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Variation of Strength of OPC-Saw Dust Ash Cement Composites with Water-Cement Ratio

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ABSTRACT:- *This work investigated the variation of strength of OPC-SDA cement composites with water-cement ratio. 180 concrete cubes of 150mm x 150mm x 150mm were produced with OPC and SDA using a constant mix ratio of 1:2:4, percentage OPC replacement with SDA of 0%, 5%, 10%, 15%, and 20%, and six water/cement ratios of 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9. 180 sandcrete cubes and 180 soilcrete cubes were also produced. Three concrete, sandcrete, and soilcrete cubes for each percentage OPC replacement with SDA and water/cement ratio were crushed to obtain their compressive strengths at 28 and 50 days of curing. It was found that the strength values of control composites generally reduced with increase in water-cement ratio, with maximum 28-day strength values of 24.00N/mm^2 for concrete, 9.80N/mm^2 for sandcrete, and 8.80N/mm^2 for soilcrete obtained at water-cement ratio of about 0.4. On the other hand, the strength of OPC-SDA composites varied with both percentage replacement of OPC with SDA and water-cement ratio. Maximum 28-day strength values of 22.00N/mm^2 for concrete, 8.70N/mm^2 for sandcrete, and 7.80N/mm^2 for soilcrete at 10% replacement of OPC with SDA were obtained using water-cement ratio of about 0.6 while maximum strength values of 19.80N/mm^2 for concrete, 7.90N/mm^2 for sandcrete, and 7.10N/mm^2 for soilcrete at 20% replacement of OPC with SDA were obtained at water-cement ratio of about 0.7. Thus, water-cement ratios of 0.6 to 0.8 should be used in producing OPC-SDA blended cement composites, depending on the mix ratio and percentage replacement of OPC with SDA.*

Keywords:- *Blended cement, cement composites, concrete, pozzolan, sandcrete, saw dust ash, soilcrete, water-cement ratio.*

I. INTRODUCTION

Researchers have within the past ten years greatly 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) report that supplementary cementitious materials have been proven to be effective in meeting most of the requirements of durable concrete and 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 $Ca(OH)_2$ 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).

Industrial waste pozzolans such as fly ash (FA) and silica fume (SF) are already widely used in many countries (Cisse and Laquerbe, 2000) and attempts are being made to produce and use pozzolanic agricultural by-product ashes such as rice husk ash (RHA) and saw dust ash (SDA) commercially in some countries. Mehta and Pirtz (2000) investigated the use of RHA to reduce temperature in high strength mass concrete and found that RHA is very effective in reducing the temperature of mass concrete compared to OPC concrete. Malhotra and Mehta (2004) found 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. 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 (SF) and RHA 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.

Wada et al. (2000) demonstrated that RHA mortar and concrete exhibited higher compressive strength than the control mortar and 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. 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 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. Elinwa, Ejeh, and Mamuda (2008) and Elinwa and Abdulkadir (2011) have also investigated the suitability of sawdust ash as a pozzolanic material and found that it could be used in binary combination with OPC to improve the properties of cement composites. Elinwa, Ejeh, and Akpabio (2005) also found that sawdust ash can be used in combination with metakaolin as a ternary blend with 3% added to act as an admixture in concrete.

Recent studies by Ettu et al. (2013a), Ettu et al. (2013b), Ettu et al. (2013c), and Ettu et al. (2013d) have confirmed the suitability of Nigerian SDA as a pozzolanic material for producing concrete, sandcrete, or soilcrete, either in binary combination with OPC or in ternary combination with OPC and one other agricultural by-product pozzolan such as RHA. What remains is to investigate the effects of some key factors such as water/cement ratio on the strengths of OPC-SDA cement composites. A number of scholars have investigated the effect of water/cement ratio on the fresh and hardened properties of self-compacting concrete and confirmed the critical role of water/cement ratio in concrete production (Felekoglu, Turkel, and Baradan (2007)).The effect of water-cement ratio on the strength of purely OPC composites is also generally well known. For example, provided sufficient compaction can be achieved, the strength of OPC concrete increases as the water-cement ratio reduces (Mehta and Monteiro (2006), Neville (2008), Neville and Brooks (2010)). This work investigated the variation of strength of OPC-SDA concrete, sandcrete, and soilcrete with water-cement ratio. It is expected that the knowledge of this variation would facilitate the production of better quality OPC-SDA cement composites for use in building and civil engineering works in South Eastern Nigeria and elsewhere.

II. METHODOLOGY

Saw dust was obtained from wood mills in Owerri, Imo State in South Eastern Nigeria. The material was air-dried and calcined into ashes in a locally fabricated furnace at temperatures generally below 650^oC. The resultant saw dust ash (SDA) 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 quality of the ash and enhance its pozzolanicity was applied because the researchers wanted to utilize simple processes that could be easily replicated by local community dwellers. 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; 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; 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; laterite free from debris and organic materials with a bulk density of 1450 Kg/m3, 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 the ash. 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. 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 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.

One hundred and eighty (180) concrete cubes of 150mm x 150mm x 150mmwere produced with OPC and SDA using a constant mix ratio of 1:2:4 (blended cement: sand: granite), percentage OPC replacement with SDA of 0% (control), 5%, 10%, 15%, and 20% and six water/cement ratios of 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9. One hundred and eighty (180) sandcrete cubes were also produced with OPC and SDA using constant blended cement: sand mix of 1:6, percentage OPC replacement with SDA of 0% (control), 5%, 10%, 15%, and 20%, and six water/cement ratios of 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9. One hundred and eighty (180) soilcrete cubes were similarly produced with OPC and SDA using constant blended cement: laterite mix of 1:6, percentage OPC replacement with SDA of 0% (control), 5%, 10%, 15%, and 20%, and six water/cement ratios of 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9.Batching was by weight and mixing was done manually on a smooth concrete pavement. The ash was first thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with the fine aggregate-coarse aggregate mix (or fine aggregate only for sandcrete and soilcrete), also at the required proportions. Water was then added gradually and the entire concrete, sandcrete, or soilcrete heap was mixed thoroughly to ensure homogeneity. All the concrete cubes were cured by immersion while the sandcrete and soilcrete cubes were cured by water sprinkling twice a day in a shed. Three concrete, sandcrete, and soilcrete cubes for each percentage OPC replacement with SDA and water/cement ratio were tested for saturated surface dry bulk density and crushed to obtain their compressive strengths at 28 and 50 days of curing.

III. RESULTS AND DISCUSSION

The particle size analysis showed that the SDA was much coarser than OPC, the reason being that the ash was not ground to finer particles. Therefore, the compressive strength values obtained using it can still be improved upon when the ash is ground to finer particles. The pozzolanicity test confirmed the SDA as pozzolanic since it fixed some quantities of lime over time. The variation of the compressive strengths of the OPC-SDA cement composites with water-cement ratio is shown in Tables 1, 2, and 3 for concrete, sandcrete, and soilcrete respectively.

Table 1: Compressive strength of binary blended cement concrete containing OPC and SDA with different water/cement ratios

W/C Ratio	28-Day Compressive Strength (N/mm^2)					50-Day Compressive Strength (N/mm^2)				
	0% SDA	5% SDA	10% SDA	15% SDA	20% SDA	0% SDA	5% SDA	10% SDA	15% SDA	20% SDA
0.4	24.00	21.60	19.70	19.10	18.10	24.60	22.80	20.50	19.80	18.80
0.5	23.60	22.70	21.90	19.60	18.70	24.10	23.40	22.90	20.80	19.30
0.6	23.00	22.90	22.00	20.20	19.00	23.50	23.60	23.00	21.40	20.00
0.7	22.00	22.60	21.50	21.10	19.80	22.60	23.30	22.50	21.90	20.50
0.8	20.00	22.20	20.70	20.60	19.30	20.70	22.80	21.50	21.20	19.90
0.9	17.30	19.60	19.00	19.00	18.50	18.00	20.60	20.10	19.90	19.30

Table 2: Compressive strength of binary blended cement sandcrete containing OPC and SDA with different water/cement ratios

W/C Ratio	28-Day Compressive Strength (N/mm^2)					50-Day Compressive Strength (N/mm^2)				
	0% SDA	5% SDA	10% SDA	15% SDA	20% SDA	0% SDA	5% SDA	10% SDA	15% SDA	20% SDA
0.4	9.80	8.20	7.80	7.30	6.80	10.10	8.70	8.30	8.00	7.40
0.5	9.50	8.70	8.40	7.60	7.10	9.90	9.00	8.60	8.30	7.80
0.6	9.30	9.20	8.70	7.90	7.40	9.70	9.50	9.00	8.60	7.60
0.7	9.00	8.90	8.50	8.40	7.90	9.30	9.10	8.70	8.90	8.20
0.8	7.40	8.20	7.90	7.70	7.50	8.00	8.90	8.60	8.20	7.80
0.9	7.00	7.90	7.60	7.20	6.70	7.50	8.50	8.00	7.70	7.30

Table 3: Compressive strength of binary blended cement soilcrete containing OPC and SDA with different water/cement ratios

W/C Ratio	28-Day Compressive Strength (N/mm^2)					50-Day Compressive Strength (N/mm^2)				
	0% SDA	5% SDA	10% SDA	15% SDA	20% SDA	0% SDA	5% SDA	10% SDA	15% SDA	20% SDA
0.4	8.80	7.30	6.90	6.40	5.90	9.10	7.90	7.40	7.10	6.50
0.5	8.60	7.90	7.50	6.60	6.20	8.90	8.10	7.70	7.40	6.90
0.6	8.40	8.30	7.80	7.00	6.50	8.70	8.60	8.30	7.60	6.70
0.7	8.00	8.10	7.60	7.50	7.10	8.40	8.10	7.80	7.80	7.30
0.8	6.30	7.30	7.00	6.80	6.50	7.10	7.90	7.50	7.40	7.00
0.9	6.00	7.00	6.60	6.30	5.90	6.60	7.60	7.10	6.80	6.30

It can be seen in Tables 1, 2, and 3 that the strength of normal OPC composites (with 0% SDA) generally reduce with increase in water-cement ratio as should be expected. The 28 and 50 day strengths are respectively 24.00N/mm^2 and 24.60N/mm^2 for concrete, 9.80N/mm^2 and 10.10N/mm^2 for sandcrete, and 8.80N/mm^2 and 9.10N/mm^2 for soilcrete at water-cement ratio of 0.4 and consistently reduce to 17.30N/mm^2 and 18.00N/mm^2 for concrete, 7.00N/mm^2 and 7.50N/mm^2 for sandcrete, and 6.00N/mm^2 and 6.60N/mm^2 for soilcrete at water-cement ratio of 0.9. On the other hand, the variation of strength of OPC-SDA composites with water-cement ratio depends on the percentage replacement of OPC with SDA. The strength generally increases with water-cement ratio up to some value of water-cement ratio, above which the strength begins to reduce. The results in Tables 1, 2, and 3 show that the 28-day strength values at 5% and 10% replacement of OPC with SDA are respectively 21.60N/mm^2 and 19.70N/mm^2 for concrete, 8.20N/mm^2 and 7.80N/mm^2 for sandcrete, and 7.30N/mm^2 and 6.90N/mm^2 for soilcrete at water-cement ratio of 0.4 and increase to a maximum of 22.90N/mm^2 and 22.00N/mm^2 for concrete, 9.20N/mm^2 and 8.70N/mm^2 for sandcrete, and 8.30N/mm^2 and 7.80N/mm^2 for soilcrete at water-cement ratio of 0.6, beyond which the respective strength values begin again to decrease. Similarly, the 28-day strength values at 15% and 20% replacement of OPC with SDA are respectively 19.10N/mm^2 and 18.10N/mm^2 for concrete, 7.30N/mm^2 and 6.80N/mm^2 for sandcrete, and 6.40N/mm^2 and 5.90N/mm^2 for soilcrete at water-cement ratio of 0.4 and increase to a maximum of 21.10N/mm^2 and 19.80N/mm^2 for concrete, 8.40N/mm^2 and 7.90N/mm^2 for sandcrete, and 7.50N/mm^2 and 7.10N/mm^2 for soilcrete at water-cement ratio of 0.7, beyond which the respective strength values begin again to decrease. The 50-day strength values also follow this pattern, although they are generally higher than the 28-day values.

Thus, at 5% and 10% replacement of OPC with SDA the strengths of concrete, sandcrete, and soilcrete increase from a minimum value at water-cement ratio of 0.4 to a maximum value at water-cement ratio of about 0.6, beyond which it begins again to decrease steadily. Similarly, at 15% and 20% replacement of OPC with SDA the strength of the composites increase from a minimum value at water-cement ratio of 0.4 to a maximum value at water-cement ratio of about 0.7, beyond which it again begins to decrease. Thus, OPC-SDA composites require more water to attain their maximum strength than required for purely OPC composites (with 0% SDA) and the extra quantity of water required depends on the percentage replacement of OPC with SDA. The extra water requirement of OPC-SDA composites could be as a result of a number of factors. First, since the SDA has less specific gravity than OPC, a larger volume of SDA is required to replace OPC when batching by weight; so, more water would be required to properly wet the excess volume of SDA and produce a suitable cement gel compared to OPC. Second, the pozzolanic reaction between silica in SDA and calcium hydroxide obtained as by-product of hydration of OPC could require some additional water for effectiveness, depending on the relative proportions of OPC and SDA.

IV. CONCLUSIONS

(i) The results of this work confirm that the strength of purely OPC composites (with 0% SDA) increase with decrease in water-cement ratio (provided full compaction can still be achieved) with maximum strength at water-cement ratio of about 0.4 (depending on the mix ratio).

(ii) The results also confirm once more that 50-day strength values of OPC-SDA composites are comparable to those of purely OPC composites (with 0% SDA).

(iii) The strength of OPC-SDA composites varies with both percentage replacement of OPC with SDA and water-cement ratio. Maximum strength values for 5% and 10% replacement of OPC with SDA are obtained at water-cement ratio of about 0.6 while maximum strength values for 15% and 20% replacement of OPC with SDA are obtained at water-cement ratio of about 0.7.

(iv) It is recommended that water-cement ratios of 0.6 to 0.8 should be used in producing OPC-SDA blended cement composites, depending on the mix ratio and percentage replacement of OPC with SDA.

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