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Research Article

Partial Replacement of Cement with Coconut Shell Ash in Sandcrete Block

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Abstract: In this study, Coconut Shell Ash (CSA) has been used to partially replace cement in Sandcrete Block (SB) manufacture in order to determine the quality of the SB produced in terms of compressive strength and durability. CSA has pozzolanic properties and as such, could serve as a partial replacement for cement and thus offset the cost of SB production. Laboratory tests were conducted to determine some engineering properties of the SB including compressive strength, water absorption, sorptivity and average density of SB with 0%, 10%, 15%, 20% and 25% cement replacement. The compressive strength was measured for 3, 14 and 28 day curing period. Results obtained clearly showed that increase in percentage of CSA in the mix produced SB of lower density, sorptivity and water absorption. Also, compressive strength of the SB increased at 10% replacement by 9% and 16% for SB of end-web to center-web ratios of 1:1 and 1:2 respectively. In addition, it was observed that the compressive strength of the SB only improved after 28 days curing. The SB produced in the course of this research is more resistant to ingress of moisture and suitable for walling in areas where surface and ground water impacts are significant and also in applications where light weight walls are desirable.

Keywords: Coconut shell ash, compressive strength, curing, sandcrete blocks, sorptivity, water absorption

INTRODUCTION

According to Nigerian Industrial Standard (2000), Sandcreteblock (SB) is composed of materials which includes cement, sand and water, that has been formed into solids of different sizes. SB can be made either in solid or hollow rectangular form. Ezeokonkwo (2012) opined that the increasing demand for SB by builders have projected the pressure on the supply of the raw materials and has also posed the issue of sustainability of the raw materials and affordability of buildings. He further asserted that in an attempt to minimize the quantity of materials used in the manufacture of a block unit, blocks are molded in such a way as to contain voids of different sizes and geometries. In Nigeria, sandcrete blocks are widely used as partition members in most buildings and this makes it a very important material in building construction. Anwar *et al*. (2001) observed that sandcrete walls have properties which makes them highly desirable for use in building construction. It is clear from literature that not much research has been conducted on the effect of partial replacement of cement with CSA on the compressive strength of hollow SB. An investigation into the relationship between cavity characteristics, web thickness and compressive strength of SB has been attempted in recent past (Agunwamba *et al*., 2016). Similarly, investigation on the replacement of cement with other pozzolanic materials such as Rice Husk Ash (RHA) in SB has also been carried out (Oyekan and Kamiyo, 2008, 2011). It was discovered that addition of RHA produced SB of lower density and also had a fairly significant effect on compressive strength of SB on low RHA content. In a related study, Ezeokonkwo (2012) also investigated two-cell hollow SB and stated that the size of the block cavity would affect its compressive strength. The ultimate effect of cavity size on the strength of sandcrete hollow blocks is necessary in the manufacture of quality SB as it has also been shown that the strength of a block is dependent on its average solid thickness (Eze-Uzomaka, 1977).

In Nigeria, two-cell hollow sandcrete blocks are produced more frequently for construction of buildings with little emphasis on other void configurations. However, it is germane to investigate other void configurations made with relatively cheaper materials that has the potential to serve as possible replacement of cement in sandcrete blocks. Coconut shell ash, which interestingly is a low cost material, is used in lieu of cement to minimize the overall cost of manufacturing the SB in this study. It also makes the production of quality SB achieved in an environmentally friendly

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manner during its construction, since coconut shell is one of the agricultural waste products that contributes to the world's pollution challenges (Gunasekaran *et al*., 2011)

Recent studies conducted at different places in Nigeria have shown that the compressive strength of SB produced in many block industries fall below the specification of the Nigerian Industrial Standard (2000), Olufisayo (2013), Arimanwa *et al*. (2014) and Wilson *et al*. (2016). Thus, if partial replacement of cement in SB production yields positive result, it will improve the quality of block units produced in Nigeria, whilst ensuring reduction in the cost of each unit of the block. This study seeks to ascertain the percentage of the CSA that will yield the optimum compressive strength in a SB. It also determines the relationship between the compressive strength and the end-web to center-web ratios of the SB.

MATERIALS AND METHODS

The following tests were conducted on the sandcrete blocks in this study: compressive strength test, water absorption test and sorptivity test. The determination of the optimum compressive strength of the hollow SB was carried out with two-cell hollow sandcrete blocks with end-web to center-web ratios of 1:1 and 1:2 as shown in Fig. 1 and 2 respectively. The compressive strengths were determined at 3, 14 and 28 days after curing the blocks under controlled conditions. The CSA was added in the ratios of 0, 10, 15, 20 and 25% by weight of the cement used. Curing was done by water sprinkling. The blocks were prepared using sand/cement ratio of 6.0 and water/cement ratio of 0.6. The blocks have nominal face dimensions of 225 mm in height by 450 mm in length and nominal thickness of 150 mm as in Fig. 1 and 2.

Number of sandcrete blocks: For the compressive strength test, 18 hollow sandcrete blocks per percentage replacement were used (3 variants for different curing age, 2 variants for different end-web to center-web ratios and 3 variants, each for the calculation of the average). Blocks = 90

For the absorption test, 3 hollow sandcrete blocks per percentage replacement were used (3 variants, each for the calculation of the average). Blocks = 15

For the sorptivity test, 3 hollow sandcrete blocks per percentage replacement were used (3 variants, each for the calculation of the average). Blocks = 15

Total = 120 blocks

The materials used and method of manufacture employed in this investigation are thus presented. The sandcrete blocks are made of sand, cement, varying

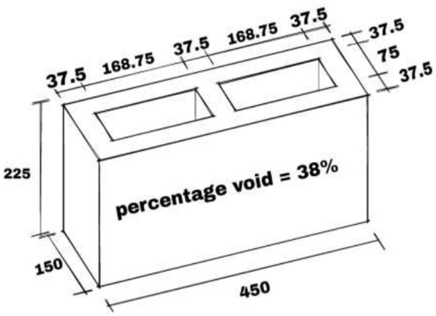

Fig. 1: Isometric view of the hollow SB with End-web to Centre-web ratio of 1:1

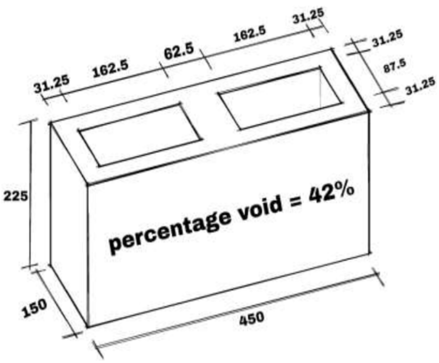

Fig. 2: Isometric view of the hollow SB with End-web to Centre-web ratio of 1:2

proportions of CSA and water. The materials are described in details below.

Cement: Dangote cement was used in this study. Dangote cement is a brand of ordinary Portland cement available locally in Nigeria with properties conforming to BS 12 (British Standards Institution, 1971).

Coconut shell: This was obtained locally from Obollo-A for, Enugu state. The coconut shell was sun dried for 48 hrs to remove moisture from it. After carbonization, the ash was collected and sieved through a BS sieve (150 microns).

Water: Fresh, colorless, odorless and tasteless potable water that was free from organic matter of any type from the Department of Civil Engineering, University of Nigeria, Nsukka was used both for the mixing of cement mortar as well as in curing of the sandcrete blocks.

Fine aggregate: Sand from Akachele hill, Obimo, Enugu State was used in mixing of cement mortar for the sandcrete blocks. It was sand passing through 3.36 mm British Standard test sieves.

Manufacture of sandcrete blocks: The procedure adopted for casting the sandcrete blocks were in accordance with BS 6073: Part 2 (British Standard Institute, 1983b). Metallic hollow molds were used in the manufacture of the sandcrete blocks. Manual mixing was employed and the materials were mixed thoroughly to ensure a homogenous mix. Addition of water was done to meet the desired water/cement ratio of 0.6. The mixture was then rammed into the hand molds, compacted and smoothed off with a steel face tool to flush with the surface of the mold. After removal from the hand molds, the blocks were left on pallets under cover in separate rows, one block high and with a space between two adjacent blocks for the curing period. The sandcrete blocks were sprinkled with water on a daily basis during the period of the curing. After the desired curing age has elapsed, the blocks were prepared for the subsequent tests necessary in the course of the study.

Carbonization of the coconut shell: The coconut shell was collected as a waste material. The coconut shells were sun-dried for three days and were cut into pieces of dimensions of about 0.01m^2 using hammer and were then placed in a container. Carbonization of the coconut shell into ash was achieved by burning the coconut shell in a furnace for a duration of about 2hrs at a temperature of 500°C. This was in accordance with the description given by Amarnath (2012), where it was noted that for controlled carbonization, the temperature should range between 400°C and 850°C. Shortly after the reduction of the coconut shell into ash, it was allowed to cool for another 3hrs in the furnace before being brought out. The coconut shell ash passing through BS 100 sieve was used for the study.

Compression test: The test was conducted in accordance with (British Standard Institute, 1983a). The manufactured SB was crushed using the compression testing machine and the values of the compressive strength of the SB were recorded.

Water absorption test: The test was conducted in accordance with (British Standard Institute, 1983b). The manufactured SB was dried up to a constant weight and then weighed. The SB was then soaked in water for a specified period and weighed again. The change in weight expressed as a percentage is the measured absorption, which is then multiplied by a correction factor to give the corrected absorption.

Sorptivity test: The test was conducted based on the capillary rise method in accordance with (American Society for Testing and Materials, 1990) due to its suitability as stipulated in (Oyekan and Kamiyo, 2008). Water absorption by capillary rise for time duration of 30 min was measured by weighing the sample using a weighing balance. Surface water on the sample was wiped off with a dampened tissue and the weighing was executed within 30 sec. The absorption of water under capillary action is dependent on the square-root of time (Hall, 1989).

RESULTS AND DISCUSSION

Results for the compressive strength, water absorption, sorptivity and average density measurements are presented in graphical forms. While the results presented for the compressive strength are for both end-web to center-web ratios, the results for the water absorption is for end-web to center-web ratio of 1:2 only. This is because it possesses lighter weight owing to its larger void percentage and as such serves as a lower bound to check ingress of moisture. It was also used for obtaining the average density of the SB. On the other hand, the results of the sorptivity test were for end-web to center-web ratio of 1:1 only. This is because it has a smaller void thus serving as an upper bound to check capillary action. These served as representatives for each percentage replacement.

The sand used for this research work when tested in the laboratory had a specific gravity of 2.65 and an average moisture content of 0.40% (data not shown). The coefficient of uniformity of the sand (C_u) was 3.48 and the coefficient of curvature/gradation (C_c) was 1.01 (data not shown). As such, the sand is uniform and well graded (Murthy, 2002).

Effect of CSA on compressive strength: The compressive strength results for end-web to center-web

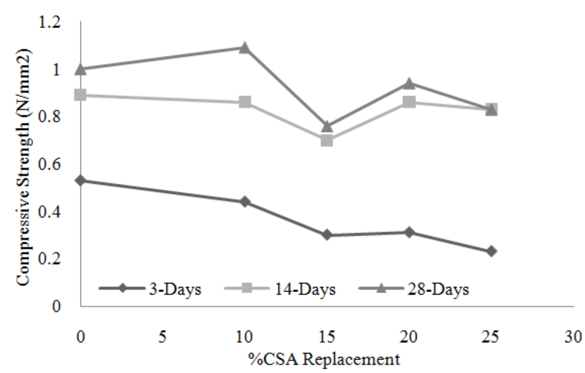

Fig. 3: Compressive strength versus percentage CSA replacement for 1:1 ratio

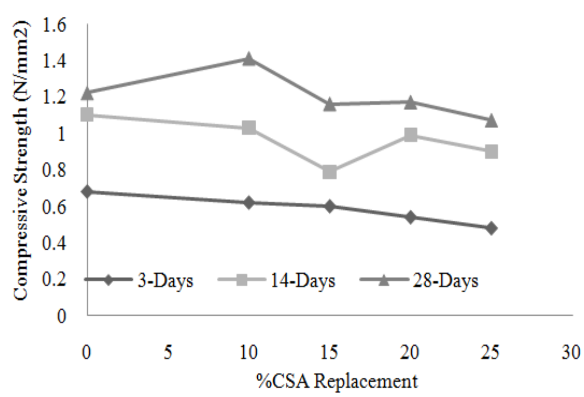

Fig. 4: Compressive strength versus percentage CSA replacement for 1:2 ratio

ratio of 1:1 and 1:2 are shown in Fig. 3 and 4 respectively.

The compressive strength of the sandcrete blocks was decreased by the use of CSA before 28 days. However, after 28 days curing, the compressive strength of the sandcrete blocks were enhanced. It was observed that 10% replacement with CSA in the mix is the optimum for improved compressive strength of the sandcrete blocks (an increase of 9% and 16% for end-web to center-web ratios of 1:1 and 1:2 respectively when compared to the control). This increase was probably due to the presence of adequate amount of Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) which are known to be the major compounds responsible for strength gain.

The blocks with end-web to center-web ratio of 1:2 gave higher strength than those of 1:1 in each case. Considering the as-cast surface of the block as a beam and the webs as supports, it is reasonable to expect higher reactions at the center-web and as such, if this central web is compensated with higher thickness, it will consequently yield higher compressive strength of the block. This explains why blocks with end-web to center-web ratio of 1:2 gave higher values of compressive strength.

The decrease in strength before 28 days may be as a result of the delay in the rate of strength gain in cement due to the addition of CSA. This delay can be attributed to the fact that the fine particles of the CSA increased the overall fines content of the mix, creating a larger surface area of fines for the cement to react with.

The increase in the compressive strength observed after 28 days curing is in contrast with that obtained by Oyekan and Kamiyo (2011). This is probably due to the incongruity in the chemical composition of the pozzolanic materials used for the partial replacement of cement.

Effect on water absorption: In Fig. 5, the water absorption rate is plotted against percentage CSA content. The absorption rate for all the percentage replacement with CSA is seen to have lower values than the control. For block to be used as external wall in a humid climate, the water-resistance ability of the block must be assessed in order to check the ingress of water. The results show that the addition of the CSA makes the average absorption value to drop lower than that of the control block. The 20% CSA replacement produced the lowest value of the average absorption. This makes it the most resistant to water absorption. This could be attributed to the strong bond formation resulting from the reaction between the cement and the fine particles of CSA, which properly sealed the pore spaces in the SB.

In comparison with the porosity test conducted by Oyekan and Kamiyo (2011), the result of this test is virtually contradictory. This could have resulted from the difference in the test method used and also the chemical composition of the pozzolanic materials used.

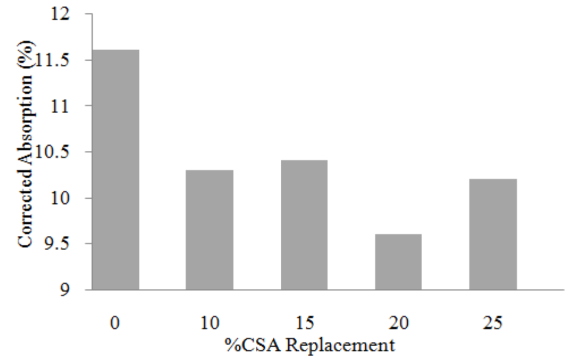

Fig. 5: Water Absorption versus percentage replacement with CSA

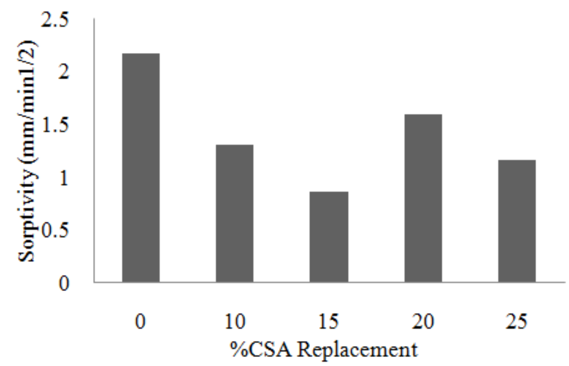

Fig. 6: Sorptivity versus percentage replacement with CSA

Effect on sorptivity: In Fig. 6, the sorptivity is plotted against percentage CSA content. The figure shows an overall reduction in Sorptivity when compared with the control. The minimum value was obtained at 15% CSA replacement. This may be due to the strong bond formation resulting from the reaction between the cement and the fine particles of CSA, which properly held the SB in well cemented form.

This result is discordant with that of Oyekan and Kamiyo (2011), who recorded an overall increase in sorptivity with percentage addition of the pozzolanic material. This disparity could be as a result of difference in the percentage composition of silicon dioxide present in the pozzolans used for the partial replacement of cement.

Effect on density: The result in Fig. 7 shows that increase in the percentage of CSA in the mix produced sandcrete blocks of lowered density. This implies that the density of the blocks actually decreased as the CSA content in the mix increased. This could be attributed to the fact that the CSA probably consist of particles with lower density in comparison to those of the Portland cement which were replaced partially with the CSA.

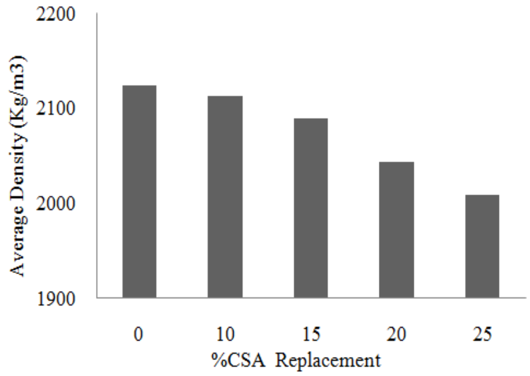

Fig. 7: Average density versus percentage replacement with CSA

This result is in agreement with that of Oyekan and Kamiyo (2011), who recorded similar reduction in density. The conformity in the results could be attributed to the fact that the pozzolanic materials used for the partial replacement of cement are roughly of the same density.

CONCLUSION

From the test result and analysis, the following conclusions can be made:

- Generally, there was no improvement for the 3-days and 14-days curing age. The only significant improvement was obtained with 28-days curing.
- Also, compressive strength of the SB at 28-days curing increased at 10% replacement by 9% and 16% for SB of end-web to center-web ratios of 1:1 and 1:2 respectively, obviously indicating that end-web to center-web ratio of 1:2 generally gave higher strength.
- Density of sandcrete blocks decreased progressively with increasing percentage CSA replacement.
- The water absorption rate is highest for 0% CSA replacement, lowest for 20% and nearly the same for other percentage replacements.
- The Sorptivity for the 0% CSA content (between 2 to 2.5mm/min$^{1/2}$) was higher than the other percentage replacements, whereas 15% replacement was the lowest.

Following the conclusions of this research work, the following recommendations are made which can be useful for commercial, public and/or private block manufacturers:

- For a higher compressive strength, low absorption and poor sorptivity, 10% replacement is recommended for use in sandcrete block production.
- End-web to center web ratio of 1:2 is preferable to end-web to center web ratio of 1:1 for a particular percentage void in a hollow SB.
- Where light weight walling materials are desired, 20% would be recommended to strike the balance between density and compressive strength.
- The SB produced in the course of this research is more resistant to water ingress and suitable for walling in areas where surface and ground water impacts are significant and also in applications where light weight walls are desirable.

CONFLICT OF INTEREST

The authors declare that there was no conflict of interest that influenced the development of this manuscript.

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