Strength of Ternary Blended Cement Concrete Containing Oil Palm Bunch Ash and Plantain Leaf Ash

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ABSTRACT:
This work investigated the compressive strength of ternary blended cement concrete containing oil palm bunch ash (OPBA) and plantain leaf ash (PLA). 105 concrete cubes of 150mm x 150mm x 150mm were produced with OPC-OPBA binary blended cement, 105 with OPC-PLA binary blended cement, and 105 with OPC-OPBA-PLA ternary blended cement, each at percentage OPC replacement with pozzolan of 5%, 10%, 15%, 20%, and 25%. Three cubes for each percentage replacement of OPC with pozzolan 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 90-day strengths obtained from ternary blending of OPC with equal proportions of OPBA and PLA were 27.00N/mm^2 for 5% replacement, 25.90N/mm^2 for 10% replacement, 25.10N/mm^2 for 15% replacement, 23.60N/mm^2 for 20% replacement, and 22.10N/mm^2 for 25% replacement, while that of the control was 24.60N/mm^2. The results show that high concrete strength values could be obtained with OPC-OPBA-PLA ternary blended cement at 50 days of hydration and above. Thus, OPC-OPBA-PLA ternary blended cement concrete could be used for various civil engineering and building works.

Key words: *Binary blended cement, ternary blended cement, concrete, pozzolan, oil palm bunch ash, plantain leaf ash.*

I. INTRODUCTION

The need to reduce the high cost of cement in order to provide accommodation for the populace in South Eastern Nigeria and other places has led to intensified efforts at sourcing local materials that could be used as partial replacement for Ordinary Portland Cement (OPC) in civil engineering and building works. Bakar, Putrajaya, and Abdulaziz (2010) assert that supplementary cementitious materials prove to be effective to meet most of the requirements of durable concrete and that blended cements are now used in many parts of the world. Calcium hydroxide [$Ca(OH)_2$] is obtained as one of the hydration products of OPC. When blended with Portland cement, a pozzolanic material reacts with the lime to produce additional calcium-silicate-hydrate (C-S-H), which is the main cementing component. Thus the pozzolanic material serves to reduce the quantity of the deleterious $Ca(OH)_2$ and increase 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 OPC (Dwivedia et al., 2006).

Much literature exists on binary blended systems where OPC is blended with different percentages of a pozzolan in making cement composites (Adewuyi and Ola, 2005; Elinwa and Awari, 2001; De Sensale, 2006; Saraswathy and Song, 2007). Attempts have been made to produce and use pozzolanicrice husk ash (RHA) commercially in several countries (Cisse and Laquerbe, 2000). Malhotra and Mehta (2004) have reported 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) had earlier investigated the use of RHAto reduce temperature in high strength mass concrete and got result showing 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 RHAon 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. Habeeb and Fayyadh (2009) investigated the influence of RHA average particle size on the properties of concrete and found that at early ages the strength was comparable, while at the age of 28 days, finer RHA exhibited higher strength than the sample with coarser RHA. Wada et al. (2000) demonstrated that RHA mortar and concrete exhibited higher compressive strength than the control mortar and concrete. 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. Rukzon, Chindaprasirt, and Mahachai (2009) studied the effect of grinding on the chemical and physical properties of rice husk ash and the effects of RHA fineness on properties of mortar and found that pozzolans with finer particles had greater pozzolanic reaction. Cordeiro, Filho, and Fairbairn (2009) 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. It was expected that the reduction of RHA particle size could improve the pozzolanic reactivity by reducing the adverse effect of the high-carbon content in the ash and increasing the homogeneity of the material. The study revealed the possibility of using ultrafine residual RHA containing high-carbon content in high-performance concrete. A number of researchers have also worked on sawdust ash and found good prospects in using binary blended cements made with sawdust ash (Elinwa, Ejeh, and Mamuda, 2008; Elinwa and Abdulkadir, 2011).

Some researchers have also investigated the possibility of ternary blended systems in order to further reduce the quantity of OPC in blended cements. Frı´as et al. (2005)studied the influence of calcining temperature as well as clay content in the pozzolanic activity of sugar cane straw-clay ashes-lime systems. All calcined samples showed very high pozzolanic activity and the fixation rate of lime (pozzolanic reaction) varied with calcining temperature and clay content. Elinwa, Ejeh, and Akpabio (2005) investigated the use of sawdust ash in combination with metakaolin as a ternary blend with 3% added to act as an admixture in 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. Ternary blended cement mixes with 70% OPC and 30% of combined FA and RHA produced strengths similar to that of the control. 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, ground Malaysian RHA, and FA. They found that compressive strength of concrete containing TBC gave low strength at early ages, even lower than that of OPC, but higher than binary blended cementitious (BBC) concrete containing FA. 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. Their results generally showed that the TBC systems could potentially be used in the concrete construction industry and could be particularly useful in reducing the volume of OPC used.

All the above works on ternary blended cements were based on blending OPC with one industrial by-product pozzolansuch as SF or FA and one agricultural by-product pozzolan, notably RHA. Being majorly agrarian, many communities in South Eastern Nigeria generate tons of agricultural and plant wastes such as oil palm bunch and plantain leaf as efforts are intensified toward food production and local economic ventures. There is currently very little or no literature on the possibility of binary blending of one of these Nigerian agricultural by-products with OPC and virtually no literature on ternary blending of any two of them with OPC. Thus, this work provides a pioneer investigation on the suitability of using two Nigerian agricultural by-products in ternary blend with OPC for concrete making. The compressive strength of ternary blended cement concrete containing oil palm bunch ash and plantain leaf ash was specifically investigated. The successful utilization of oil palm bunch ash and plantain leaf ash in ternary combination with OPC for making concrete would further add value to these wastes and reduce the volume of OPC currently required for civil engineering and building works.

II. METHODOLOGY

Oil palm bunch was obtained from palm oil mill in Ohaji-Egbema,Imo Stateand Plantain leaf from Ogbunikedistrict in Anambra State, both in South East Nigeria. These materials were air-dried, pulverized into smaller particles, and calcined into ashes in a locally fabricated furnace at temperatures generally below 650^{o}C. The oil palm bunch ash (OPBA) and plantain leaf ash (PLA) 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 ashes and enhance their pozzolanicity was applied because the researchers wanted to utilize simple processes that could be easily replicated by local community dwellers.

The OPBA had a bulk density of 820 Kg/m^3, specific gravity of 2.00, and fineness modulus of 1.98. The PLA had a bulk density of 760 Kg/m^3, specific gravity of 1.86, and fineness modulus of 1.36. 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 2.68, and fineness modulus of 2.82; Crushed granite of 20 mm nominal size free from impurities with a bulk density of 1515 Kg/m^3, specific gravity of 2.96, and fineness modulus of 3.62; and water free from organic impurities.

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_4 solution of known concentration at time intervals of 30, 60, 90, and 120 minutes using Methyl Orange as indicator at 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 standard 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. For binary blending with OPC, each of the ashes 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. For ternary blending, the two ashes were first blended in equal proportions and subsequently blended with OPC at the required proportions before mixing 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 of 150mm x

150mm x 150mm were produced with OPC-OPBA binary blended cement, one hundred and five (105) with OPC-PLA binary blended cement, and one hundred and five (105) with OPC-OPBA-PLA ternary blended cement, each at percentage OPC replacement with pozzolan of 5%, 10%, 15%, 20%, and 25%. An equal combination of OPBA and PLA was used in the ternary blended system. Twenty one control cubes with 100% OPC or 0% replacement with pozzolan were also produced. This gives a total of 336 concrete cubes. All the cubes were cured by immersion. Three cubes for each percentage replacement of OPC with pozzolan 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.

III. RESULTS AND DISCUSSION

The particle size analysis showed that both the OPBA and the PLA were much coarser than OPC, the reason being that the ashes were not ground to finer particles. Therefore, the compressive strength values obtained using them can still be improved upon when the ashes are ground to finer particles. The pozzolanicity test confirmed both ashes as pozzolans since they fixed some quantities of lime over time. The compressive strengths of the OPC-OPBA and OPC-PLA binary blended cement concretes as well as the OPC-OPBA-PLA ternary blended cement concrete are shown in tables 1 and 2 for 3-21 and 28-90 days of curing respectively.

The tables 1 and 2 show that concrete produced from ternary blend of OPC with equal proportions of OPBA and PLA have compressive strength values in between those of binary blends of OPC and OPBA on one hand and OPC and PLA on the other hand for all percentage replacements and curing ages. Also, the variation of strength for concrete produced from ternary blended cements is similar to those of concrete produced from binary blended cements for all percentage replacements and curing ages. More importantly for civil engineering and building construction purposes, the 90-day strengths obtained from ternary blending of OPC with equal proportions of OPBA and PLA were 27.00N/mm^2 for 5% replacement, 25.90N/mm^2 for 10% replacement, 25.10N/mm^2 for 15% replacement, 23.60N/mm^2 for 20% replacement, and 22.10N/mm^2 for 25% replacement, while that of the control was 24.60N/mm^2. Thus, the 90-day strength values for 5-15% replacement are higher than that of the control and those for 20-25% replacement are not much less than that of the control. The results in table 2 show that high concrete strength values could be obtained with OPC-OPBA-PLA ternary blended cement at 50 days of hydration and above.

Table 1. Compressive strength of blended OPC-OPBA-PLA cement concrete at 3-21 days of curing

OPC Plus	Compressive Strength (N/mm^2) for					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
	Strength at 3 days					
OPBA	8.90	5.60	5.10	4.90	4.10	4.00
PLA	8.90	5.00	4.90	4.60	4.40	4.20
OPBA & PLA	8.90	5.40	5.00	4.70	4.30	4.10
	Strength at 7 days					
OPBA	15.00	10.00	9.00	7.10	6.30	5.70
PLA	15.00	8.50	8.40	8.20	7.90	7.40
OPBA & PLA	15.00	9.20	8.80	7.60	7.20	6.90
	Strength at 14 days					
OPBA	22.50	17.50	16.40	14.70	13.00	11.20
PLA	22.50	16.70	15.80	15.00	13.50	12.30
OPBA & PLA	22.50	17.10	16.00	14.80	13.20	11.80
	Strength at 21 days					
OPBA	23.10	20.60	20.00	17.30	15.00	12.80
PLA	23.10	19.30	18.90	18.20	15.50	13.20
OPBA & PLA	23.10	20.20	18.90	17.90	15.30	13.00

Table 2. Compressive strength of blended OPC-OPBA-PLA cement concrete at 28-90 days of curing

OPC Plus	Compressive Strength (N/mm^2) for					
	0% Poz.	**5% Poz.**	**10% Poz.**	**15% Poz.**	**20% Poz.**	**25% Poz.**
	Strength at 28 days					
OPBA	24.00	23.80	22.10	20.40	18.20	16.30
PLA	24.00	24.70	23.00	21.20	19.00	17.20
OPBA & PLA	24.00	24.30	22.60	20.70	18.50	16.90
	Strength at 50 days					
OPBA	24.50	25.20	24.40	22.60	20.50	19.30
PLA	24.50	26.00	25.20	23.10	21.20	20.00
OPBA & PLA	24.50	25.70	24.80	23.00	20.90	19.60
	Strength at 90 days					
OPBA	24.60	26.70	25.80	25.00	23.40	21.80
PLA	24.60	27.30	26.20	25.30	24.00	23.00
OPBA & PLA	24.60	27.00	25.90	25.10	23.60	22.10

It can be seen in tables 1 and 2 that 100% OPC concrete (the control) strength increased steadily till the age of about 28 days, after which it increased only gradually until the age of about 90 days. Table 1 shows the low strength of OPC-OPBA-PLA ternary blended cement concrete relative to the strength of the control concrete at early ages of 3 to 21 days, especially at 3-14 days. The poor early strength gets more pronounced with increase in percentage replacement of OPC with OPBA-PLA combination as shown in table 2. This very low early strength could be due to the fact that pozzolanic reaction was not yet appreciable at early ages. The pozzolanic reaction set in after some days and increased with days of curing/hydration such that the strength of blended cement concrete increased more and more with age than that of the control. Table 1 clearly shows that very high strength could be achieved for OPC-OPBA-PLA ternary blended cement concrete with 10 to 15% replacement of OPC with pozzolans at 50 to 90 days of curing.

Tables 1 and 2 also show that the strength values of OPC-OPBA binary blended cement concrete are higher than those of OPC-PLA binary blended cement concrete with5-10% OPC replacement at 3-21 days of hydration. Compressive strength values of OPC-PLA binary blended cement concretegets higher than those of OPC-OPBA binary blended cement concrete with15-25% OPC replacement at 3-21 days and at 28-90 days for all percentage replacements of OPC with pozzolan. The higher strength of OPC-OPBA binary blended cement concrete relative to that of OPC-PLA binary blended cement concreteat the earlier days of hydration shows that the pozzolanic reaction with OPBA sets in faster than that with PLA. Also, the fact that the strength of OPC-PLA binary blended cement concretegets higher than that of OPC-OPBA binary blended cement concrete at later days of hydration would suggest that PLA contains more quantity of non-amorphous silica than does OPBA. The strength value of OPC-OPBA-PLA ternary blended cement concrete consistently lies in-between the values for OPC-OPBA and OPC-PLA binary blended cement concretes for all percentage replacements and curing ages. This suggests that a disproportionate blending of the two pozzolans should be in favour of OPBA for optimization of the early strength of OPC-OPBA-PLA ternary blended cement concrete and in favour of PLA if the later strength of OPC-OPBA-PLA ternary blended cement concrete is of greater importance.

IV. CONCLUSIONS

Ternary blended cement concrete produced from blending OPC with equal proportions of OPBA and PLA have compressive strength values in between those of binary blended OPC-OPBA and OPC-PLA cement concretes for all percentage replacements of OPC with pozzolansand at all curing ages. Also, the variation of strength for OPC-OPBA-PLA ternary blended cement concrete is similar to those of OPC-OPBA and OPC-PLA binary blended cement concretes for all percentage replacements and curing ages. More importantly,the 90-day strengths of OPC-OPBA and OPC-PLAbinary blended cement concrete as well as that of OPC-OPBA-PLA ternary blended cement concrete are all higher than the control values for 5-15% replacement of OPC with pozzolans and close to the control values for 20-25% replacement. The implication of this is that very high strength values of OPC-OPBA and OPC-PLA binary blended cement concrete as well as OPC-OPBA-PLA ternary blended cement concrete could be obtained if high target strength is intentionally designed for and good quality control is applied such as the quality control measures used in producing 100% OPC (control) concrete with high strength values. Thus, OPC-OPBA-PLA ternary blended cement concrete could be used for various civil engineering and building works, especially where early strength is not a major requirement.

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