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Strength of Ternary Blended Cement Sandcrete Containing Afikpo Rice Husk Ash and Saw Dust Ash

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Abstract: This work investigated the compressive strength of ternary blended cement sandcrete containing Afikpo rice husk ash (RHA) and sawdust ash (SDA). 105 sandcrete cubes of 150mm x 150mm x 150mm were produced with OPC-RHA binary blended cement, 105 with OPC-SDA binary blended cement, and 105 with OPC-RHA-SDA 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 RHA and SDA were 11.80N/mm^2 for 5% replacement, 11.20N/mm^2 for 10% replacement, 10.60N/mm^2 for 15% replacement, 10.00N/mm^2 for 20% replacement, and 9.10N/mm^2 for 25% replacement, while that of the control was 10.90N/mm^2. This suggests that very high sandcrete strength values could be obtained with OPC-RHA-SDA ternary blended cement with richer mixes, high quality control, and longer days of hydration. Thus, OPC-RHA-SDA ternary blended cement sandcrete could be used for various civil engineering and building works, especially where early strength is not a major requirement.

KeyWords: *Binary blended cement, ternary blended cement, compressive strength, sandcrete, pozzolan, rice husk ash, sawdust ash.*

I. INTRODUCTION

Gross inadequacy of accommodation for the densely populated areas of South 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 societies could be used as partial replacement of Portland cement to achieve this purpose. 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. During hydration of Portland cement, lime or calcium hydroxide [$Ca(OH)_2$] is obtained as one of the hydration products. When a pozzolanic material is blended with Portland cement it reacts with the lime 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 OPC (Dwivedia et al., 2006). At temperatures around 40°C and in the presence of water, the amorphous silica contained in pozzolans such as rice husk ash (RHA) reacts with $Ca(OH)_2$ to form more C-S-H gel (Poon, Kou, and Lam, 2006). Much has been reported on binary blended systems whereby 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 pozzolanic 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 as higher substitution amounts result 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 rice husk ash to reduce temperature in high strength mass concrete and concluded that RHA is very effective in reducing the temperature of mass concrete compared to OPC concrete. 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. Sakr (2006) investigated the effects of silica fume and rice husk ash 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. 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. Wada et al. (2000) demonstrated that RHA mortar and concrete exhibited higher compressive strength than the control mortar and concrete. 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. 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). A few researchers have also investigated the possibility of ternary blended systems in order to further reduce the quantity of OPC in blended cements. 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. 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. 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 pozzolans 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.

The above works on ternary blended cements were based on the ternary blending of OPC with an industrial by-product pozzolan (i.e. FA) and an agricultural by-product pozzolan (i.e. RHA). Being majorly agrarian, many communities in South Eastern Nigeria have continued to generate tons of agricultural and plant wastes such as rice husk and sawdust as efforts are intensified toward food production and local economic ventures. This work investigated the suitability of using two agricultural by-products in ternary blend with OPC for sandcrete making. The compressive strength of ternary blended cement sandcrete containing Afikpo rice husk ash and sawdust ash was specifically investigated. The successful utilization of rice husk ash and sawdust ash in ternary combination with OPC for making sandcrete would further add value to these wastes. Moreover, by reducing the volume of OPC required for making sandcrete, it will also reduce the cost of civil engineering and building works that make much use of sandcrete blocks.

II. METHODOLOGY

Rice husk was obtained from rice milling factories in Afikpo, Ebonyi State and Saw dust from wood mills in Owerri, Imo State, all in South Eastern Nigeria. These materials were air-dried and calcined into ashes in a locally fabricated furnace at temperatures generally below 650^{o}C. The rice husk ash (RHA) and sawdust ash (SDA) 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 RHA had a bulk density of 770 Kg/m^3, specific gravity of 1.84, and fineness modulus of 1.48. The SDA had a bulk density of 810 Kg/m^3, specific gravity of 2.05, and fineness modulus of 1.89. 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; 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. The chemical analysis of the ashes showed they both 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 1:6 (blended cement: sand) was used for the 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. 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 sand, 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 sand, also at the required proportions. Water was then added gradually and the entire sandcrete heap was mixed thoroughly to ensure homogeneity. One hundred and five (105) sandcrete cubes of 150mm x 150mm x 150mm were produced with OPC-RHA binary blended cement, one hundred and five (105) with OPC-SDA binary blended cement, and one hundred and five (105) with OPC-RHA-SDA ternary blended cement, each at percentage OPC replacement with pozzolan of 5%, 10%, 15%, 20%, and 25%. An equal combination of RHA and SDA 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 sandcrete cubes. All the cubes were cured by water sprinkling twice daily in a shed. 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 RHA and the SDA 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-RHA and OPC-SDA binary blended cement sandcrete as well as the OPC-RHA-SDA ternary blended cement sandcrete are shown in tables 1 and 2 for 3-21 and 28-90 days of curing respectively.

As can be seen in tables 1 and 2, the results show that sandcrete produced from ternary blend of OPC with equal proportions of RHA and SDA have compressive strength values in between those of binary blends of OPC and RHA on one hand and OPC and SDA on the other hand for all percentage replacements and curing ages. Also, the variation of strength for sandcrete produced from ternary blended cements is similar to those of sandcrete produced from binary blended cements for all percentage replacements and curing ages. More significantly for civil engineering and building construction purposes, the 90-day strengths obtained from ternary blending of OPC with equal proportions of RHA and SDA were 11.80N/mm^2 for 5% replacement, 11.20N/mm^2 for 10% replacement, 10.60N/mm^2 for 15% replacement, 10.00N/mm^2 for 20% replacement, and 9.10N/mm^2 for 25% replacement, while that of the control was 10.90N/mm^2. Thus, the 90-day strength values for 5-10% replacement are higher than that of the control and those for 15-25% replacement are not much less than that of the control. This suggests that very high sandcrete strength values could be obtained with OPC-RHA-SDA ternary blended cement with richer mixes, high quality control, and longer days of hydration.

Table 1. Compressive strength of blended OPC-RHA-SDA cement sandcrete 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					
RHA	3.30	2.40	2.40	2.20	2.10	2.10
SDA	3.30	2.40	2.30	2.20	2.10	1.90
RHA & SDA	3.30	2.40	2.30	2.20	2.10	2.00
	Strength at 7 days					
RHA	5.60	3.60	3.50	3.10	2.90	2.10
SDA	5.60	3.40	3.30	3.10	3.00	2.70
RHA & SDA	5.60	3.50	3.40	3.10	2.90	2.70
	Strength at 14 days					
RHA	7.70	5.00	4.60	4.10	3.80	3.40
SDA	7.70	4.80	4.40	4.00	3.60	3.20
RHA & SDA	7.70	4.90	4.50	4.00	3.70	3.30
	Strength at 21 days					
RHA	8.60	5.80	5.40	4.60	4.40	3.80
SDA	8.60	5.60	5.10	4.60	4.20	3.60
RHA & SDA	8.60	5.70	5.30	4.60	4.30	3.70

Table 2. Compressive strength of blended OPC-RHA-SDA cement sandcrete 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					
RHA	9.90	8.20	7.00	6.40	5.60	4.70
SDA	9.90	7.90	6.60	5.90	5.30	4.50
RHA & SDA	9.90	8.00	6.80	6.10	5.40	4.60
	Strength at 50 days					
RHA	10.30	10.40	9.50	8.60	7.70	6.80
SDA	10.30	9.60	8.70	8.00	7.50	6.70
RHA & SDA	10.30	10.00	9.10	8.40	7.60	6.70
	Strength at 90 days					
RHA	10.90	11.90	11.40	10.70	10.10	9.40
SDA	10.90	11.80	11.10	10.60	10.00	8.90
RHA & SDA	10.90	11.80	11.20	10.60	10.00	9.10

As would be expected, 100% OPC sandcrete (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 very low strength of OPC-RHA-SDA ternary blended cement sandcrete relative to the strength of the control concrete at early ages of 3 to 21 days. The poor early strength gets more pronounced with increase in percentage replacement of OPC with RHA-SDA combination as shown in table 2. For example, whereas the 3-day strength at 5% replacement is $2.40N/mm^2$, it is $2.00N/mm^2$ at 25% replacement. 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 sandcrete increased more and more with age than that of the control. Table 1 clearly shows that very high strength could be achieved for ternary blended cement sandcrete containing OPC, RHA, and SDA with 10 to 15% replacement of OPC with pozzolans at 50 to 90 days of curing. By way of comparison, it can be seen from tables 1 and 2 that the strength values of OPC-RHA binary blended cement sandcrete are greater than those of OPC-SDA binary blended cement sandcrete at all percentage replacements of OPC with pozzolan and at all curing ages. The strength value of OPC-RHA-SDA ternary blended cement sandcrete consistently lies in-between the two for all percentage replacements and curing ages. This suggests that a disproportionate blending of the two pozzolans should be in favour of RHA for optimization of the strength of the ternary blended cement sandcrete.

IV. CONCLUSIONS

Ternary blended cement sandcrete produced from blending OPC with equal proportions of RHA and SDA have compressive strength values in between those of binary blended OPC-RHA and OPC-SDA cement sandcrete for all percentage replacements and curing ages. Also, the variation of strength for OPC-RHA-SDA ternary blended cement sandcrete is similar to those of OPC-RHA and OPC-SDA binary blended cement sandcrete for all percentage replacements and curing ages. More importantly, similar to the results of binary blending, the 90-day strengths of OPC-RHA-SDA ternary blended cement sandcrete are higher than the control values for 5-10% replacement of OPC with pozzolans and close to the control values for 15-25% replacement. The implication of this is that very high values of OPC-RHA-SDA ternary blended cement sandcrete strengths 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) sandcrete with very high strength values. Thus, OPC-RHA-SDA ternary blended cement sandcrete could be used for various civil engineering and building works, especially where early strength is not a major requirement.

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