

Strength of Binary Blended Cement Composites Containing Coconut Husk Ash

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Abstract: This work investigated the strength characteristics of binary blended cement composites made with Ordinary Portland Cement (OPC) and Coconut Husk Ash (CHA). 105 concrete cubes and 105 sandcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with CHA of 5%, 10%, 15%, 20%, and 25% and crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, and 90 days of curing. The 3-28 day compressive strength values of OPC-CHA binary blended cement concrete were found to be much lower than the control values; the 50 day strengths were comparable to the control values; while the 90 day strengths were higher than the control values especially at 5-10% replacements of OPC with CHA, ranging from 24.00N/mm² for 10% replacement of OPC to 25.10N/mm² for 5% replacement of OPC compared with the control value of 23.60N/mm². This same trend was observed for OPC-CHA binary blended cement sandcrete. The variation in density was not significant. Mathematical models were developed for predicting compressive strengths of OPC-CHA binary blended cement composites using polynomial regression analysis. The model values of compressive strengths obtained from the various model equations were found to be either exactly the same as those of the equivalent laboratory values or very close to them, especially at ages 28-90 days, with differences ranging from 0 to 0.5N/mm². Thus, OPC-CHA binary blended cement composites could be good for civil engineering works and the developed model equations can be easily used to estimate their strengths for various curing ages and percentage OPC replacement with CHA.

Keywords: Binary blended cement, composites, compressive strength, concrete, pozzolan, sandcrete.

1. Introduction

Researchers have continued to seek ways of reducing the cost of production of Portland cement and improve the quality of cement in order to provide accommodation for the increasing populace in Nigeria and many other parts of Africa. Suitable low-cost, sustainable materials could be used as partial replacement of Portland cement to achieve this purpose. Industrial and agricultural by-products regarded as wastes in technologically disadvantaged communities could be harnessed in this regard. Recent efforts have been focused on such substitute materials in making cement composites such as concrete and sandcrete[1]. Blended cements are currently used in many parts of the world [2]. During hydration of Portland cement, lime or calcium hydroxide [Ca(OH)₂] is obtained as one of the hydration products and it greatly contributes toward the deterioration of concrete. 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 lime and increases the quantity of C-S-H. Therefore, the cementing quality is enhanced if a good pozzolanic material is blended in suitable quantity with Portland cement [3].

The incorporation of agricultural by-product pozzolans has been used in the manufacture and application of blended cements [4]. Elinwa and Awari[5] successfully investigated the potentials of groundnut husk ash concrete by partially replacing Ordinary Portland Cement with groundnut husk ash. Adewuyi and Ola [6] applied waterworks sludge as partial replacement for cement in concrete production. Ezeh and Ibearugbulem[7] found good prospect in partially replacing cement with periwinkle shell ash in river stone aggregate concrete. Many other researchers have confirmed rice husk ash a pozzolanic material that can be used to partially replace OPC in making cement composites [8], [9],

[10]. Martirena, Middendorf, and Budelman[11] found that sugar industry solid wastes such as sugar cane straw ash has pozzolanic activity derived from its high content of amorphous silica. Some other researchers have also confirmed the possibility of using sugar industry wastes as pozzolans[12], [13], [14]. Adesanya[15] investigated the properties of blended cement mortar, concrete, and stabilized earth made from OPC and Corn Cob Ash and recommended that corn cob ash can serve as replacement for OPC in the production of cement composites. Adesanya[16] further studied the characteristics of lateritic bricks and blocks stabilized with corn cob fillers and obtained results that confirm the usability of corn cob ash as laterite stabilizer for block making. Nimityongskul and Daladar [17] highlighted the potentialities of coconut husk ash, corn cob ash, and peanut shell ash as good pozzolans. Dwivedia et al. [18] successfully investigated the pozzolanicity of bamboo leaf ash. A number of researchers have also found good prospects in using blended cements made with sawdust ash [19], [20], [21]. Studies by Chandrasekar et al. [22] suggest that soil chemistry as well as climatic and geographical conditions could affect the physical and chemical properties and consequently the pozzolanicity of agricultural and plant by-products.

Intensified local agricultural and economic ventures in many Nigerian communities have led to increased agricultural and plant wastes such as coconut husk. Large quantities of coconut husk are generated in various communities all over South Eastern Nigeria. There is therefore a need to specifically investigate the suitability of using Nigerian coconut husk ash as possible cement replacement in making cement composites. Its utilization as pozzolanic material would add commercial value to the otherwise waste product and encourage massive cultivation of coconut.

2. Methodology

Coconut husk was obtained from Owerri district of Imo State, Nigeria, crushed into smaller particles, air-dried, and calcined into ashes in a locally fabricated combustion chamber at temperatures generally below 650°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 coconut husk ash (CHA) had a bulk density of 750 Kg/m³, specific gravity of 1.82, and fineness modulus of 1.60. Other materials used for the work are Ibeto brand of Ordinary Portland Cement (OPC) with a bulk density of 1650 Kg/m³ and specific gravity of 3.13; river sand free from debris and organic materials with a bulk density of 1580 Kg/m³, specific gravity of 2.70, and fineness modulus of 2.84; Crushed granite of 20 mm nominal size free from impurities with a bulk density of 1510 Kg/m³, specific gravity of 2.94, and fineness modulus of 3.65; and water free from organic impurities.

A simple form of pozzolanicity test was carried out for the CHA. 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. However, the chemical analysis of the ash did not fully satisfy the ASTM requirement that the sum of SiO₂, Al₂O₃, and Fe₂O₃ should be not less than 70% for standard pozzolans.

A common mix ratio of 1:2:4 (blended cement: sand: granite) was used for concrete and 1:6 (blended cement: sand) for 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. The CHA 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. 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) concrete cubes and one hundred and five (105) sandcrete cubes of 150mm x 150mm x 150mm were produced at percentage OPC replacement with CHA of 5%, 10%, 15%, 20%, and 25%. Twenty one concrete cubes and twenty one sandcrete cubes with 100% OPC were also produced to serve as controls. This gives a total of 126 concrete cubes and 126 sandcrete cubes. All the concrete cubes were cured by immersion while the sandcrete cubes were cured by water sprinkling twice daily in a shed. Three concrete cubes and three sandcrete cubes for each percentage replacement of OPC with CHA 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.

Average values of concrete and sandcrete compressive strengths and densities for the various curing ages and percentages of OPC replacement with CHA were obtained and presented in tables and graphs. Mathematical models were developed in form of equations through polynomial regression analysis of the data showing the variation of concrete and sandcrete compressive strengths with curing age and percentage replacement of OPC with CHA. Suitable analytical tools in Microsoft Excel were used to plot appropriate polynomial curves, generate the corresponding mathematical equations, and obtain model values of compressive strengths for comparison with corresponding laboratory values.

3. Results and Discussion

The particle size analysis showed that the CHA was much coarser than OPC, the reason being that it was not ground to finer particles. The implication of this is that whatever compressive strength values obtained using it can still be improved upon when the ash is ground to finer particles. The pozzolanicity test confirmed CHA as a pozzolan since it fixed some quantities of lime over time, thereby reducing the alkalinity of the mixture as reflected in the smaller titre value over time compared to the blank titre.

The compressive strengths of the binary blended cement concrete and sandcrete produced with OPC and CHA are shown in tables 1 and 2 respectively.

Table 1. Compressive strength of blended OPC-CHA cement concrete

Age days	Compressive Strength (N/mm ²) for					
	0 % CHA	5 % CHA	10 % CHA	15 % CHA	20 % CHA	25 % CHA
3	7.90	4.20	3.80	3.50	3.30	3.10
7	14.00	8.00	7.80	7.00	6.50	6.10
14	21.50	15.70	15.20	12.30	10.70	10.00
21	22.10	18.80	17.10	16.00	13.60	12.50
28	23.00	21.90	20.00	19.00	15.20	13.00
50	23.50	23.40	21.70	20.00	18.00	16.50
90	23.60	25.10	24.00	23.00	20.50	18.50

Table 2. Compressive strength of blended OPC-CHA cement sandcrete

Age days	Compressive Strength (N/mm ²) for					
	0 % CHA	5 % CHA	10 % CHA	15 % CHA	20 % CHA	25 % CHA
3	2.70	1.70	1.70	1.70	1.50	1.30
7	5.00	2.60	2.50	2.30	2.00	1.80
14	7.10	4.00	3.90	3.00	2.50	2.10
21	8.00	4.80	4.20	3.80	3.20	2.90
28	9.30	6.20	6.10	5.50	4.80	4.00
50	9.70	8.20	7.90	7.30	6.90	6.00
90	10.30	10.60	10.30	9.90	9.40	8.00

It can be seen from table 1 that the compressive strength values of OPC-CHA binary blended cement concrete consistently decrease with increase in percentage replacement of OPC with CHA. The 3-21 day compressive strength values are much lower than the control values for all percentage replacements of OPC with CHA. The 3-day strengths range from 3.10N/mm² at 25% replacement of OPC to 4.20N/mm² at 5% replacement of OPC compared with the control value of 7.9 N/mm². The 7-day strengths range from

6.10N/mm² at 25% replacement of OPC to 8.00N/mm² at 5% replacement of OPC compared with the control value of 14N/mm². The 21-day strengths range from 12.50N/mm² at 25% replacement of OPC to 18.80N/mm² at 5% replacement of OPC compared with the control value of 22.10N/mm².

However, the 90-day strength at 5-10% replacement of OPC with CHA is higher than that of the control, ranging from 24.00 N/mm² for 10% replacement of OPC to 25.10N/mm² for 5% replacement of OPC compared with the control value of 23.60N/mm². This same trend of blended cement concrete strength variation with age and percentage replacement of OPC with CHA relative to the control values is noticeable for blended cement sandcrete as shown in table 2. The 3-21 day low strength values compared to the control can be attributed to the low rate of pozzolanic reaction at those ages. The silica from 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.

The density results suggests that although the saturated surface dry bulk densities of OPC-CHA binary blended cement concrete and sandcrete reduce slightly with both curing age and percentage replacement of OPC with CHA, the variations are of no significance for engineering purposes as they all still fall within the range for normal weight composites.

The results show that the strength of 100% OPC concrete (the control) increases steeply with age until about 14 days. The strength still increases steadily but less steeply between 14 and 28 days, after which the strength increases much more slowly such that the strength at 90 days is not much greater than the strength at 50 days. The variation in strength with age for the binary blended OPC-CHA cement concrete is different from that of the control, especially at high percentages of OPC replacement with CHA. The variation for 5% OPC replacement with CHA is not much different from that of the control, although the binary blended cement concrete continues to attain much higher strength values up to 90 days. The variation for 10% and 15% OPC replacement with CHA is significantly different from that of the control. The binary blended cement concrete strength picks up more slowly up to 21 days, after which it begins to increase rapidly until 90 days and beyond. At 20% and 25% OPC replacement with CHA the strength picks up even more gradually during the early ages up to 21 days than at 10-15% replacement levels. However the increase in strength continues more steeply at the later ages of 50 days and above.

4. Mathematical Models for Predicting Compressive Strength of OPC-CHA Cement Composites

The mathematical equations for predicting compressive strength of OPC-CHA binary blended cement concrete and sandcrete obtained from the results of polynomial regression analysis are presented in this section.

4.1 Variation of OPC-CHA concrete strength with percentage CHA

$$Y_3 = -0.00000880X^5 + 0.00065333X^4 - 0.01836667X^3 + 0.24366667X^2 - 1.57533333X + 7.90000000 \text{-----(1)}$$

Where Y₃ is the 3-day compressive strength in N/mm² of the OPC-CHA binary blended cement concrete and X is the percentage replacement of OPC with CHA.

$$Y_7 = -0.00002240X^5 + 0.00160667X^4 - 0.04273333X^3 + 0.51783333X^2 - 2.90766667X + 14.00000000 \text{----- (2)}$$

$$Y_{14} = 0.00024333X^4 - 0.01297407X^3 + 0.23219444X^2 - 1.95322751X + 21.43849206 \text{-- (3)}$$

$$Y_{21} = 0.00012000X^4 - 0.00653333X^3 + 0.11800000X^2 - 1.12738095X + 22.12142857 \text{-- (4)}$$

$$Y_{28} = 0.00009000X^4 - 0.00443333X^3 + 0.05725000X^2 - 0.47095238X + 23.05357143 \text{-- (5)}$$

$$Y_{50} = -0.00002667X^4 + 0.00204444X^3 - 0.05300000X^2 + 0.18293651X + 23.51190476 \text{-- (6)}$$

$$Y_{90} = -0.00002333X^4 + 0.00195926X^3 - 0.06413889X^2 + 0.53701058X + 23.63134921 \text{-- (7)}$$

4.2 Variation of OPC-CHA sandcrete strength with percentage CHA

$$Y_3 = -0.00000107X^5 + 0.00010667X^4 - 0.00386667X^3 + 0.06133333X^2 - 0.42266667X + 2.70000000 \text{----- (8)}$$

$$Y_7 = -0.00000587X^5 + 0.00045333X^4 - 0.01313333X^3 + 0.17466667X^2 - 1.07800000X + 5.00000000 \text{----- (9)}$$

$$Y_{14} = -0.00080741X^3 + 0.03877778X^2 - 0.66275132X + 6.94920635 \text{----- (10)}$$

$$Y_{21} = -0.00000293X^5 + 0.00028000X^4 - 0.00976667X^3 + 0.15500000X^2 - 1.20400000X + 8.00000000 \text{----- (11)}$$

$$Y_{28} = -0.00001147X^5 + 0.00083333X^4 - 0.02250000X^3 + 0.27316667X^2 - 1.52033333X + 9.30000000 \text{----- (12)}$$

$$Y_{50} = 0.00002667X^4 - 0.00185185X^3 + 0.04177778X^2 - 0.45068783X + 9.68730159 \text{----- (13)}$$

$$Y_{90} = -0.00011111X^3 - 0.00247619X^2 + 0.03944444X + 10.34523810 \text{----- (14)}$$

Model values of OPC-CHA binary blended cement concrete and sandcrete strengths from equations (1) to (14) together with their equivalent laboratory values are shown in tables 3 and 4 respectively.

Table 3. Model and laboratory values of OPC-CHA concrete strength

Age days	Compressive Strength in N/mm ² for					
	0 % CH A	5 % CH A	10 % CHA	15 % CHA	20 % CHA	25 % CHA
L3	7.9	4.2	3.8	3.5	3.3	3.1
M3	7.9	4.2	3.8	3.5	3.3	3.1
L7	14	8	7.8	7	6.5	6.1
M7	14.0	8.0	7.8	7.0	6.5	6.1
L14	21.5	15.7	15.2	12.3	10.7	10
M14	21.4	16.0	14.6	12.9	10.4	10.1
L21	22.1	18.8	17.1	16	13.6	12.5
M 21	22.1	18.7	17.3	15.8	13.7	12.5
L28	23	21.9	20	19	15.2	13
M28	23.1	21.6	20.5	18.5	15.5	12.9
L50	23.5	23.4	21.7	20	18	16.5
M50	23.5	23.3	21.8	19.9	18.1	16.5
L90	23.6	25.1	24	23	20.5	18.5
M90	23.6	24.9	24.3	22.7	20.7	18.5

L3 = Laboratory value at 3 days; M3 = Model value at 3 days.

Table 4. Model and laboratory values of OPC-CHA sandcrete strength

Age day s	Compressive Strength in N/mm ² for					
	0 % CHA	5 % CH A	10 % CHA	15 % CHA	20 % CHA	25 % CHA
L3	2.7	1.7	1.7	1.7	1.5	1.3
M3	2.7	1.7	1.7	1.7	1.5	1.3
L7	5	2.6	2.5	2.3	2	1.8
M7	5.0	2.6	2.5	2.3	2.0	1.8
L14	7.1	4	3.9	3	2.5	2.1
M14	6.9	4.5	3.4	3.0	2.7	2.0
L21	8	4.8	4.2	3.8	3.2	2.9
M 21	8.0	4.8	4.2	3.8	3.2	2.9
L28	9.3	6.2	6.1	5.5	4.8	4
M 28	9.3	6.2	6.1	5.5	4.8	4.0
L50	9.7	8.2	7.9	7.3	6.9	6
M50	9.7	8.3	7.8	7.4	6.8	6.0
L90	10.3	10.6	10.3	9.9	9.4	8
M90	10.3	10.5	10.4	10.0	9.3	8.0

L3 = Laboratory value at 3 days; M3 = Model value at 3 days.

It can be seen from tables 3 and 4 that the model values of compressive strengths obtained from the various model equations 1 to 14 are either exactly the same as those of the equivalent laboratory values or very close to them, especially

at ages 28-90 days, with differences ranging from 0 to 0.5N/mm². Therefore, the respective model equations are all suitable for determining the compressive strength values of OPC-CHA binary blended cement concrete and sandcrete for various curing ages and percentage replacement of OPC with CHA.

5. Conclusions

The strength of OPC-CHA binary blended cement concrete is higher than that of the control at 90 days of curing for 5-15% replacement. Therefore, OPC-CHA binary blended cement concrete can be used for high strength requirements at curing ages greater than 50 days.

There is similarity in the pattern of variation of OPC-CHA binary blended cement sandcrete strength with that of OPC-CHA binary blended cement concrete for different percentage replacements of OPC with CHA at 3 to 90 days of curing. Just as for concrete, OPC-CHA binary blended cement sandcrete has very low strength compared to the control at early ages up to 21 days. The strength improves greatly thereafter and increases to become greater than that of the control at ages above 50 days. Thus, OPC-CHA binary blended cement sandcrete could also be used in civil engineering works where early strength is not a major requirement.

The mathematical models/equations developed for predicting compressive strength of OPC-CHA binary blended cement composites can be used as guide in determining appropriate percentage replacement and minimum curing age to use for required strength values since the model values of compressive strengths obtained from the equations are either exactly the same as those of the equivalent laboratory values or very close to them, especially at ages 28-90 days.

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