Strength Variation of OPC-Saw Dust Ash Composites with Percentage Saw Dust Ash

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Abstract

This work investigated the variation of OPC-Saw Dust Ash (SDA) composites strength with percentage SDA. 231 concrete cubes, 231 sandcrete cubes, and 231 soilcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with SDA of 0% (control), 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50% and crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, and 90 days of curing. For concrete, the 90-day strength values decreased from 28.00N/mm^2 at 5% SDA to 25.60N/mm^2 at 15% SDA to 20.50N/mm^2 at 35% SDA to 15.80N/mm^2 at 50% SDA, while the control value was 27.00N/mm^2. The 90-day strength values also decreased from 11.50N/mm^2 at 5% SDA to 5.40N/mm^2 at 50% SDA for sandcrete while the control value was 11.10N/mm^2. Soilcrete strength values decreased from 9.70N/mm^2 at 5% SDA to 4.50N/mm^2 at 50% SDA while the control value was 9.50N/mm^2. The results suggest that, with good quality control of the concreting process, 5% to 25% OPC replacement with SDA could be suitable for general reinforced concrete works, 25% to 40% for minor works in concrete, and 45% to 50% for plain concrete works. Also, 5% to 20% OPC replacement with SDA could be used for light load-bearing sandcrete and soilcrete works, while 25% to 50% could still be suitable for non-load-bearing works.

Keywords: Blended cement, Composites, Compressive strength, Concrete, Sandcrete, Saw dust ash, Soilcrete.

1. Introduction

Researchers have made much effort 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. 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.

Cordeiro, Filho, and Fairbairn (2009) carried elaborate studies of 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. Fadzil et al. (2008) 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 Akpabio (2005) 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. 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.

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 on the strengths of OPC-SDA cement composites. The effect of curing age on the strength of purely OPC composites is well known. For example, so long as the hydration of anhydrous cement particles goes on, concrete strength increases with increase in the moist curing period (Mehta and Monteiro 2006). This is so because the strength of concrete depends on the amount of gel (the C-S-H which is the essential cementing compound) in the cement paste at any time, and this itself is a function of curing age. The amount of gel produced at any given time also depends on the type of cement because different cements require a different length of time to produce the same quantity of gel (Neville 2008). This work investigated the variation of strength of OPC-SDA cement composites with percentage SDA. The knowledge of this variation would be of great importance to civil and structural engineers in determining the percentage of SDA to be blended with OPC for various categories of concrete, sandcrete, and soilcrete works.

2. Methodology

Saw dust was obtained from timber milling factories in Owerri, Imo State, Nigeria, air-dried, and calcined into ashes in a locally fabricated combustion chamber at temperatures generally below 650^{o}C. The ash 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 ash quality and enhance its pozzolanicity was applied because the researchers wanted to utilize simple processes that can be easily replicated by local community dwellers. The resultant saw dust ash (SDA) had a bulk density of 820 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 2.80, and fineness modulus of 2.90; crushed granite of 20 mm nominal size free from impurities with a bulk density of 1550 Kg/m^3, specific gravity of 3.00, and fineness modulus of 3.70; laterite free from debris and organic materials with a bulk density of 1470 Kg/m^3, specific gravity of 2.40, and fineness modulus of 3.35; and water free from organic impurities.

A simple form of pozzolanicity test was carried out for the SDA. 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 hydrochloric acid solution of known concentration at time intervals of 30, 60, 90, and 120 minutes using phenolphthalein 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.

A standard mix ratio of 1:2:4 (blended cement: sand: granite) was used for concrete, 1:6 (blended cement: sand) for sandcrete, and 1:6 (blended cement: laterite) for 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. The SDA 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.

Two hundred and thirty-one (231) granite concrete cubes, two hundred and thirty-one (231) sandcrete cubes, and two hundred and thirty-one (231) soilcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with SDA of 0% (control), 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%. All the concrete cubes were cured by immersion while the sandcrete and soilcrete cubes were cured by water sprinkling twice daily in a shed. Three concrete cubes, three sandcrete cubes, and three soilcrete cubes for each percentage replacement of OPC with SDA 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.

3. 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 percentage SDA is shown in Tables 1, 2, and 3 for concrete, sandcrete, and soilcrete respectively.

It can be seen from Tables 1, 2, and 3 that the compressive strength values of the OPC-SDA blended cement composites at all percentage replacement of OPC with SDA were much lower than the control values at 3-21 days, but increased to become comparable to and even greater than the control values at 50 to 90 days of curing. This consistent pattern for all the composites has been explained by Ettu et al. (2013e) and Ettu et al. (2013f) as being a result of the low rate of pozzolanic reaction at those early 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.

For concrete, the 90-day strength values decreased from 28.00N/mm^2 at 5% SDA to 25.60N/mm^2 at 15% SDA to 20.50N/mm^2 at 35% SDA to 15.80N/mm^2 at 50% SDA, while the control value was 27.00N/mm^2. Thus, 5% SDA attained 104% of the control strength, 15% SDA attained 95% of the control strength, 35% SDA attained 76% of the control strength, and 50% SDA attained 59% of the control strength.

For sandcrete, the 90-day strength values decreased from 11.50N/mm^2 at 5% SDA to 10.70N/mm^2 at 15% SDA to 7.00N/mm^2 at 35% SDA to 5.40N/mm^2 at 50% SDA, while the control value was 11.10N/mm^2. Thus, 5% SDA attained 104% of the control strength, 15% SDA attained 96% of the control strength, 35% SDA attained 63% of the control strength, and 50% SDA attained 49% of the control strength.

For soilcrete, the 90-day strength values decreased from 9.70N/mm^2 at 5% SDA to 9.30N/mm^2 at 15% SDA to 5.40N/mm^2 at 35% SDA to 4.50N/mm^2 at 50% SDA, while the control value was 9.50N/mm^2. Thus, 5% SDA attained 102% of the control strength, 15% SDA attained 98% of the control strength, 35% SDA attained 57% of the control strength, and 50% SDA attained 47% of the control strength.

These results suggest that, with good quality control of the concreting process, 5% to 25% OPC replacement with SDA could be suitable for general reinforced concrete works, 25% to 40% for minor works in concrete, and 45% to 50% for plain concrete works. Also, 5% to 20% OPC replacement with SDA could be used for light load-bearing sandcrete and soilcrete works, while 25% to 50% could still be suitable for non-load-bearing works.

4. Conclusions

i. The compressive strength values of the OPC-SDA blended cement composites at all percentage replacement of OPC with SDA were much lower than the control values at 3-21 days, but increased to become comparable to and even greater than the control values at 50 to 90 days of curing.
ii. For concrete, at 90 days of curing 5% SDA attained 111% of the control strength, 15% SDA attained 98% of the control strength, 35% SDA attained 80% of the control strength, and 50% SDA attained 62% of the control strength.
iii. For sandcrete, at 90 days of curing 5% SDA attained 105% of the control strength, 15% SDA attained 99% of the control strength, 35% SDA attained 71% of the control strength, and 50% SDA attained 57% of the control strength.

iv. For soilcrete, at 90 days of curing 5% SDA attained 105% of the control strength, 15% SDA attained 100% of the control strength, 35% SDA attained 64% of the control strength, and 50% SDA attained 50% of the control strength.

v. The strength variation of OPC-SDA composites suggest that with good quality control of the concreting process, 5% to 25% OPC replacement with SDA could be suitable for general reinforced concrete works, 25% to 40% for minor works in concrete, and 45% to 50% for plain concrete works. Also, 5% to 20% OPC replacement with SDA could be used for light load-bearing sandcrete and soilcrete works, while 25% to 50% could still be suitable for non-load-bearing works.

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Table 1. Compressive strength of OPC-SDA cement concrete

% SDA	Compressive Strength (N/mm²) at						
	3 days	7 days	14 days	21 days	28 days	50 days	90 days
0%	8.00	14.10	21.70	22.40	23.30	25.40	27.00
5%	5.00	9.30	17.30	21.00	24.30	25.80	28.00
10%	4.60	9.20	17.10	20.40	22.20	24.00	27.10
15%	4.10	7.80	15.20	18.40	20.20	23.10	25.60
20%	3.50	7.50	13.40	16.50	18.20	21.70	24.00
25%	2.70	6.80	12.00	15.80	17.00	19.00	22.30
30%	2.40	5.50	10.80	13.70	15.50	18.20	21.00
35%	2.00	4.00	8.00	11.10	13.60	16.60	20.50
40%	1.80	3.20	5.50	9.00	11.30	14.40	19.00
45%	1.30	2.70	5.00	7.00	9.10	13.20	17.10
50%	1.20	1.90	3.20	5.00	7.90	11.00	15.80

Table 2. Compressive strength of OPC-SDA cement sandcrete

% SDA	Compressive Strength (N/mm²) at						
	3 days	7 days	14 days	21 days	28 days	50 days	90 days
0%	2.80	5.00	7.20	8.10	9.50	10.30	11.10
5%	1.90	2.90	4.00	4.80	7.30	9.40	11.50
10%	1.80	2.80	4.90	4.70	7.10	9.00	11.30
15%	1.70	2.30	3.40	4.40	6.30	8.60	10.70
20%	1.40	2.20	2.90	3.90	5.50	7.80	9.80
25%	1.30	2.00	3.00	3.60	5.00	6.20	8.20
30%	1.20	1.80	2.80	3.40	4.50	6.00	7.80
35%	1.00	1.50	2.30	2.80	3.60	5.70	7.00
40%	0.80	1.20	1.60	2.30	3.10	5.30	6.50
45%	0.60	1.00	1.20	1.80	2.70	4.60	6.10
50%	0.40	0.70	1.00	1.50	2.10	4.00	5.40

Table 3. Compressive strength of OPC-SDA cement soilcrete

% SDA	Compressive Strength (N/mm²) at						
	3 days	7 days	14 days	21 days	28 days	50 days	90 days
0%	2.70	4.00	5.70	6.40	8.20	9.00	9.50
5%	1.80	2.70	4.00	4.80	7.00	8.40	9.70
10%	1.60	2.60	3.70	4.60	6.50	8.20	9.50
15%	1.40	2.50	3.20	3.60	6.20	8.00	9.30
20%	1.30	2.20	3.00	3.40	5.10	7.80	9.00
25%	1.20	2.00	2.70	3.00	4.80	5.70	7.00
30%	1.10	1.80	2.20	2.60	4.00	5.30	6.00
35%	0.80	1.30	1.90	2.30	3.50	4.80	5.40
40%	0.60	1.00	1.50	1.90	3.00	4.20	5.10
45%	0.40	0.90	1.20	1.50	2.00	3.40	4.40
50%	0.30	0.60	0.90	1.20	1.80	3.00	4.50