reduces the quantity of lime and increases the quantity of C-S-H. Therefore, the cementing quality is enhanced if a pozzolan is blended in suitable quantity with Portland cement (Padney et al., 2003).

Agricultural by-product pozzolans have been used in the manufacture and application of blended cements (Malhotra and Mehta, 2004). Nimityongskul and Daladar (1995) highlighted the potentialities of coconut husk ash, corn cob ash, and peanut shell ash as good pozzolans. Elinwa and Awari (2001) successfully investigated the potentials of groundnut husk ash concrete by partially replacing Ordinary Portland Cement with groundnut husk ash. Adesanya (1996) investigated the properties of blended cement mortar, concrete, and stabilized earth made from OPC and corn cob ash and recommended that corn cob ash can serve as replacement for OPC in the production of cement composites. Dwivedia et al. (2006) successfully investigated the pozzolanicity of bamboo leaf ash.Martirena, Middendorf, and Budelman (1998) found that sugar industry solid wastes such as sugar cane straw ash has pozzolanic activity derived from its high content of amorphous silica. Some other researchers have also confirmed the possibility of using sugar industry wastes as pozzolans (Hernandez et al., 1998; Singh, Singh, and Rai, 2000; Middendorf et al., 2003). Many other researchers have confirmed rice husk ash a pozzolanic material that can be used to partially replace OPC in making cement composites (Cordeiro, Filho, and Fairbairn, 2009; Habeeb and Fayyadh, 2009; Rukzon, Chindaprasirt, and Mahachai, 2009). A number of researchers have also found good prospects in using blended cements made with sawdust ash (Mehta, 1997; Elinwa, Ejeh, and Mamuda, 2008; and Elinwa and Abdulkadir, 2011). Studies by Chandrasekar et al. (2003) suggest that soil, climatic, and geographical conditions could affect the physical and chemical properties and consequently the pozzolanicity of agricultural by-products.

The commitment to crop farmingby many Nigerian rural community dwellers have led to increased agricultural wastes, large quantities of which are generated in various rural communities all over South Eastern Nigeria. There is therefore a need to further investigate the suitability of using Nigerian agricultural by-products as possible cement replacement in concrete making. The successfulutilization of these products as pozzolanic materials would add commercial value to the otherwise waste products and encourage massive cultivation of the crops for various uses. This work investigated the strength characteristics of binary blended cement concrete made with Ordinary Portland Cement (OPC) and each of eight agricultural by-products in South Eastern Nigeria, namely Rice Husk Ash (RHA), Saw Dust Ash (SDA), Oil Palm Bunch Ash (OPBA), Cassava Waste Ash (CWA), Coconut Husk Ash (CHA), Corn Cob Ash (CCA), Plantain Leaf Ash (PLA), and Paw-Paw Leaf Ash (PPLA).

II. Methodology

Rice husk was obtained from rice milling factories in Afikpo, Ebonyi State; Saw dust from wood mills in Owerri, Imo State; Oil palm bunch from palm oil mill in Ohaji-Egbema, Imo State; Cassava waste (the peel from cassava tubers) from Ihiagwa in Imo State; Coconut Husk from Orlu in Imo State; Corn cob from Aba district in Abia State; Plantain leaf from Ogbunike town in Anambra State; and Paw-paw leaf from Escobedo in Imo State, all in South Eastern Nigeria. These materials were air-dried; the bigger and harder ones such as corn cob and oil palm bunch were pulverized; and calcined into ashes in a locally fabricated furnace at temperatures generally below 650^{o}C. The resultant Rice Husk Ash (RHA), Saw Dust Ash (SDA), Oil Palm Bunch Ash (OPBA), Cassava Waste Ash (CWA), Coconut Husk Ash (CHA), Corn Cob Ash (CCA), Plantain Leaf Ash (PLA), and Paw-Paw Leaf Ash (PPLA) were 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 quality of the ashesand enhance their pozzolanicity was applied because the researchers wanted to utilize simple processes that can be easily replicated by local community dwellers. Other materials used for the work are Ibeto brand of Ordinary Portland Cement (OPC), river sand free from debris and organic materials, crushed granite of 20 mm nominal size free from impurities, and water free from organic impurities.

Tests were carried out to determine the specific gravity, bulk density, and fineness modulus of each of the ashes and the aggregates. A simple form of pozzolanicity test was carried out for each of the ashes. 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 H_2SO_4solution of known concentration at time intervals of 30, 60, 90, and 120 minutes using Methyl Orange as indicatorat normal temperature. For each of the ashes the titre value was observed to reduce with time, confirming the ash as a pozzolan that fixed more and more of the calcium hydroxide, thereby reducing the alkalinity of the mixture.

A common mix ratio of 1:2:4 (blended cement: sand: granite) was used for the concrete. Batching was by weight and a constant water/cement ratio of 0.6 was used. Mixing was done manually on a smooth concrete pavement. Rice husk ash (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. Each of the remaining seven ashes was also used to produce binary blended cement concrete using this same procedure. One hundred and five (105) concrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with each of the eight ashes of 5%, 10%, 15%, 20%, and 25%. Twenty one concrete cubes with 100% OPC were also produced to serve as controls. This gives a total of 861 concrete cubes.All the cubes were cured by immersion. Three concrete cubes for each percentage replacement of OPC with each of the eight ashes 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 compressive strengths and densities for the various curing ages and percentages of OPC replacement with each of the ashes were obtained and presented in tables and graphs.

III. Results and Discussion

A summary of the specific gravity, bulk density, and fineness modulus of each of the ashes and aggregates is shown in table 1.

Table 1. Summary of specific gravity, bulk density, and fineness modulus of ashes and aggregates

Material	Specific Gravity	Bulk Density (Kg/m^3)	Fineness Modulus
Granite	2.90	1500	3.62
Sand	2.68	1560	2.82
Laterite	2.40	1470	3.30
RHA	1.80	765	1.38
SDA	1.90	790	1.75
OPBA	2.00	800	1.95
CWA	1.85	810	1.80
CCA	1.80	795	1.90
CHA	1.78	760	1.55
PLA	1.75	755	1.36
PPLA	1.82	775	1.32
OPC	3.13	1650	NA

The particle size analysis showed that all the eight agricultural by-product ashes were much coarser than OPC, the reason being that they werenot ground to finer particles. The implication of this is that the compressive strength values obtained using each of theseashes can still be improved upon when the ash is ground to finer particles. It can also be seen from table 1 that the bulk density and specific gravity of each of the ashes were much lower than that of OPC. Thus, partially replacing the ashes with OPC would result in reduced weight of concrete members. The pozzolanicity test confirmed all the ashes aspozzolans since each of them fixed some quantities of lime over time, thereby reducing the alkalinity of the calcium hydroxide-ash mixture as reflected in the smaller titre value over time compared to the blank titre. The chemical compositions of the ashes showed that only RHA satisfied the ASTM requirement that the sum of SiO_2, Al_2O_3, and Fe_2O_3 should be not less than 70%. However, since the pozzolanicity tests were positive for all the eight materials, confirming them all as pozzolans, it couldbe reasoned that the ASTM requirement does not mean any material that falls short of it is not pozzolanic; it could rather be interpreted as criterion for high pozzolanicity of materials.

The compressive strengths of the binary blended cement concrete produced with OPC and each of the eight agricultural by-product pozzolans are shown in tables 2, 3, 4, 5, 6, 7, and 8 for 3, 7, 14, 21, 28, 50, and 90 days of curing respectively.

Table 2. Compressive strength of blended OPC-AgricPozzolan cement concrete at 3 days of curing

Age (days)	Compressive Strength (N/mm^2) for					
	0% Poz.	**5% Poz.**	**10% Poz.**	**15% Poz.**	**20% Poz.**	**25% Poz.**
RHA	8.00	5.40	4.90	4.40	3.70	3.50
SDA	8.00	5.10	4.40	4.20	3.80	3.40
OPBA	8.00	4.80	4.30	4.10	3.30	3.20
CWA	8.00	4.20	4.00	3.90	3.60	3.50
CCA	8.00	5.50	5.20	4.70	4.20	3.90
CHA	8.00	4.40	4.00	3.70	3.50	3.30
PLA	8.00	4.20	4.10	3.80	3.60	3.40
PPLA	8.00	4.10	3.90	3.60	3.40	3.20

Table 3. Compressive strength of blended OPC-AgricPozzolan cement concrete at 7 days of curing

Age (days)	Compressive Strength (N/mm^2) for					
	0% Poz.	**5% Poz.**	**10% Poz.**	**15% Poz.**	**20% Poz.**	**25% Poz.**
RHA	14.10	10.00	9.50	8.40	7.50	7.30
SDA	14.10	9.60	9.00	7.30	7.10	6.80
OPBA	14.10	9.30	8.30	4.50	4.30	4.00
CWA	14.10	7.00	6.40	5.60	5.10	4.60
CCA	14.10	9.70	9.40	8.30	7.40	6.60
CHA	14.10	8.30	8.10	7.30	6.80	6.40
PLA	14.10	7.80	7.70	7.50	7.20	6.70
PPLA	14.10	7.30	7.20	6.80	6.30	5.80

Table 4. Compressive strength of blended OPC-AgricPozzolan cement concrete at 14 days of curing

Age (days)	Compressive Strength (N/mm^2) for					
	0% Poz.	**5% Poz.**	**10% Poz.**	**15% Poz.**	**20% Poz.**	**25% Poz.**
RHA	21.60	18.30	18.00	15.80	12.00	11.30
SDA	21.60	17.40	16.60	15.20	13.10	11.80
OPBA	21.60	16.80	15.70	14.00	10.30	9.30
CWA	21.60	12.90	12.00	11.30	10.30	9.80
CCA	21.60	19.00	17.80	14.80	11.20	10.80
CHA	21.60	16.00	15.50	12.60	11.00	10.30
PLA	21.60	15.00	14.30	12.10	11.80	11.30
PPLA	21.60	13.40	12.90	11.30	11.10	10.30

Table 5. Compressive strength of blended OPC-AgricPozzolan cement concrete at 21 days of curing

Age (days)	Compressive Strength (N/mm^2) for					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
RHA	22.30	22.40	21.80	19.30	16.00	14.40
SDA	22.30	20.60	19.90	16.70	16.10	13.40
OPBA	22.30	20.00	17.50	15.50	13.40	11.40
CWA	22.30	18.60	14.40	14.30	12.40	11.40
CCA	22.30	21.60	18.90	16.40	13.40	11.40
CHA	22.30	19.20	17.50	16.40	14.00	12.90
PLA	22.30	18.70	18.30	17.60	13.80	12.40
PPLA	22.30	18.40	17.40	15.40	13.40	11.40

Table 6. Compressive strength of blended OPC-AgricPozzolan cement concrete at 28 days of curing

Age (days)	Compressive Strength (N/mm^2) for					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
RHA	23.20	25.70	22.90	21.20	18.30	16.40
SDA	23.20	22.60	20.40	19.40	18.20	16.20
OPBA	23.20	22.20	20.40	18.50	17.30	13.40
CWA	23.20	22.40	20.10	18.90	15.80	14.40
CCA	23.20	22.50	21.50	19.70	16.40	14.20
CHA	23.20	22.30	20.40	19.40	15.60	13.40
PLA	23.20	24.10	20.80	19.50	16.70	14.40
PPLA	23.20	23.40	20.90	18.90	17.40	15.40

Table 7. Compressive strength of blended OPC-AgricPozzolan cement concrete at 50 days of curing

Age (days)	Compressive Strength (N/mm^2) for					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
RHA	23.70	28.50	25.20	24.30	22.10	20.50
SDA	23.70	24.90	23.50	22.30	19.80	19.00
OPBA	23.70	23.90	23.40	20.60	19.00	17.50
CWA	23.70	25.80	23.60	22.10	18.50	17.70
CCA	23.70	24.60	23.60	21.50	19.60	18.50
CHA	23.70	23.90	22.20	20.50	18.50	17.00
PLA	23.70	24.80	22.60	21.90	19.90	18.50
PPLA	23.70	24.50	23.50	22.50	20.50	19.50

Table 8. Compressive strength of blended OPC-AgricPozzolan cement concrete at 90 days of curing

Age (days)	Compressive Strength (N/mm^2) for					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
RHA	23.80	30.20	27.30	26.40	23.60	22.50
SDA	23.80	27.10	25.50	24.20	22.50	22.00
OPBA	23.80	26.20	24.80	23.50	22.30	20.50
CWA	23.80	26.50	25.30	24.30	22.50	21.50
CCA	23.80	27.50	26.20	24.50	23.00	21.00
CHA	23.80	25.60	24.50	23.50	21.00	19.00
PLA	23.80	26.30	24.90	23.60	22.00	19.50
PPLA	23.80	26.50	25.00	23.50	23.00	21.70

It can be seen from tables2 to 8 that the compressive strength values of OPC-Agricultural by-product binary blended cement concrete consistently decrease with increase in percentage replacement of OPC with agricultural by-product ash. Tables 2 to 4 show that the 3-14 day compressive strength values are much lower than the control values for all percentage replacements of OPC with each of the agricultural by-product ashes. Tables 5 and 6 show that the strength of the OPC-Agricultural by-product binary blended cement concrete begins to approach the control value at 21 to 28 days of curing, and tables 7 and 8 show that the binary blended cement concrete strengths for some of the ashes, notably RHA, exceeds the control value at 50 to 90 days of curing, especially for 5-15% replacement of OPC with agricultural by-product ash. 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 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 that at 50 days. Unlike the control, the binary blended cement concrete strength picks up more slowly up to 21 days, after which it begins to increase steadily until 90 days and beyond.

Comparatively speaking, it can be seen from tables 2 to 8 that OPC-RHA binary blended cement concrete consistently has higher strength than the other seven binary blends. Its value at 5% replacement of OPC becomes marginally greater than the control value at 21 days of curing and continues to increase more and more than the control value at later ages of hydration. Table 8 suggests that the good performance of rice husk ash (RHA) is followed in descending order by corn cob ash (CCA), saw dust ash (SDA), cassava waste ash (CWA), pawpaw leaf ash (PPLA), plantain leaf ash (PLA), oil palm bunch ash (OPBA), and coconut husk ash (CHA). It is interesting to note from table 8 that the 90-day strengths of the binary blended cement concrete made with each of these ashes is good enough for use in reinforced concrete works even at 25% replacement of OPC with any of the eight agricultural by-product ashes. The 90-day strength values at 5-10% replacement of OPC range from 24.50N/mm^2 for 10% replacement with CHA to 30.20N/mm^{2}for 5% replacement with RHA, compared to the control value of 23.80N/mm^2.

IV. Conclusions

All the eight Nigerian agricultural by-products investigated in this work, namely Rice Husk Ash (RHA), Saw Dust Ash (SDA), Oil Palm Bunch Ash (OPBA), Cassava Waste Ash (CWA), Coconut Husk Ash (CHA), Corn Cob Ash (CCA), Plantain Leaf Ash (PLA), and Paw-Paw Leaf Ash (PPLA) are reasonably pozzolanic since they fix some quantities of lime over time thereby reducing the alkalinity of their mixture with calcium hydroxide as reflected in the smaller titre values recorded over time compared to the blank titre. All the ashes were much coarser than OPC, the reason being that they were not ground to ultrafine particles. The implication of this is that the compressive strength values obtained using them can still be improved upon when they are ground to finer particles.

The compressive strength values of binary blended cement concrete consistently decrease with increase in percentage replacement of OPC with pozzolan and increase with increase in curing age. The 3-14 day compressive strength values are much lower than the control values for all percentage replacements of OPC with pozzolan. However, the 90-day strength at 5-10% replacement of OPC in binary blending with each of the eight pozzolans is higher than that of the control, ranging from 24.50N/mm^2 for 10% replacement of OPC with coconut husk ash (CHA) to 30.2N/mm^2 for 5% replacement of OPC with RHA compared with the control value of 23.8N/mm^2.

Thus, all the eight agricultural by-products investigated in this work could be good for binary blending with OPC in making structural concrete. However, since blended cement concrete take a longer time to attain adequate strength than 100% OPC concrete, structural elements constructed with blended cement concrete should be allowed a longer time before loading, say 28-50 days for 5-15% replacement of OPC with agricultural by-product pozzolans and 50-90 days for 15-25% replacement of OPC.

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