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PARTIAL REPLACEMENT OF ORDINARY PORTLAND CEMENT (OPC) WITH COCONUT HUSK ASH (CHA) IN SANDCRETE BLOCK PRODUCTION

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Abstract: This research was conducted to develop new kinds of pozzolana from Agricultural wastes using Coconut Husk Ash (CHA) as a case study. Some experiments were conducted to determine the properties of CHA, mortar and sandcrete blocks having a certain percent replacement of Cement by this ash. Tests conducted include: Consistency test, moisture content test, slump test and compressive strength test. In addition, densities of the OPC/CHA sandcrete blocks were also determined. To determine the compressive strength, 150 x 225 x 450mm hollow sandcrete blocks were cast, cured and crushed for 7, 14, 21, and 28 days at 0%, 5%, 10%, 15%, 20% and 25% CHA replacement levels. Test results revealed that the compressive strength of the OPC/CHA sandcrete blocks increases with age and decreases as the percentage of CHA increases. The highest strengths at 28 days that met the NIS specification for non-load bearing sandcrete blocks were 4.19N/mm^2, 3.66N/mm^2 and 2.53N/mm^2 for 0%, 5% and 10% CHA respectively. The NIS specification for non-load bearing sandcrete blocks (150 x 225 x 450mm) is 2.5N/mm^2, hence this indicates that the replacement of cement with coconut husk ash in sandcrete blocks is relatively possible not exceeding 10%. The study therefore arrived at an optimum replacement level of 10%.

Keywords: Coconut Husk Ash (CHA), Ordinary Portland Cement (OPC), sandcrete blocks, compressive strength.

INTRODUCTION

The need to add value to wastes and the use of cement replacement materials for cheaper sandcrete blocks were the grounds for this work that aims at the production of sandcrete blocks with Coconut Husk Ash (CHA) as a partial replacement for Ordinary Portland Cement (OPC). Chaatveera B. and Nimityongskul P. (1994) submitted that Coconut Husk Ash cannot be utilized as pozzolana while Corn Cob Ash and Peanut Shell Ash can be classified as F and N pozzolana respectively. E. B Oyetola and M Abdullahi in their work on Rice Husk Ash (RHA) submitted that 20% is the optimum replacement level of Ordinary Portland Cement with RHA. This is so because it is the cheapest block that met the minimum compressive strength required for sandcrete blocks at 28 days. A. Fragata, H. Paiva, A. L. Velosa, M. R. Veiga and V. M. Ferreira submitted that flat construction glass is a material with a high percentage of amorphous silica, favouring pozzolanic reactivity. This property was evaluated using a chemical test based on the standard EN 196-5 - Methods of testing cement - Part 5: Pozzolanicity test of pozzolanic cement. The results obtained by this test indicate the material's capacity to react with calcium hydroxide, forming hydrated calcium alumino-silicates. B. A. Alabadan; M. A. Olutoye, M. S. Abolarin and M. Zakariya examined Ordinary Portland Cement (OPC) and Bambara Groundnut Shell Ash (BGSA) concrete and concluded that a partial replacement of Ordinary Portland Cement with about 10% Bambara Groundnut Shell ash in concrete is acceptable.

MATERIALS AND METHODS

For the purpose of this work, 150 x 225 x 450mm hollow sandcrete blocks were produced at the concrete laboratory of the Department of Civil Engineering, University of Lagos, Akoka, Lagos State, Nigeria. The mix ratio used was 1:6 (one part of binder to six parts of sand) according to NIS 87:2004 at different replacement levels of OPC and Coconut Husk Ash (CHA). For each replacement level, about 20 block samples were cast. The replacement levels and water/binder ratios used are as shown in Table 1, while the mix type designation for the various mixes are tabulated as shown in Table 2.

Table 1 Percentage Replacement Levels & Water / Binder Ratio

Replacement level [%]	Water/Binder ratio
100% OPC, 0% CHA	0.74
95% OPC, 5% CHA	0.83
90% OPC, 10% CHA	0.82
85% OPC, 15% CHA	0.76
80% OPC, 20% CHA	0.77
75% OPC, 25% CHA	0.76

Table 2 Mix Type Designation and Descriptions

Mix type no.	(OPC content in %)	(CHA content in %)
1	100	0
2	95	5
3	90	10
4	85	15
5	80	20
6	75	25

Preparation of the Ash Sample

The following procedures were used in the production of the Coconut Husk Ash:

i. Collection of Coconut husk from source (Epe, Lagos State, Nigeria).

ii. The husks were sun dried in the open field for 7 days.

iii. The dried husks were burnt in a gas furnace at the Federal Institute of Industrial Research, Oshodi (FIIRO), Lagos State, at an average temperature of 1000°C, using cooking gas as the combustion medium.
iv. After allowing the burnt products to cool off, it was then collected and sieved using sieve size 600µm.
v. The materials passing the 600µm sieve were used for the practical work.

Laboratory Tests

Series of laboratory tests were performed in order to determine the mechanical properties and the durability characteristics of the sandcrete blocks containing recycled materials (CHA). Tests conducted include: Consistency test, free moisture content test and slump test. Compressive strength and density of the OPC/CHA sandcrete blocks were also determined.

Consistency test

The consistency test was carried out based on the water/binder ratio. The volume of water required in each mix to achieve workability was noted and expressed as a percentage of the volume of binder.

Moisture content test

The moisture content of a sample is the ratio of the weight of water to weight of solids. This was performed as soon as the sand was brought to the lab and just before the commencement of the experimental work in the soil lab of Civil Engineering Dept, University of Lagos, Akoka.

The soil sample was placed on a container and weighed, oven dried and weighed again. The loss in weight is the weight of water in the original sample, and the weight of solids is the final weight less the weight of the container.

$$\text{Moisture content, M} = \frac{\text{Weight of water}}{\text{Weight of solids}} \times 100\%$$

Slump test

The slump test was performed on the freshly mixed mortar for each percentage replacement according to BS 1881: part 102: 1983.

The mould in the form of a hollow frustum of a cone having the following internal dimensions was used:

diameter of base: 200 mm
diameter of top: 100 mm
height: 300 mm

It was ensured that the internal surface of the mould was clean and damp but free from superfluous moisture before commencing the test. The mould was placed on a smooth, horizontal, rigid and non-absorbent surface free from vibration and shock. The mould was held firmly against the surface below whilst it was filled in three layers, each approximately one-third of the height of the mould when tamped. Each layer was tamped with 25 strokes of the tamping rod, the strokes being distributed uniformly over the cross-section of the layer. Each layer was tamped to its full depth, ensuring that the tamping rod does not forcibly strike the surface below when tamping the first layer and just passes through the second and top layers into the layers immediately below. The mortar was heaped above the mould before the top layer was tamped. After the top layer had been tamped, the mortar was leveled with the top of the mould with a sawing and rolling motion of the tamping rod. The mould was then removed from the mortar by raising it vertically, slowly and carefully, in such a manner as to impart minimum lateral or torsional movement to the mortar. Immediately after the mould was removed, the slump was measured by using a ruler to determine the difference between the height of the mould and of the highest point of the mortar.

Compressive Strength Test

The compressive strengths of the block samples were determined in accordance with the standard procedure for pre-cast concrete blocks (BS 882: 1972: Compressive Strength of cubical concrete specimens). The 150 x 225 x 450mm sandcrete blocks were required to perform the uni-axial compressive test in order to obtain the compressive strength, and the weights of the block samples were always taken before the compressive strength test was conducted.
To determine the compressive strengths at different replacement levels, five sample blocks of each replacement percentage were crushed at 7, 14, 21 and 28 days after casting using the compressive testing machine in the concrete laboratory of Department of Civil Engineering, University of Lagos, Akoka, Lagos, Nigeria.

Production of the Block Samples

For the purpose of this study, about one hundred and twenty hollow sandcrete blocks (150mm x 225mm x 450mm) were produced. The sand was first measured by volume i.e. 6 parts of sand and poured on to the concrete floor of the concrete lab, Unilag. The OPC and CHA measured by volume (i.e. 1 part) at various replacement percentages were mixed thoroughly and poured on top of the sand. The OPC, CHA and sand were then mixed together to obtain a homogeneous mixture. Water was then sprayed on to the mixture using a bucket and the quantity of water required to achieve workability in each case of percentage replacement was determined. The mixture was further turned with a shovel until a mix of the required workability was obtained. The resulting mortar was then transferred to the block moulding machine to produce fresh hollow blocks.

Curing

The block samples were removed from the palettes after 24 hours of casting and stored in the concrete laboratory. They were later taken outside and sprinkled with water twice daily. The block samples were taken inside the laboratory 24 hours before crushing to enable atmospheric curing. Testing was carried out on the sandcrete blocks at 7, 14, 21 and 28 days.

Method of Testing

The sandcrete blocks were subjected to compressive test with the aid of the Universal Testing Machine in the concrete laboratory. The load applied to each sample was gradually increased until the ultimate failure load was attained. These compressive strength tests were carried out in accordance with BS 1881; part 3: 1970 at ages of 7, 14, 21 and 28 days.

RESULTS AND DISCUSSIONS

The results of the various tests carried out on OPC, sand sample, CHA and sandcrete blocks are presented in tabular form, and discussed in the preceding sections.

Consistency test

Table 3 shows the result of the consistency test carried out during the laboratory work. Test result revealed that the water required to achieve the desired consistency fluctuates with the percentage increase in Nigeria Coconut Husk Ash.

Table 3 Consistency Test

Replacement of OPC with CHA (%)	0	5	10	15	20	25
OPC (Ltr)	37.60	35.72	33.84	31.96	30.08	28.2
CHA (Ltr)	0	1.88	3.76	5.64	7.52	9.4
Water (ml)	27.9	31.10	30.70	28.7	29.7	28.4
Water/Binder Ratio (%)	74	83	82	76	79	76

The reduced water demand is as a result of small carbon content. The loss on ignition for OPC is slightly less than the loss on ignition of CHA. This is because the carbon content of OPC is small compared to that in CHA. So as ash is introduced into the mix, the carbon content increases and the water requirement fluctuates. The carbon content of rice husk ash is very high and as such greater amount of water was needed compared to CHA to achieve the same consistency. This is in agreement with the results obtained in *Oyetola E. B. and Abdullahi M.*

Moisture content test

(i) Immediately the sand was brought to the laboratory:
Moisture content, M = 4.13%

(ii) After 2 weeks of drying in the laboratory:
Moisture content, M = 0.52%

Slump test

Table 4 shows the result of the slump test carried out on the freshly mixed mortar. Test result indicates the absence of a slump, hence mixes with greater CHA content requires almost the same water content to achieve a reasonable workability. This was due to the low carbon content of the Coconut Husk Ash (CHA).

***Table 4** Actual Water/Binder Ratio and Slump Values*

Replacement of OPC with NCHA (%)	0	5	10	15	20	25
Actual Water/Binder Ratio	0.74	0.83	0.82	0.76	0.79	0.76
Slump (mm)	0	0	0	0	0	0

Compressive Strength Test

The variations of compressive strength with age at curing and percentage replacement are presented in Table 5.

The compressive strength generally increases with age and decreases with percentage increase in CHA.

***Table 5** Compressive Strength of Block samples*

% Replacement Level	**Compressive Strength (N/mm²)**				**Remarks**
	7 Days	14 Days	21 days	28 Days	
100% OPC, 0% CHA	1.66	1.93	2.04	4.19	The compressive strength generally increases with age and decreases as the CHA content increases.
95% OPC, 5% CHA	1.56	2.34	2.64	3.66	
90% OPC, 10% CHA	1.29	1.61	1.77	2.53	
85% OPC, 15% CHA	1.18	1.67	1.75	2.04	
80% OPC, 20% CHA	1.13	1.45	1.64	1.88	
75% OPC, 25% CHA	0.92	1.29	1.34	1.67	

This decrease in strength is as a result of the low OPC content and high content of CHA which is not a good pozzolana. The reaction between the OPC/CHA with water is known as hydration. Setting and hardening of Portland cement is caused by the formation of water-containing compounds, forming as a result of reactions between cement components and water. Usually, cement reacts in a plastic mixture only at water/cement ratios between 0.25 and 0.75. As a result of the reactions (which start immediately), a stiffening was observed which was very small in the beginning, but increased with time. The hydration products primarily affecting the strength are Calcium Silicate Hydrates ("C-S-H phases"). Further hydration products are Calcium Hydroxide, Sulfatic Hydrates (AFm and AFt phases), and related compounds, Hydrogarnet, and Gehlenite Hydrate. Calcium Silicate Hydrates contain less CaO than the Calcium Silicates in cement clinker, so Calcium Hydroxide is formed during the hydration of Portland cement.

The simplified reaction of alite with water may be expressed as:
$2Ca_3OSiO_4 + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$

This is a relatively fast reaction, causing setting and strength development in the first few days.

The reaction of belite is:
$2Ca_2SiO_4 + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$
This reaction is relatively slow, and is mainly responsible for strength growth after one week.

Hydration proceeds with the presence of evaporable water, hence water was continuously provided in the course of curing while the hydration process continued. The result in Table V is in line with the submission made in *Oyetola E. B. and Abdullahi M* for RHA. However it was reported that the compressive strength of concrete for the mix with partial replacement of Acha Husk Ash is not directly related to its maturity. It was found that at 7 and 14 days hydration period the 10% and 20% AHA/OPC concrete strength was higher than that of conventional concrete.

The same was the case for CHA. At the 14 and 21 days hydration period the compressive strength of the 5% CHA/OPC sandcrete block was higher than that of conventional sandcrete block. The deviation might be due to the different material composition in the samples and the water/binder ratio which had the highest value of 0.83. At the 28 days hydration period, only blocks made with 0% CHA (4.19N/mm^2) and 5% CHA (3.66 N/mm^2) met the minimum required standard for load bearing sandcrete blocks (3.45N/mm^2), while 10% OPC (2.53 N/mm^2) met the minimum required standard for non-load bearing sandcrete blocks (2.5N/mm^2). Other percentage replacement levels fell below the minimum standard. The 10% replacement is then the optimum replacement level of OPC with CHA for non-load bearing sandcrete blocks. This is so because it is the cheapest block that met the minimum compressive strength required for non-load bearing sandcrete blocks at 28 days hydration period. The low optimum percentage replacement of CHA (10%) obtained confirms the submission made in *Chaatveera B. and Nimityongskul P. (1994)* which reported that CHA is not a good pozzolana. This replacement percentage of CHA is less than the 20% optimum obtained for RHA as reported in *Oyetola E. B. and Abdullahi M* and this confirms that CHA is less pozzolanic than RHA.

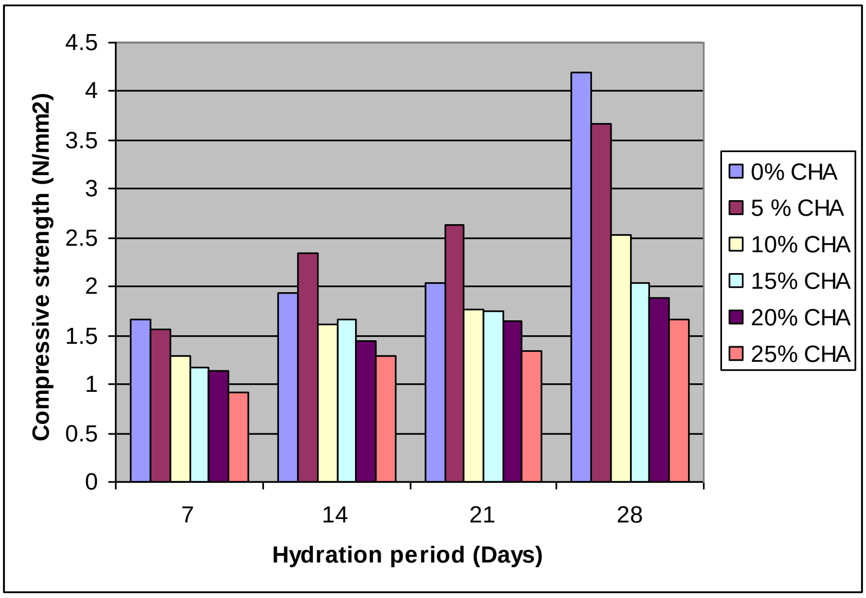

Fig. 1 Bar chart representation of the compressive strength against hydration period for all percentage replacement of CHA

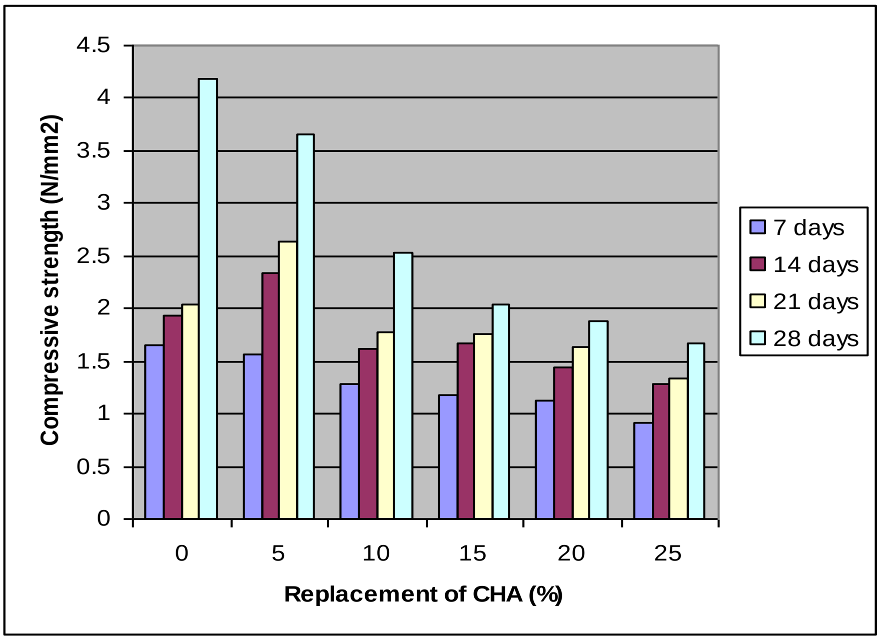

Fig. 2 Compressive strength against % replacement of CHA

Furthermore, the variations of compressive strength with the mix proportions and densities at various ages of curing are shown in Table 6.

Table 6 Compressive Strength and Densities of Sandcrete Blocks

Mix ratio	Age at curing (days)	Average weight of blocks (Kg)	Density (Kg/m^3)	Failure loads (KN)					Average failure load (KN)	Compressive strength (N/mm^2)
0% CHA, 100% OPC	7	16.72	1997.6	5	6	6	7	7	6.2	1.67
	14	16.70	1995.2	9	5	7	6	9	7.2	1.94
	21	16.62	1985.7	6	9	6	9	8	7.6	2.04
	28	16.46	1966.6	16	14	16	16	16	15.6	4.19
5% CHA, 95% OPC	7	17.04	2035.8	5	4	5	7	8	5.8	1.56
	14	17.12	2045.4	9	5	7	6	9	7.2	1.94
	21	17.16	2050.2	6	9	6	9	8	7.6	2.04
	28	16.70	1995.2	14	13	16	12	13	13.6	3.66
10% CHA 90% OPC	7	16.80	2007.2	5	5	4	5	5	4.8	1.29
	14	16.68	1992.8	6	5	6	6	7	6.0	1.61
	21	16.70	1995.2	7	6	7.5	5	7.5	6.6	1.77
	28	16.46	1966.6	9	10	10	9	9	9.4	2.53
15% CHA 85% OPC	7	17.00	2031.1	5	4	5	4	4	4.4	1.18
	14	16.72	1997.6	5	6	7	7	6	6.2	1.67
	21	16.82	2009.6	6	7	6	6.5	7	6.5	1.75
	28	16.80	2007.2	6	7	7	9	9	7.6	2.04
20% CHA 80% OPC	7	17.26	2062.1	4	4	4	4	5	4.2	1.13
	14	17.20	2054.9	5	6	5	5	6	5.4	1.45
	21	17.06	2038.2	5	7	4	9	5.5	6.1	1.64
	28	16.68	1992.8	8	7	7	6	7	7.0	1.88
25% CHA 75% OPC	7	16.50	1971.3	4	3	3	3	4	3.4	0.92
	14	16.82	2009.6	4	5.5	6	4.5	4	4.8	1.29
	21	16.60	1983.3	5	5	5	5	5	5.0	1.34
	28	16.64	1988.1	8	5	8	5	5	6.2	1.67

Test result indicates that the compressive strength decreases with increase in CHA content for all ages at curing. For higher percentage replacement levels such as 15% CHA, 20% CHA and 25% CHA, the amount of silica in the Coconut Husk Ash is less than required to combine with the liberated Calcium Hydroxide in the course of the hydration thereby causing a reduction in strength. The values obtained for the density of OPC/CHA hollow sandcrete blocks falls within the range specified for sandcrete blocks (500 - 2100 kg/m^3). The CHA content does not affect the density of the hollow blocks as it is a lightweight material and its inclusion is in minute quantity. As the percentage ash in the ash-cement composition increases, the compressive strength decreases. At 0% CHA and 100% OPC that serve as the control, strength increased from 1.66 N/mm^2 at 7 days to 4.19 N/mm^2 at 28 days, which is about 60% increment. Strength of 95:5 cement/ash increased from 1.56 N/mm^2 at 7days by about 57.4%. At 10% ash, strength increased by 49% while increases of about 42.2%, 39.9% and 44.6% were recorded for 15%, 20% and 25% ash respectively from 7 days to 28 days curing period. In terms of cost effectiveness, a bag of cement in Nigeria currently costs about ₦3,000 and 10% gives ₦300. This indicates that with 10% CHA, you save

₦300 on every bag of cement. Though, considering the cost of preparing the ash (transportation, burning, packaging etc.), it may appear to be more expensive, but in very large quantities, partial replacement with CHA becomes more economical.

CONCLUSIONS

From the tests conducted on OPC/CHA hollow sandcrete blocks as presented in the various sections, the following conclusions are made:

- The coconut husk ash produced by burning the husk in a gas kiln is slightly pozzolanic and therefore suitable for use in sandcrete block production;
- For a given mix, the minimum water/binder ratio was found to be 0.74 and the maximum was 0.83;
- The average density of OPC/CHA sandcrete block was found to be 2011.7 kg/m^3;
- The compressive strength of the blocks for all mix increases with age and decreases as the CHA content increases;
- Coconut husk is available in significant quantities as a waste and can be utilized for making blocks. This will go a long way to reduce the quantity of wastes in our environment;
- Partial replacement of Ordinary Portland Cement with about 10% Coconut Husk Ash in sandcrete block production is acceptable for non-load bearing sandcrete blocks (NIS 87: 2004).

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