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

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ABSTRACT: This study investigated the compressive strengths of soilcrete produced from blended cements made of Ordinary Portland Cement (OPC), Afikpo rice husk ash (RHA), and sawdust ash (SDA). 135 soilcrete cubes of 150mm x 150mm x 150mm were produced with OPC-RHA binary blended cement, 135 with OPC-SDA binary blended cement, and 135 with OPC-RHA-SDA ternary blended cement, each at percentage OPC replacement with pozzolans 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, 90, 120, and 150 days of curing. The 150-day strength values for OPC-RHA binary blended cement soilcrete were 10.50N/mm^2 for 5% replacement, 10.30N/mm^2 for 10% replacement, 10.10N/mm^2 for 15% replacement, 10.00N/mm^2 for 20% replacement, and 9.80N/mm^2 for 25% replacement; values for OPC-SDA binary blended cement soilcrete were 10.10N/mm^2 for 5% replacement, 9.90N/mm^2 for 10% replacement, 9.70N/mm^2 for 15% replacement, 9.50N/mm^2 for 20% replacement, and 9.50N/mm^2 for 25% replacement; values for OPC-RHA-SDA ternary blended cement soilcrete were 10.30N/mm^2 for 5% replacement, 10.10N/mm^2 for 10% replacement, 9.90N/mm^2 for 15% replacement, 9.80N/mm^2 for 20% replacement, and 9.60N/mm^2 for 25% replacement; while the control value was 8.70N/mm^2. This shows that OPC-RHA and OPC-SDA binary blended cements as well as OPC-RHA-SDA ternary blended cement could all be used in producing soilcrete with sufficient strength for building and civil engineering works.

Key words: Binary blended cement, ternary blended cement, soilcrete, pozzolan, rice husk ash, sawdust ash.

I. INTRODUCTION

Houses have become unaffordable for the vast majority of persons in South Eastern Nigeria due to the high cost of building materials relative to the economic status of the people. Reducing the cost of cement used insoilcrete production could go a long way toward solving this problem because soilcreteis an important element of low-cost buildings in the suburbs and villages. In order to achieve this purpose, agricultural by-products regarded as wastes in technologically underdeveloped societies could be used as partial replacement of Ordinary Portland Cement (OPC). It has already been established thatsupplementary cementitious materials prove to be effective to meet most of the requirements of durable concrete and blended cements are now used in many parts of the world (Bakar, Putrajaya, and Abdulaziz, 2010). Incorporating agricultural by-product pozzolans such as rice husk ash (RHA) calcined at high temperatures has been studied with positive results in the manufacture and application of blended cements (Malhotra and Mehta, 2004). Cisse and Laquerbe (2000) reported that sandcrete blocks obtained with unground Senegalese RHA as partial replacement of OPC had greater mechanical resistance than 100% OPC sandcrete blocks. Their study also revealed that the use of unground RHA enabled production of lightweight sandcrete block with insulating properties at a reduced cost. Agbede and Obam (2008) have also 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. Elinwa and Awari (2001) found that groundnut husk ash could be suitably used as partial replacement of OPC in concrete making. Oyekan and Kamiyo (2011) reported thatsandcrete blocks made with RHA-blended cement had lower heat storage capacity and lower thermal mass than 100% OPC sandcrete blocks. They explained that the increased thermal effusivity of the sandcrete block with RHA content is an advantage over 100% OPC sandcrete block as it enhances human thermal comfort. Many researchers have particularly found sawdust ash a suitable agricultural by-product for use in formulating binary blended cements with OPC (Elinwa, Ejeh, and Mamuda, 2008; Elinwa and Abdulkadir, 2011).

Several other researchers have also investigated the combination of OPC with different percentages of a pozzolan in making binary blended cement composites (Adewuyi and Ola, 2005; De Sensale, 2006; Nair, Jagadish, and Fraaij, 2006; Saraswathy and Song, 2007; Ganesan, Rajagopal, and Thangavel, 2008). Wada et al.

(2000) demonstrated that RHA mortar and concrete exhibited higher compressive strength than the control mortar and concrete. 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. Cordeiro, Filho, and Fairbairn (2009) investigated Brazilian RHA and rice straw ash (RSA) and demonstrated that grinding increased 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.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. Malhotra and Mehta (2004) 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. Habeeb and Fayyadh (2009) also 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. 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) further 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.

Some researchers have also investigated the possibility of ternary blended systems whereby OPC is blended with two different pozzolans. The ternary blended system has the additional environmental and economic advantages that it enables a further reduction of the quantity of OPC in blended cements and also makes it possible for two pozzolans to be combined with OPC even if neither of them is available in very large quantity. 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. Tyagher, Utsev, and Adagba (2011) found that sawdust ash-lime mixture as partial replacement for OPC is suitable for the production of sandcrete hollow blocks. They reported that 10% replacement of OPC with SDA-lime gave the maximum strength at water-cement ratio of 0.55 for 1:8 mix ratio. 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.Fadzil et al. (2008) studied the properties of ternary blended cementitious (TBC) systems containing OPC, ground Malaysian RHA, and fly ash (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. Their results suggested the possibility of using TBC systems in the concrete construction industry and that TBC systems could be particularly useful in reducing the volume of OPC used. 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.

Much of the previous works by researchers on ternary blended cements were based on the ternary blending of OPC with an industrial by-product pozzolan such as FA or silica fume (SF) and an agricultural by-product pozzolan, notably RHA. Tons of agricultural and plant wastes such as rice husk and sawdust are generated in Afikpo district in Ebonyi State and in many other communities in South Eastern Nigeria due to intensified food production and local economic ventures. Little has been reported on the possibility of binary combination of these Nigerian agricultural by-products with OPC in developing blended cements and no literature exists on the possibility of ternary blending of two of them with OPC. This work is part of a pioneer investigation of the suitability of using two Nigerian agricultural by-products in ternary blend with OPC for soilcrete making. The compressive strength of binary and ternary blended cementsoilcrete containing rice husk ash and sawdust ash was specifically investigated. It is hoped that the successful utilization of rice husk ash and sawdust ash in binary and ternary combination with OPC for making soilcrete would further add value to these agricultural by-product wastes as well as reduce the cost of building works and some other civil engineering projects that make much use of soilcrete.

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^oC. 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; laterite free from debris and organic materials with a bulk density of 1450 Kg/m^3, specific gravity of 2.30, and fineness modulus of 3.30; 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: laterite) was used for the soilcrete. 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 laterite, 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 laterite, also at the required proportions. Water was then added gradually and the entire sandcrete heap was mixed thoroughly to ensure homogeneity. One hundred and thirty-five (135) soilcrete cubes of 150mm x 150mm x 150mm were produced with OPC-RHA binary blended cement, one hundred and thirty-five (135) with OPC-SDA binary blended cement, and one hundred and thirty-five (135) 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 seven control cubes with 100% OPC or 0% replacement with pozzolan were also produced. This gives a total of 432soilcrete 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, 90, 120, and 150 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. This implies that 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 soilcrete as well as the OPC-RHA-SDA ternary blended cement soilcrete are shown in tables 1, 2, and 3 for 3-14 days, 21-50 days, and 90-150 days of curing respectively.

Table 1. Compressive strength of blended OPC-RHA-SDA cement soilcrete at 3-14 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	2.60	1.80	1.70	1.70	1.50	1.40
SDA	2.60	1.60	1.50	1.40	1.40	1.30
RHA & SDA	2.60	1.70	1.60	1.50	1.50	1.40
	Strength at 7 days					
RHA	4.00	3.10	3.00	2.80	2.70	2.50

SDA	4.00	3.00	2.90	2.70	2.50	2.40
RHA & SDA	4.00	3.00	3.00	2.80	2.60	2.40
	Strength at 14 days					
RHA	5.70	5.00	4.80	4.70	4.50	4.30
SDA	5.70	4.70	4.40	4.20	4.10	4.00
RHA & SDA	5.70	4.80	4.60	4.50	4.30	4.10

Table 2. Compressive strength of blended OPC-RHA-SDA cement soilcrete at 21-50 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 21 days					
RHA	6.30	5.70	5.50	5.30	5.20	5.00
SDA	6.30	5.10	4.90	4.70	4.60	4.40
RHA & SDA	6.30	5.40	5.10	5.00	4.80	4.70
	Strength at 28 days					
RHA	8.00	7.50	7.30	7.20	6.90	6.60
SDA	8.00	6.80	6.50	6.30	6.20	6.10
RHA & SDA	8.00	7.00	6.70	6.60	6.50	6.40
	Strength at 50 days					
RHA	8.30	8.60	8.40	8.30	8.10	7.90
SDA	8.30	8.30	8.10	8.00	7.90	7.60
RHA & SDA	8.30	8.50	8.30	8.20	8.00	7.80

Table 3. Compressive strength of blended OPC-RHA-SDA cement soilcrete at 90-150 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 90 days					
RHA	8.50	9.30	9.10	9.00	8.80	8.60
SDA	8.50	9.00	8.90	8.70	8.60	8.30
RHA & SDA	8.50	9.10	9.00	8.90	8.70	8.50
	Strength at 120 days					
RHA	8.60	10.00	9.90	9.70	9.50	9.40
SDA	8.60	9.80	9.50	9.40	9.30	9.10
RHA & SDA	8.60	9.90	9.70	9.60	9.40	9.30
	Strength at 150 days					
RHA	8.70	10.50	10.30	10.10	10.00	9.80
SDA	8.70	10.10	9.90	9.70	9.50	9.50
RHA & SDA	8.70	10.30	10.10	9.90	9.80	9.60

The results in tables 1 to 3 show that soilcrete 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 of OPC with pozzolans and at all curing ages. Also, the variation of strength for soilcrete produced from OPC-RHA-SDA ternary blended cements is similar to those of soilcrete produced from OPC-RHA and OPC-SDA binary blended cements for all percentage replacements and curing ages. The 3-28 day soilcrete strengths obtained from ternary blending of OPC with equal proportions of RHA and SDA are less than the control values, the 50-day strengths are equal to the control values, while the 90-150 day strengths are greater than the control values for 5-25% replacement of OPC with pozzolans. The 150-day strength values for OPC-RHA binary blended cement soilcrete were 10.50N/mm^2 for 5% replacement, 10.30N/mm^2 for 10% replacement, 10.10N/mm^2 for 15% replacement, 10.00N/mm^2 for 20% replacement, and 9.80N/mm^2 for 25% replacement; values for OPC-SDA binary blended cement soilcrete were 10.10N/mm^2 for 5% replacement, 9.90N/mm^2 for 10% replacement, 9.70N/mm^2 for 15% replacement, 9.50N/mm^2 for 20% replacement, and 9.50N/mm^2 for 25% replacement; values for OPC-RHA-SDA ternary blended cement soilcrete were 10.30N/mm^2 for 5% replacement, 10.10N/mm^2 for 10% replacement, 9.90N/mm^2 for 15% replacement, 9.80N/mm^2 for 20% replacement, and 9.60N/mm^2 for 25% replacement; while the control value was 8.70N/mm^2. This clearly shows that OPC-RHA and OPC-SDA binary blended cements as well as OPC-RHA-SDA ternary blended cement could all be used in producing soilcrete with sufficient strength for use in building and civil engineering works.

It can further be seen from tables 1 – 3 that the strength values for 100% OPC soilcrete (the control) are much higher than those obtained from OPC-RHA and OPC-SDA binary blended cements as well as OPC-RHA-SDA ternary blended cement at 3-21 days of hydration. This is so because pozzolanic reactivity had not set in appreciably at those early days of curing. It would also be noticed from the results in tables 1 – 3 that whereas the strength of 100% OPC soilcrete plateaus at about 50 days of curing, with very little increment between 50 and 150 days, the strength of OPC-RHA and OPC-SDA binary blended cements as well as OPC-RHA-SDA ternary blended cement soilcrete continues to increase steadily up to 150 days of curing such that the 150-day strengths of the blended cement soilcrete are much higher than those of the control. This means pozzolanic reaction continues to take place up until 150 days for 5-25% OPC replacement with pozzolans. The continued increase in strength of the blended cement soilcrete is due to the production of additional calcium silicate hydrate (C-S-H) as product of the pozzolanic reaction between silicon and calcium hydroxide, itself a by-product of hydration of Ordinary Portland Cement. More and more C-S-H will be produced, leading to higher and higher strength of the blended cement soilcrete, so long as this pozzolanic reaction goes on. The pozzolanic reaction will stop when the silicon has fixed all the calcium hydroxide available, in case of excess pozzolan, or when the available silicon has been exhausted in the pozzolanic reaction, in case of less silicon than calcium hydroxide.

Tables 1-3 also show that the strength of OPC-RHA binary blended cement soilcrete is consistently greater than that of OPC-SDA binary blended cement soilcrete for all percentage replacements of OPC with pozzolans and at all curing ages. The strength of the OPC-RHA-SDA ternary blended cement soilcrete consistently lies in-between the values of the OPC-RHA and OPC-SDA binary blended cement soilcrete. This suggests that more RHA should be used than SDA if the two pozzolans were to be used disproportionately to optimize the strength of the OPC-RHA-SDA ternary blended cement soilcrete.

IV. CONCLUSIONS

OPC-RHA and OPC-SDA binary blended cement soilcrete as well as OPC-RHA-SDA ternary blended cement soilcrete have compressive strength values less than those of 100% OPC soilcrete for 5-25% replacement of OPC with pozzolans at 3-21 days of hydration. The blended cement soilcrete strength values become equal to the control values at about 50 days of curing and greater than the control values at 90-150 days of hydration. This clearly shows that OPC-RHA and OPC-SDA binary blended cements as well as OPC-RHA-SDA ternary blended cement could be used in producing soilcrete with sufficient strength for use in building and civil engineering works where the need for high early strength is not a critical factor.

The strength of OPC-RHA binary blended cement soilcrete is consistently greater than that of OPC-SDA binary blended cement soilcrete for all percentage replacements of OPC with pozzolans and at all curing ages. The strength of the OPC-RHA-SDA ternary blended cement soilcrete consistently lies in-between the values of the OPC-RHA and OPC-SDA binary blended cement soilcrete. This suggests that more RHA should be used than SDA if the two pozzolans were to be used disproportionately to optimize the strength of the OPC-RHA-SDA ternary blended cement soilcrete.

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