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Experimental Investigation on Replacement of Fine Aggregate with Crushed Cow Bones and Waste Glasses in Production of Sandcrete Blocks

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Abstract

The increasing demand for infrastructural development in developing nations has intensified the global adoption of sand as fine aggregate in construction works. To overcome the restrictions placed on the extraction of natural sand by most communities, satisfying its stretched need with gross reduction in construction cost in order to achieve sustainable development, there arises the need for consideration of the use of cheaper and locally available materials. In this study, crushed cow bones (CCB) and waste glass (WG) were employed as sand replacement materials for investigation of compressive strength and water absorption of sandcrete blocks, at 0%, 10%, 20%, 30%, 40%, 50% and 100% sand replacements using cement/combined aggregate ratio of 1: 6. Seven hollow blocks of dimension 450 mm x 225 mm x 225 mm were produced for each percentage sand replacement. A total of 168 hollow blocks were produced, 84 blocks for sand-CCB-blocks and 84 blocks for sand-WG-blocks. The blocks were moulded manually and were tested after curing by water sprinkling for 7, 14, 21 and 28 days. The blocks were cured by sprinkling them with water twice daily. As for 50% sand replacement with CCB blocks and WG blocks, the compressive strength was 4.71 N/mm^2 and 2.29N/mm^2 at 7days curing respectively, and 5.67 N/mm^2 and 2.82 N/mm^2 at 28-days curing respectively, both were within the range of minimum strength stipulated in NIS 87. The 2.82 N/mm^2 compressive strength value for 50% replacement levels still qualified the WG-Sandcrete blocks used for this investigation to be classified as non-load bearing solid block. 10.27% and 4.80% were obtained as the water absorption capacity of CCB and WG sandcrete blocks respectively, at 50% sand replacement after 28 curing days. All water absorption values obtained from both CCB and WG sandcrete blocks fell below the maximum NIS stipulation of 12%. Based on the study outcome, CCB and WG can be used reliably as a partial replacement of sand; hence they are recommended for adoption in construction activities as it reduces environmental pollution, production cost of sandcrete blocks and promotes sustainable structural development.

Keywords: Sandcrete blocks, Crushed cow bone (CCB), Waste glasses (WG), Compressive strength, Water absorption.

1. Introduction

The urgency to focus on sustainable infrastructures is desirable considering the rapid development and growth of the population. Urbanization tends to increase the demand and provision of shelter. Shelter is an integral component of human life. The integrity of shelter lies on its walling material. Walling materials varies but the prevalent in Nigeria is the sandcrete hollow and solid blocks. Sandcrete blocks consists of natural sand, water and cement. Sandcrete blocks are adopted for construction of over 80% of residential, institutional and industrial infrastructures in Nigeria, as a durable and low-maintenance investment (Alejo, 2020).

The need for sandcrete blocks produced in different parts of the country to stand the taste of time have led to more investigations on their ability to satisfy minimum building requirements. The standard organization of Nigeria (SON), in an attempt to enhance the manufacturing practice and best materials, developed a reference document in the year 2000, which prescribed the minimum requirements and uses of different kinds of sandcrete blocks. After reviewing the document in 2004, it was also revised in 2007, which serve as the recommended reference document for sandcrete block production in Nigeria (Anosike and Oyebade, 2012).

In recent time, managing agricultural and industrial wastes has been an issue. Considering the aesthetic and ecological problems caused by their improper disposal, there has been an increasing investigation among scholars on the area of minimizing waste accumulation through reclamation and recycling (Afolayan et al., 2017; Nwa-David et al., 2023a; Nwa-David et al., 2023b; Nwa-David, 2023a; Nwa-David, 2023b; Nwa-David, 2023c; Adenaike et al., 2023). Research areas aimed at waste reduction include the use of crushed cow bone and waste glass to partially replace natural sand in the production of sandcrete blocks as addressed in this study.

Human and industrial consumption of cow meat has led to the production of cow bones which constitute a big nuisance in abattoirs. Foul odour is usually noticed at their dumpsites as the heaps of cow bones are frequently worm-infested. Reusing these bones in the production of sandcrete blocks will enhance infrastructural development and environmental sustainability. This work is effort to study the suitability of crushed cow bones and their effect on properties of sandcrete blocks.

The increased utilization of glass products due to urbanization and industrialization, has a corresponding effect on its waste quantity in the landfills. The presence of waste glass in the landfill sites makes the environment unfriendly as they are not biodegradable. Reusing waste glasses in concrete production is of great advantage to the construction industry as it reduces production cost, minimizes the consumption of the natural aggregate from the river bed as well as preserve the natural river path (Topcu and Canbuz, 2004; Gautam et al., 2012).

Several scholars have carried out investigations on properties of sandcrete blocks. Oyekan and Kamiyo (2011) studied the effect of cement partial replacement with rice husk ash (RHA) on some engineering properties of vibrated hollow sandcrete blocks of size 225 x 225 x 450 mm with 1:6 cement-sand mix ratios. Their study revealed that the inclusion of RHA produced blocks with lower density. The density of the blocks reduced with increase in the RHA content. The compressive strength of the block was not enhanced. The thermal and hygrothermal properties of the blocks were significantly affected. The authors did not consider the partial replacement of the fine aggregate, neither was CCB and WG materials employed.

Akanbi et al., (2022) investigated the characteristic of hollow sandcrete blocks for ten (10) producers. The sieve analysis carried out by the authors showed that the sand used by all the sandcrete block producers are not in accordance with the specifications of the Nigeria industrial standard (NIS 87:2007). Further test of dimension and mix-proportions showed that all the block producers do not comply with the specified dimension of 450mm x 225mm x 225mm and mix ratio of 1:8 as specified by NIS. The authors developed a regression model that has the weight of sand, weight of water and weight of cement as the independent variable while compressive strength as the dependent variable.

Anya and Osadebe (2015) replaced river sand with quarry dust to ascertain its impact on split tensile strength, water absorption, flexural strength and compressive strength of sandcrete blocks at percentages ranging from 0 to 40 at cement/combined aggregate ratio of 1: 6. Their results showed that the inclusion of quarry dust improved the properties, with the maximum improvement being at 40% replacement for all the properties.

Ewa, Ukpata, Egbe and Akeke (2022) investigated the density, compressive strength, water absorption, static modulus, water absorption and thermal conductivity of sandcrete-laterite blocks, using a mix ratio of 1:8, a water-cement ratio of 0.5 and block sizes of 450 x 225 x 150mm. Laterite was added up to 50% replacement of sand using 10% replacement interval. Curing was done for 3, 7, 14, and 28 days. The authors recommended 10% replacement level of sand with laterite.

Afolayan et al., (2017) replaced cement with sawdust ash in the production of sandcrete blocks in various proportions (0%, 5% 10%, 15% and 20%). Cubes were produced using mix ratio 1:4 and water-cement ratios of 0.40, 0.50, 0.55 and 0.60. The cubes were produced with the use of a vibrating block moulding machine with a double (50mm x 50mm x 50mm) mould. The outcome of their study showed that sandcrete blocks with up to 10% SDA replacement at water-cement ratios 0.55 and 0.60 can be used for non-load bearing walls.

Popoola et al., (2019) investigated the properties of foamed sandcrete solid block (FSSB) with varying percentage of sand replacement with fly-ash. These properties include workability, wet and dry density, stability, water absorption capacity and compressive strength. As percentage replacement increased, the compressive strength reduced, yet the 28-day compressive strength of 2.77N/mm^2 obtained from 50% sand replacement with fly-ash at the designed density of 1500kg/m3 meets the minimum strength requirement for classification as a non-load bearing wall unit. It falls between 2.5N/mm^2 and 3.45N/mm^2 as recommended by Nigerian Industrial Standard (NIS).

Akorli et al., (2023) studied the effect of partially replacing pit sand with quarry dust on compressive strength of sandcrete blocks. The authors considered the sand replacement at 20%, 30%, 40%, 50%, 60%, 70% and 80%. The maximum compressive strength of 1.46N/mm^2 was obtained at 20% replacement of pit sand with quarry dust at 28days of curing.

Although Fapohunda et al., (2016), Ogarekpe et al., (2017) and Akinleye et al., (2020), employed crushed cow bones as partial replacement for fine aggregate, their work did not capture its effect on properties of sandcrete blocks. Their study was centered on concrete production. The authors studied the effect of water-cement ratio on CCB as partial replacement for fine aggregate and the effect of the bones on compressive strength of concrete. Gautam et al., (2012) employed glass wastes as fine aggregate in concrete. Sandcrete blocks were not addressed. The absence of much studies using CCB and WG for partial replacement of sand in production of sandcrete blocks distinguishes this study and this gap is worth filling.

Ahmad et al., (2023) created three models that predicts the compressive strength of concrete that contains waste glass as a substitute for sand. These models include a linear regression, a non-linear regression and an artificial neural network (ANN) model. Different statistical tools, such as root mean squared error, scatter index, OBJ value, mean absolute error and coefficient of determination were used to evaluate the accuracy of these models. Their study showed that exceeding 15% sand replacement can have a negative impact on the compressive strength of the concrete. There was no consideration for sandcrete blocks.

Several studies have been done on the effect of partially replacing fine aggregate with agro-industrial waste materials on the properties of sandcrete blocks. More attention is drawn towards the adoption of crushed cow bones and waste glasses as the amount of generated waste glass will increase due to the increasing demand for glass components. Also there is an enormous production of beefs by slaughterhouses in the country. Annually, Nigeria produces over 14 million cows due to the growing demand for cow meats (Aweda, Omoniyi and Ohijeagbon, 2018; Oyejide, Adetola and Lawal, 2022). And in the next three decades, Nigeria's population will increase swiftly (FAO, 2019).

This study is aimed at ascertaining the feasibility of using available raw materials such as crushed cow bones and waste glasses as partial replacement materials for sand in the production of sandcrete blocks. The objectives of this study is to investigate the effect of crushed cow bones and waste glasses on the compressive strength and water absorption of sandcrete blocks and to compare their outcome. This study has practical implications on sustainable infrastructural development as it enhances production cost of sandcrete blocks and reduces environmental pollution emanating from the dumped materials, coupled with its scientific contribution to the understanding of sandcrete blocks behaviour.

2.0 Material and methods

2.1 Materials

The materials used for this work are cement, water, sand, crushed cow bone and waste glass. Potable water obtained from a borehole was used in all the processes of manufacture and curing of blocks. Crushed cow bones (CCB) were obtained from Ndoro abattoir at Umuahia, Abia State. The cow bones were washed, cleaned and sun-dried in open field for fourteen days where flesh and dirt were removed. It was then broken down into smaller pieces with a medium-sized hammer. The broken pieces of bone were then taken to the mechanical workshop at Federal University of Technology, Owerri (FUTO), where it was crushed to fine aggregates employing a locally fabricated hammer mill machine. The waste glasses (WG) used herein were waste bottles obtained from the dumpsite of Crunches Restaurant, Umuahia. The labels and corks were removed from the waste bottles and they were washed, crushed and screened to produce the suitable design gradation.

BUA brand of Ordinary Portland cement which conformed to NIS 444(2003), was used. River sand was obtained from Otamiri River in Imo State. The sand, CCB and WG were sieved through 10mm British Standard test sieve to remove cobbles to conform to the requirements of BS 882 (1992). The water was fetched from Concrete Laboratory of Civil Engineering Department, FUTO. The water used was fresh, odorless and free from any kind of organic matters.

2.2 Methodology

2.2.1 Production of Sandcrete Blocks

Preliminary tests such as sieve analysis, bulk density and specific gravity were conducted on the constituent materials to ascertain their suitability for sandcrete block production. Batching was done by weight. River sand was replaced with crushed cow bones (CCB) and waste glass (WG) at percentages ranging from 0 to 50 at cement/combined aggregate ratio of 1:6 (one portion of cement to six portions of sand). Mixing of the constituents was done manually using shovels. First, the sand, CCB and WG which had been previously completely dried were mixed homogeneously. Cement was then added and the whole process of mixing continued until a uniform mix was obtained. Water was finally added and the mixing continued until the colour of the paste was unvarying. The blend was then loaded into the metal moulds where they were compacted and demoulded immediately. CCB-sandcrete blocks were produced separately; also WG-sandcrete blocks were produced independently. Seven hollow blocks of dimension 450 x 225 x 225mm were produced for each percentage sand replacement. A total of 168 hollow blocks were produced, 84 blocks for sand-CCB-blocks and 84 blocks for sand-WG-blocks. The blocks were moulded manually and were tested after curing by water sprinkling for 7, 14, 21 and 28 days, twice daily.

2.2.2 Sample Testing

2.2.2.1 Compressive Strength Test

The compressive strength refers to the ability of the sample to withstand an axially applied load, whether on the bed-face of the block or on the edge. With the aid of the compression testing machine, the test for compressive strength of the sandcrete blocks was done in accordance with NIS 87 (2004). The compressive strength Cs of the blocks were determined from the expression in equation 1.

$$\text{Compressive Strength } (C_S) = \frac{\text{Crushing Load (N)}}{\text{Effective surface area of the block (mm}^2\text{)}} \qquad (1)$$

2.2.2.2. Water Absorption Test

This refers to the weight of water the block sample absorbs when immersed in water at a normal temperature for the stated length of time. The test was done as recommended by BS EN 771-1:(2011). The cured blocks were dried to constant mass after which they were completely immersed in water for 24 hours. The blocks were weighed after removing the surface water with a towel. The water absorption, (W_a) of the block was calculated as the difference between the mass of the saturated block, M_w and the dry mass, M_d expressed as a percentage of the dry mass.

$$W_a = \frac{M_w - M_d}{M_d} \text{ x } 100\% \qquad (2)$$

3.0 Results and Discussions

3.1 Characterization of constituents

The values of coefficient of gradation, Cc, and coefficient of uniformity, Cu, obtained from Fig. 1 for the river sand are respectively 0.88 and 2.87. These values indicate that the sand is well graded (Cc is approximately 1) but with a small range of particle size. The corresponding values for the crushed cow bone (CCB) and waste glasses (WG) are

0.64 and 2.86, 0.76 and 2.56 respectively. The aggregates also fall into zone 2 of the grading requirements of NIS 87 (2000) for fine aggregates and are suitable for block production.

The results of the specific gravity of the materials used and their other attributes were presented in Table 1. These values fall within the range specified by Neville, (2011) for natural aggregates. The results of the specific gravity of the river sand, crushed cow bone and waste glasses in Table 1 are within the acceptable limits for aggregates specified by ACI Education Bulletin (2007), ranged from 2.30 to 2.90. Based on these, they were considered suitable aggregates for production of sandcrete block.

Table 1. Physical Attributes of Constituent Materials

Physical Properties	Sand	CCB	WG
Specific gravity	2.66	2.41	2.53
Bulk density compacted (kg/m^3)	1568	1426	1274
Colour	Off-white	Filemot	Light-grey
Moisture content (%)	0.92	1.2	0.89

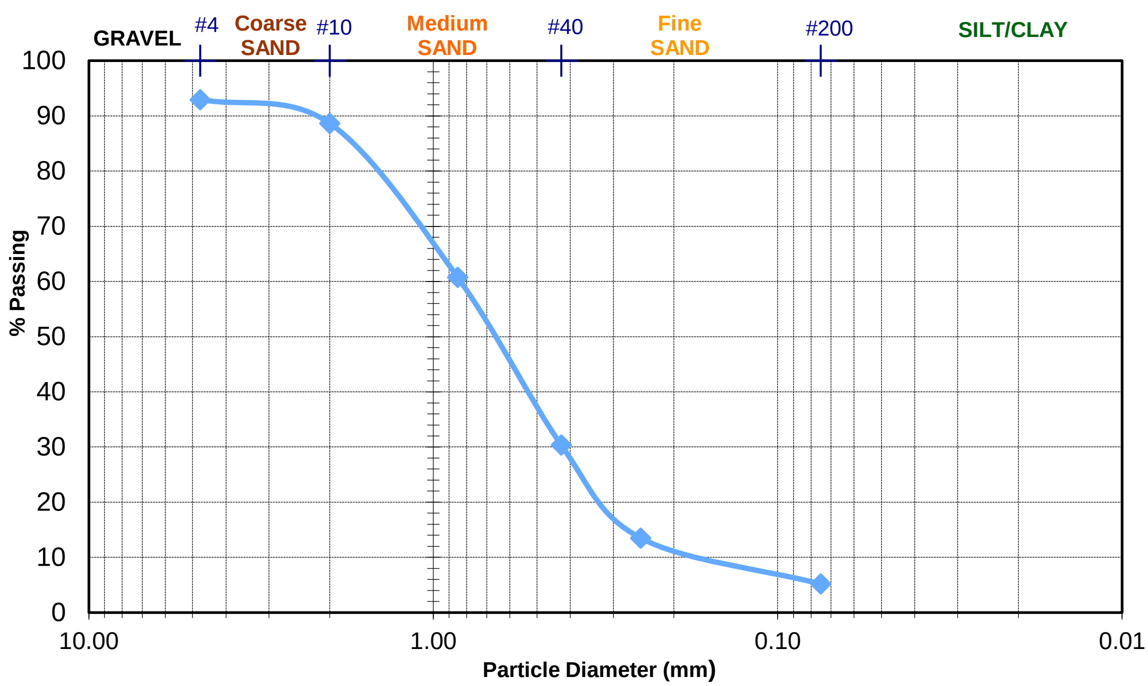

Figure 1: Particle Size Distribution of sand

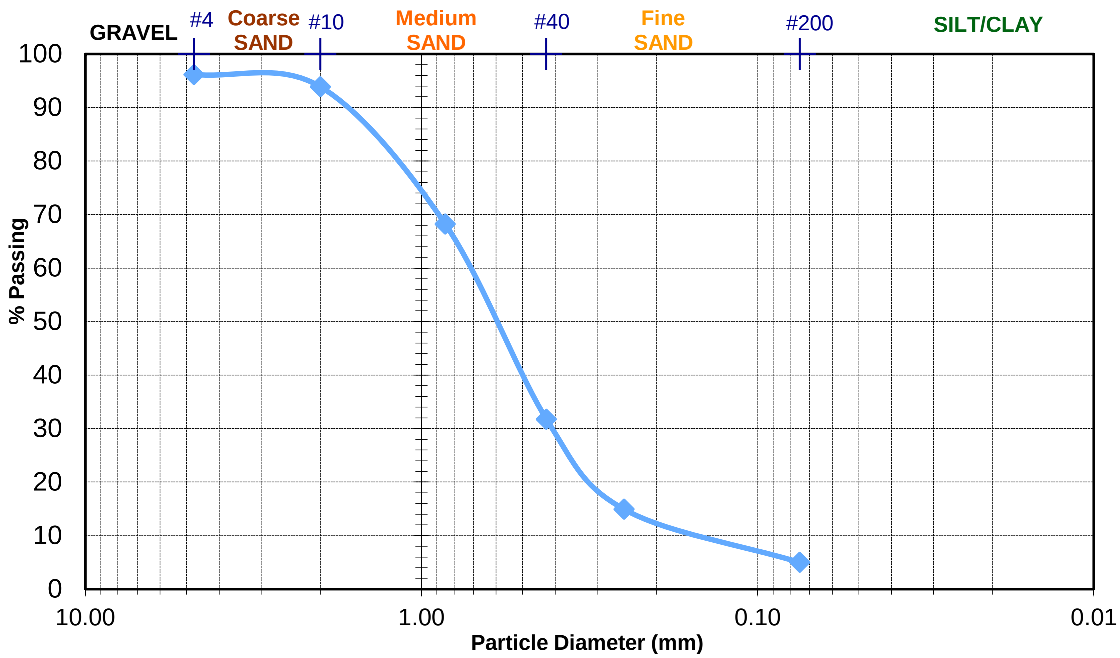

Figure 2: Particle Size Distribution of Crushed Cow Bones

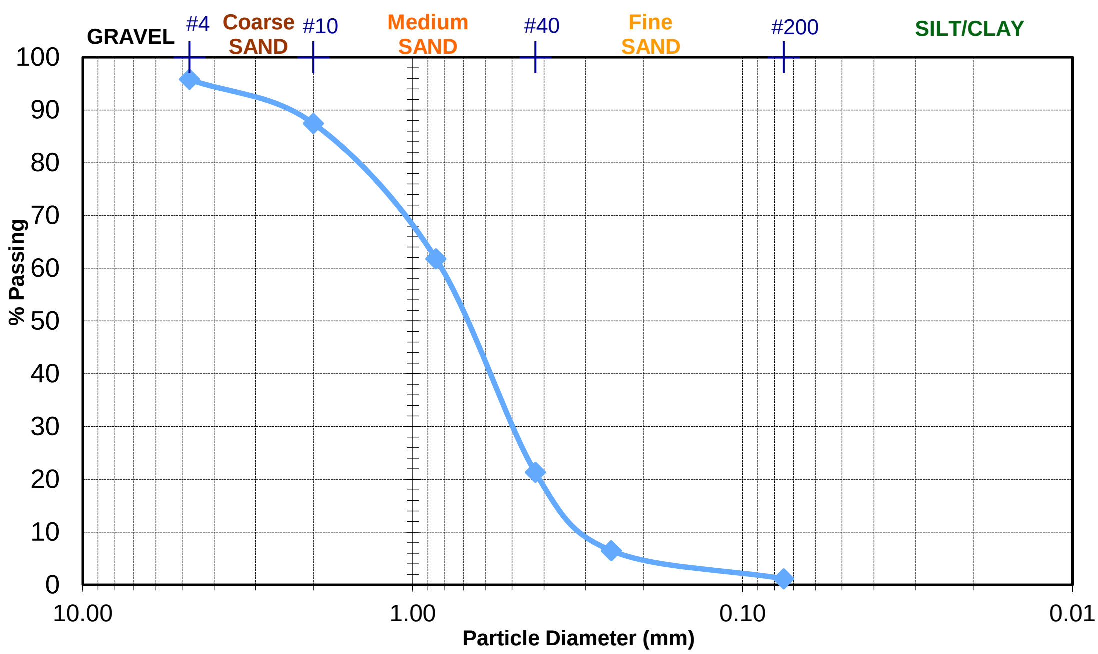

Figure 3: Particle Size Distribution of Waste Glasses

3.2 Results of compressive strength test

The results of compressive strength test of CCB and WG sandcrete blocks were displayed in Figures 4 to 7. The compressive strength of CCB-Sandcrete blocks were higher compared to those of WG-Sandcrete blocks. At all curing ages, as the sand replacement percentage increased, the compressive strength increased for CCB-Sandcrete blocks, and decreased for WG-Sandcrete blocks. The continuous increase in strength with increase in percent replacement of sand, up to 50% of CCB, is similar to the results obtained previously by Anya and Osadebe (2015), also Nagabhushana and Sharada (2011) albeit for mortar and concrete cubes. This rise in strength is contrary to the findings of Fapohunda et al., (2016) and Ogarekpe et al., (2017) as they employed CCB for concrete production. The continuous reduction in strength with increase in percent replacement of sand, up to 50% of WG, is similar to the results obtained previously by Popoola et. al., (2019).

From Figure 4, at 7-days curing age, the strengths were 3.25 N/mm^2, 3.53 N/mm^2, 3.76 N/mm^2, 3.91 N/mm^2, 4.45 N/mm^2 and 4.71 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with CCB respectively, while the strengths were 3.13 N/mm^2, 2.85 N/mm^2, 2.76 N/mm^2, 2.42 N/mm^2, 2.32 N/mm^2 and 2.29 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with WG respectively. This represent 8.62%, 15.69%, 20.31%, 36.92%, and 44.92% increase in strength from the control; for 10%, 20%, 30%, 40% and 50% sand replacement with CCB respectively. This represent 8.95%, 11.82%, 22.68%, 25.88%, and 26.84% reduction in strength from the control; for 10%, 20%, 30%, 40% and 50% sand replacement with WG respectively.

From Figure 5, at 14-days curing age, the strengths were 3.32 N/mm^2, 3.49 N/mm^2, 3.73 N/mm^2, 3.98 N/mm^2, 4.67 N/mm^2 and 4.83 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with CCB respectively, while the strengths were 3.24 N/mm^2, 2.92 N/mm^2, 2.84 N/mm^2, 2.61 N/mm^2, 2.49 N/mm^2 and 2.36 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with WG respectively. From Figure 6, at 21-days curing age, the strengths were 3.56 N/mm^2, 3.81 N/mm^2, 4.26 N/mm^2, 4.50 N/mm^2, 4.74 N/mm^2 and 5.01 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with CCB respectively, while the strengths were 3.62 N/mm^2, 3.23 N/mm^2, 3.01 N/mm^2, 2.98 N/mm^2, 2.66 N/mm^2 and 2.47 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with WG respectively

From Figure 7, at 28-days curing age, the strengths were 4.23 N/mm^2, 4.67 N/mm^2, 4.83 N/mm^2, 5.12 N/mm^2, 5.50 N/mm^2 and 5.67 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with CCB respectively, while the strengths were 3.86 N/mm^2, 3.34 N/mm^2, 3.12 N/mm^2, 3.07 N/mm^2, 2.95 N/mm^2 and 2.82 N/mm^2 for 0%, 10%, 20%, 30%, 40% and 50% sand replacement with WG respectively

As for 50% sand replacement with CCG blocks and WG blocks, the compressive strength was 4.71 N/mm^2 and 2.29N/mm^2, and 5.67 N/mm^2 and 2.82 N/mm^2 at 7-days and 28-days curing age respectively, both satisfied the minimum compressive strength of 1.8 N/mm^2 and 2.5 N/mm^2 at the curing age of 7-days and 28-days respectively for conventional sandcrete block for building wall unit as allowed by Nigerian Industrial Standard (N.I.S). The 2.82 N/mm^2 compressive strength value for 50% replacement levels still qualified the WG-Sandcrete blocks used for this investigation to be classified as non-load bearing solid block (BS EN 12390-3. 2009).

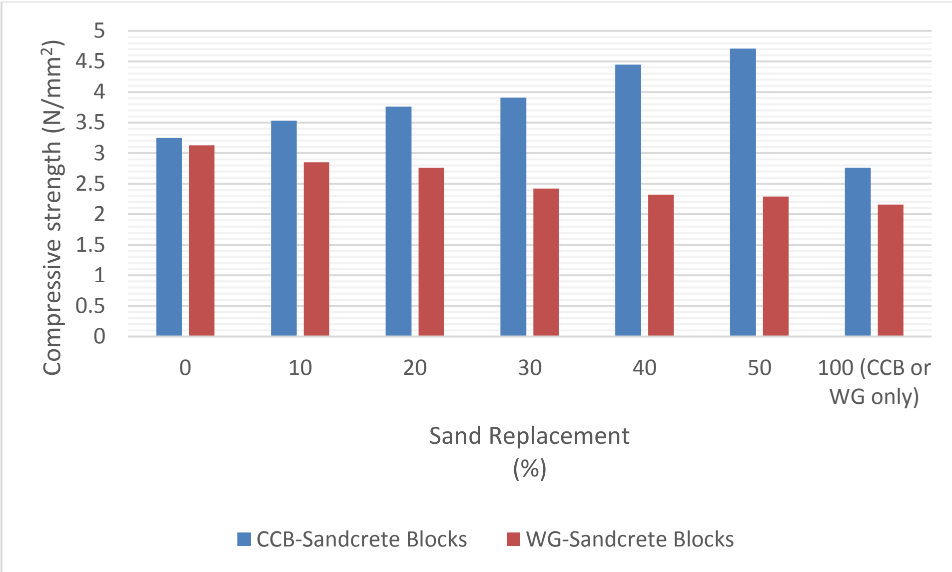

Figure 4: Variation of the Compressive Strength with percentage replacement at 7 days curing.

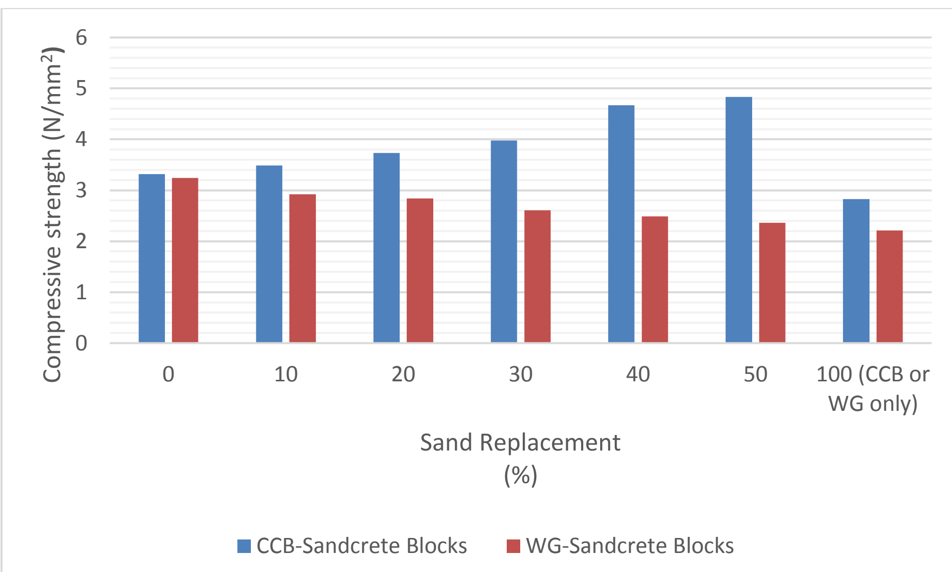

Figure 5: Variation of the Compressive Strength with percentage replacement at 14 days curing.

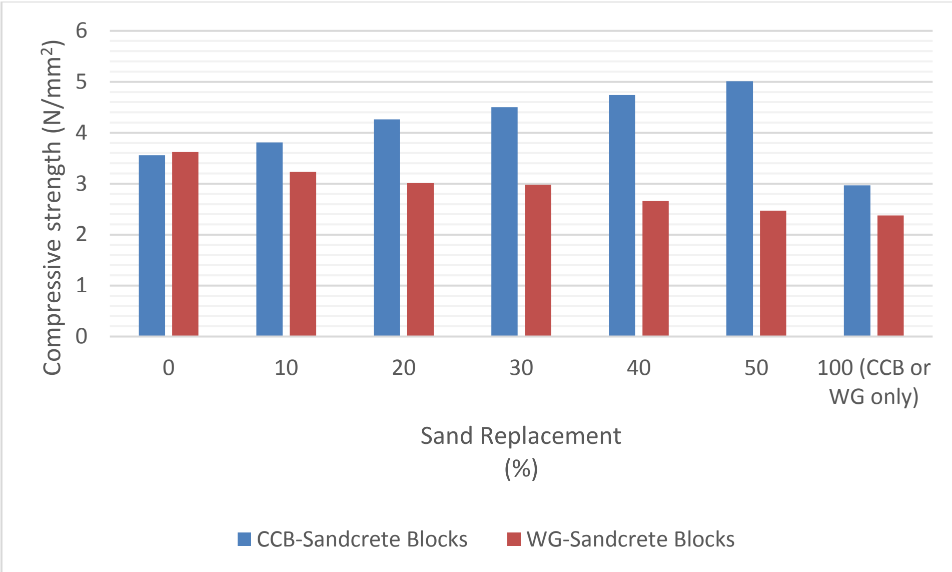

Figure 6: Variation of the Compressive Strength with percentage replacement at 21 days curing.

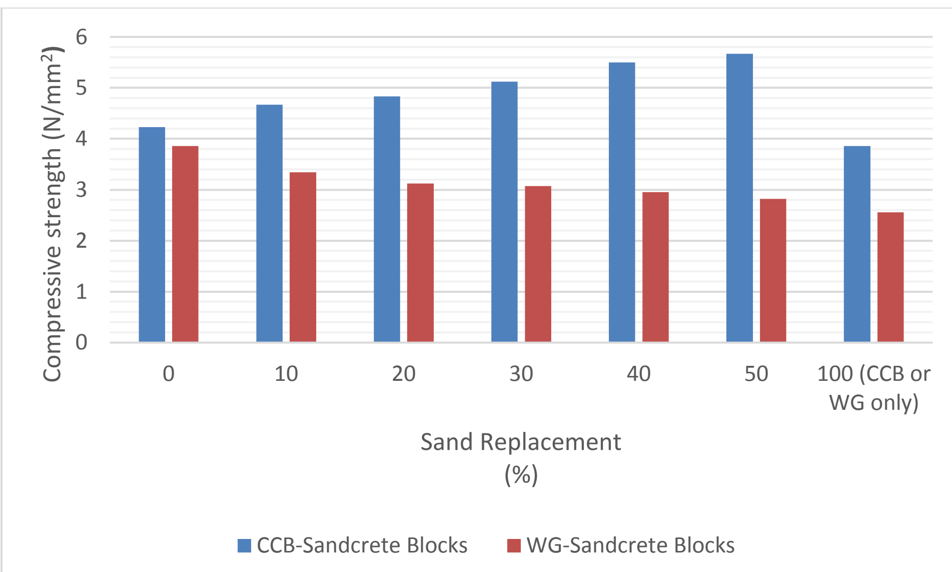

Figure 7: Variation of the Compressive Strength with percentage replacement at 28 days curing.

3.3 Results of water absorption test

From the results displayed in Figure 8, it is noticed that the water absorption rate of CCB-sandcrete blocks increased as the CCB content increased and also as the curing days increased. The highest water absorption value 10.67 % obtained at 28 days curing for CCB-sandcrete blocks was within the allowable limit, as the maximum water absorption requirement is 12% as recommended by the NIS 87 (2004). The higher water absorption rate of CCB-sandcrete blocks could be traceable to the fibre content in the animal bones and the large void ratio within the block which results to high water permeability. This outcome was similar to the study of Ugwuishiwu et al., (2013) and

Esegbuyota et al., (2019). Shrinkage of blocks after drying, block cracking, joints opening are possible defects that may occur when the water absorption rate exceeds beyond the appreciable limit.

In Figure 9, WG-sandcrete blocks showed a different outcome. The water absorption capacity of the block decreased as the waste glass content increased. This outcome was similar to the study of Anya and Osadebe (2015) whose study employed quarry dust as partial replacement of sand. The water absorption rate of WG-sandcrete blocks increased as the curing periods increased.

From Figure 8, it was observed that the water absorption at 50% replacement was 53% greater than and 4% lower than when only sand (0% replacement) and crushed cow bone (100% replacement) were used respectively. While in Figure 9, the water absorption at 50% replacement was 27 % and 38 % lower than when only sand (0% replacement) and waste glasses (100% replacement) were used respectively. All values obtained from both CCB and WG sandcrete blocks fell below the maximum NIS stipulation. Hence, the blocks are durable and can resist the elements of weather with normal protection.

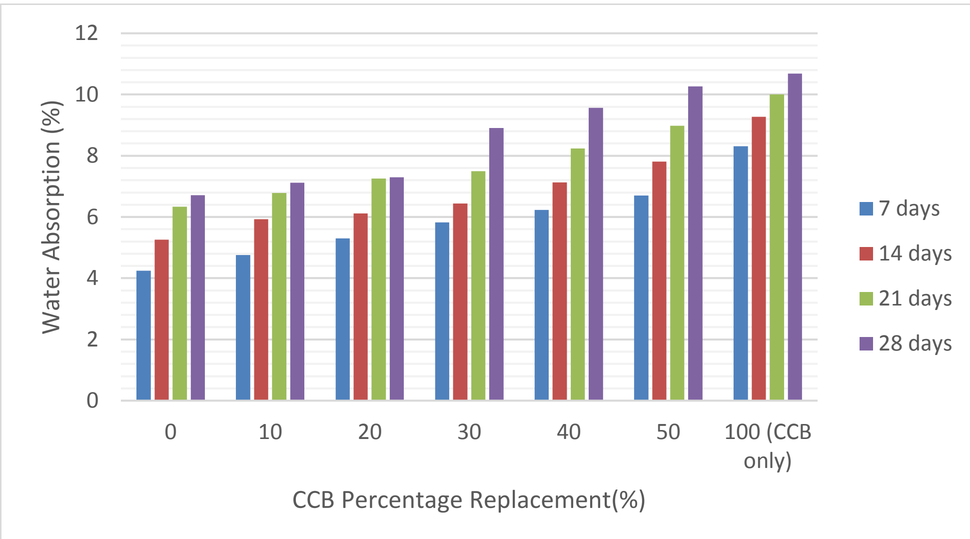

Figure 8: Water absorption capacity of CCB-sandcrete blocks at varying curing days.

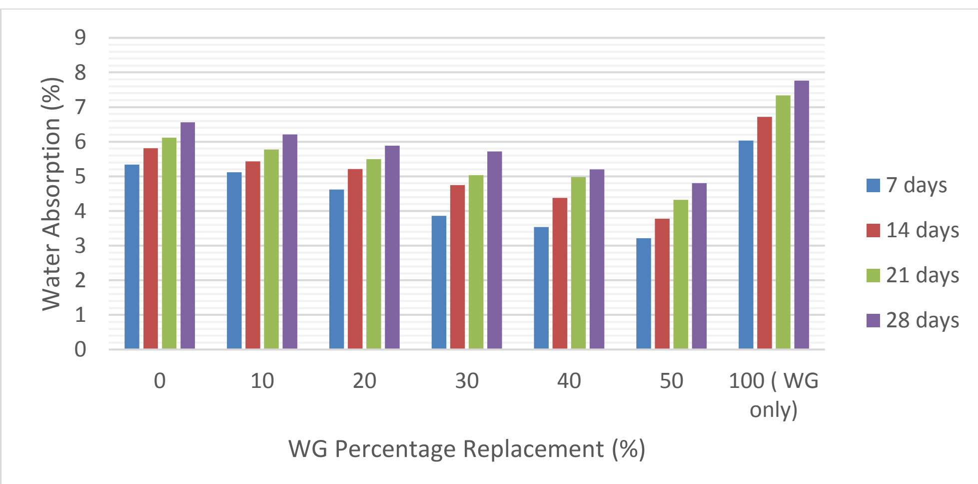

Figure 9: Water absorption capacity of WG-sandcrete blocks at varying curing days.

4.0. Conclusion

This study presented the effect of partial replacement of sand with crushed cow bone and waste glasses on properties of sandcrete blocks. CCB and WG were added up to 50% replacement of sand. The CCB-Sandcrete blocks had greater compressive strength than those of WG-Sandcrete blocks. The compressive strength increased for CCB-Sandcrete blocks, and decreased for WG-Sandcrete blocks at each rise in the percentage of sand replacement for the entire curing periods. The 2.82 N/mm^2 compressive strength value of WG-Sandcrete blocks at 50% replacement levels is 12.8 % greater than the minimum requirement of 2.5 N/mm^2 by the Nigerian Industrial Standard Code for individual blocks and 50.3 % less than the 5.67 N/mm^2 compressive strength value of CCB-Sandcrete blocks. Both CCB and WB sandcrete blocks conformed with the minimum standard requirement for compressive strength value of 2.5 N/mm^2 and 3.45 N/mm^2 for non-load resisting wall and load resisting walls. All water absorption values obtained from both CCB and WG sandcrete blocks fell below the maximum NIS stipulation of 12%. Therefore, CCB and WG can be used to partially replace sand in the production of sandcrete blocks. The adoption of crushed cow bones and waste glass materials for construction works will not only reduce the use of natural material in construction but also will increase public awareness of the problem of waste and benefits of recycling. It will also reduce waste disposal costs, emanating from the rise in landfill tax.

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