Recycling of animal bone as partial replacement for coarse aggregate in lightweight hollow sandcrete blocks

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Abstract. Animal bone waste (ABW) is hazardous to the environment and necessitates a sizable area for disposal. This study aims to employ animal bone waste (ABW) in functionalised compact concrete as a partial substitution for cementitious materials, the source of which are both unswerving and appropriate for substitute preventive solutions promotes the industry's ecological sustainability by minimizing and reducing the negative impact of the concrete industry due to the explosive usage of raw materials. As a result, this paper examines the impact of using crushed animal bones as coarse aggregates in place of sand and cement in the production of concrete. With an improved step level of 10% through cement mass, ABW was applied at a percentage range of 0 to 40%. Bone's various characteristics in its fresh and hardened states were looked examined. A Sieve shaker machine was employed to sieve the bone after which the bone was boiled and dried to remove moisture. To evaluate whether the employed aggregates and crushed animal bone were suitable for use in concrete, a physical analysis of each was performed.

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1 Introduction

Concrete is a widely used building material in the modern world. Along with urbanization and industrialization, there is a steady increase in the need for concrete. Because of this, the manufacture of concrete requires a lot of raw materials and natural resources [1] [2]. A significant amount of agricultural waste and other types of solid material disposal such as animal bones are also creating significant environmental problems [3]. Globally, sandcrete is often employed as an enclosing component and for the construction of homes. Because it offers roofing systems, disaster protection, and structures for human efforts, it is regarded as the foundation of contemporary built environment development [4]. In terms of infrastructure, it significantly contributes to the economic growth of a country. However, these traditional materials are rare and more expensive, particularly cement, which is used as a binding agent in most construction projects [5]. Presently, a variety of waste products are used in place of one or more sandcrete constituent materials. The strategy provided a different way to maximize the use of naturally occurring conventional construction materials while also reducing waste that contributes to environmental deterioration and other associated issues [6]. Equally, the need for natural resources for infrastructure has increased as a result of the rising demand for shelter, facilities, and systems brought on by development, population expansion, and economic advancement [7]. One of the bulky house materials used for the erection of homes is sandcrete blocks. However, research has revealed that the ongoing use of river sand as a raw material for the creation of composite materials for buildings like sandcrete blocks, mortar, and concrete greatly adds to the depletion of natural resources, leading to flooding and the erosion of coastal regions [8] The possibility of using both treated and untreated coconut husk in place of some of the fine aggregates in masonry blocks was investigated by [9]. [10] reported that periwinkle shells are one such example of a marine waste product that can be used as a substitute, viable resource to substitute raw materials in order to limit difficulties with land-filling generated wastes and reduce pollution and manufacturing expenses. In nearly every Local Government Area in Nigeria, block production is carried out on a small- or large-scale industrial basis. Block manufacturing is undoubtedly a successful business if it is properly handled or managed. As a result, resource conservation, inexpensive design, and responsible consumption might all be achieved by the construction sector [11] [12] [13]. Investigations have shown a range of agro-waste products as potential replacements for natural aggregates in the production of construction materials like sandcrete blocks. Glass, plastic, bricks, tires, and bio-waste like palm kernel shells are some of these waste items [14]. They also include waste from building and demolition efforts. The findings of these experiments revealed that by including these materials as elements, the quality of blocks and bricks may be conserved. Additionally, research analyses have shown that pozzolanic recycled materials, including metakaolin, waste glass, ceramic and tile wastes, sawdust, fly ash, sewage sludge ash, rice husk, and clay brick, can be utilized as substitutes for cement to produce high-quality blocks and bricks for building [15] [16] [17] [18]. Studies are also examining ways to supply inexpensive or reasonable construction materials for homes without sacrificing their worth, as well as how to help create a sustainable, neat ecosystem by reclaiming these unwanted items. [19]. Substantial demand for sandcrete blocks and their high production is due to the extensive utilsation of these sandcrete blocks. Recent instances of building collapse in Nigeria are heartbreaking and disturbing. A compilation of fatalities and building collapses during the past 12 years (2010-2022) indicates a worrying trend that must be addressed immediately. In the past year, structural failures have claimed the lives of numerous people and destroyed property worth millions of Naira in Lagos State [20]. Approximately Sixty-one (61) incidents of failure in structure in Lagos State between January-December, 2022 were recorded. The use of substandard materials is responsible for the loss. The occurrence is a result of low-valued sandcrete blocks used as enclosing units. Therefore, quality is a vital factor to consider in the sandcrete block's production. This can be achieved by analyzing the materials that make up sandcrete to find out their bulk density, specific gravity, water absorption rate, and moisture content. According to the authors [21] [22], several common agricultural wastes, such as bagasse, rice husk ash, corn cob ash, bamboo leaf ash, corn stalk ash, and palm kernel shell ash, are frequently employed as agro-waste replacement coarse aggregates for sand. Agricultural waste in the form of particulate for concrete matrix composites is becoming increasingly important, and this has benefits for both our manufacturing industries and the environment by turning agricultural waste from agro-processes into valuable raw materials for engineering [23]. Several scholars have made an effort to look into the characteristics of specific ashes at different replacement amounts, grinding times, curing ages, etc. However, [24] Charitha, Athira, Jittin, Bahurudeen, & Nanthagopalan, 2021 similarly investigated the ideal replacement level of each bio-waste ash including sugarcane bagasse ash (SCBA), rice husk ash (RHA), groundnut husk ash (GHA), cassava peel ash (CPA), wheat straw ash (WSA), palm oil fuel ash (POFA), corncob ash (CCA), coconut shell ash (CSA), wood ash (WA), elephant grass ash (EGA), Rice straw ash (RSA), sugarcane straw ash (SCSA), tobacco ash (TA) and bamboo leaf ash (BLA). Thorough comparisons of various ashes were made. A detailed assessment of the mechanical characteristics of mixed concrete with AWAs at various replacement levels is also provided. Most of the bio-waste ashes are discovered to have a large proportion of silica content. However, compared to other AWAs, the silica content of tobacco ash (24%) and groundnut husk ash (21%) is quite small. Additionally, the total of SiO2, Al2O3, and Fe2O3 for RHA, RSA, BLA, and SCBA is greater than 70%, which exceeds the ASTM C618 least prerequisite [25]. In an effort to achieve the viable expansion goals of preserving natural resources through responsible consumption, this study looked into the practicality of recycling waste-crushed animal bones as a possible substitute for fine aggregates in the construction of sandcrete blocks. This is a result of rising construction-related demands for non-renewable conventional aggregates such as river sand, as well as their exploitation and use. The purpose of the current paper is to advance our knowledge in this field by examining the effects of employing crushed animal bones as a partial replacement for river sand and stone dust on the weight, density, strength, and tendency for water absorption of hollow sandcrete blocks. The examined literature lists a few agricultural waste products that have proved useful for the partial replacement of coarse aggregate, including aloe vera, bean pod ash, cow horn, groundnut shells, coconut shells, rice husks, and so on. However, pulverised bone was found to have excellent reinforcing properties. They also improved the strength qualities of the different mixtures created in comparison to the as-cast materials. This study also establishes the valorization of agro waste, evaluates the compressive strength of bone concrete in fractional substitutes for gravel, and reduces the economic value (production cost) of the sandcrete block.

2 Materials

2.1 Description of Raw Materials

Fine sand, cement, crushed bones, and water are the main ingredients in concrete blocks as displayed in Figures 1 - 3. The makeup of the raw materials and the manufacturing procedure define the characteristics of sandcrete blocks and bricks. The most expensive raw material utilized to make concrete bricks is cement. Sandcrete blocks are made by combining three composite ingredients: fine sand, cement, and water. However, recycled waste crushed animal bones obtained from an open market are employed in this study.

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Figure 1: Sand and Stacked cement

Figure 2: (a) Whole Bones (b) Crushed Bones

Figure 3: Water

2.2 Microstructural characteristics of various agro-waste ash types

Figure 4 depicts the microstructural analysis of different agro-waste ashes including Sugarcane bagasse ash (SCBA), Rice husk ash (RHA), Palm oil fuel ash (POFA), Corncob ash (CCA), Coconut shell ash (CSA), Wood ash (WA), Groundnut husk ash (GHA), Cassava peel ash (CPA), Wheat straw ash (WSA), Elephant grass ash (EGA), Rice straw ash (RSA), Sugarcane straw ash (SCSA), Tobacco ash (TA), and Bamboo leaf ash (BLA). This provides the detailed microscopic structure of the agro waste that will help the enhancement of the quality of sandcrete. The likely flaws and defects in these wastes were carefully examined with the SEM analysis that creates images with high resolution.

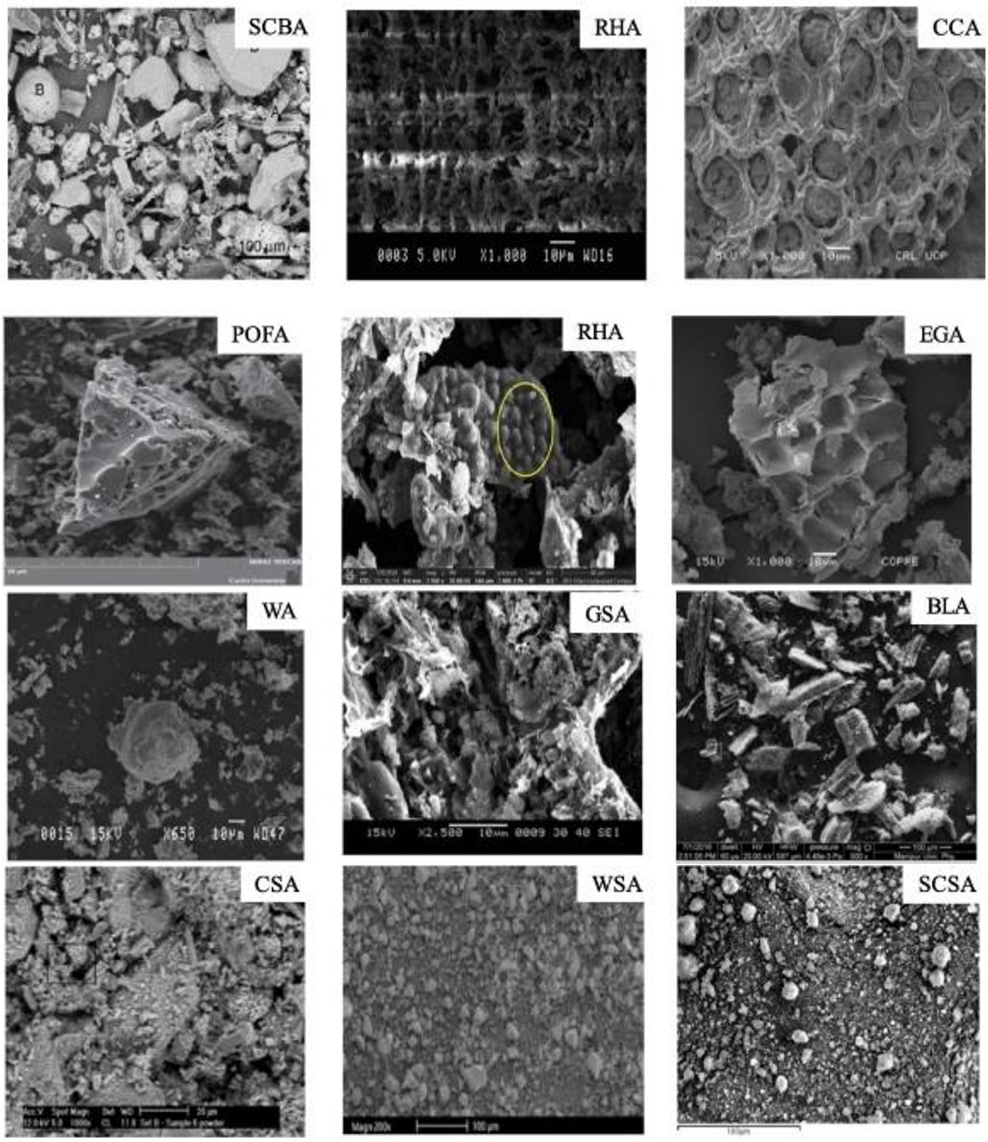

Figure 4: SEM micrographs of different agro waste ashes [24]

3 Experimental Procedure

The crushed bones were sieved to a different particle size using a sieve shaker machine and coarse particle size of 10.25 mm diameter was employed as displayed in Table 1. A cement/sand ratio of 1:6 measured by volume using a suitable engine was employed to cast the sandcrete block as presented in Table 2. Crushed animal bone was substituted for cement at levels of 0, 5, 10, 15, and 20 in a 1:2:4 mix ratio with a water-to-cement ratio of 0.6. Concrete was cast using standard 150 x 150 x 150 mm cubes, and after 28 days, the sample specimens were dried and crushed to assess their compressive strength. A uniform color and evenness are achieved by hand mixing for an extended period of time. In order to obtain the binding, water is introduced for additional mixing using a water hose. A device made of steel is used to fill and flatten the molds, after a shovel was deployed to thoroughly blend the composite components with the addition of the required amount of water. Moulds are pieces of equipment that are made of pre-assembled steel or wooden form boxes that have the requisite measurements and have one end that is open and rests a removable steel or wooden plate at the bottom. The mixtures tested for workability revealed that the slump increased as the quantity of cement substitution increased. The main process involves about six stages, described below.

3.1 Microstructural characteristics of crushed bones

Figure 5 represents the SEM micrographs of crushed bones at various magnifications, which gives a comprehensive understanding of the structure of the ground bones. The microstructural examination of crushed bones is crucial because it has a substantial impact on the functionalization of the mixed cementitious system including crushed bones, specifically its stability and strength properties. Considering the asperities of the different agro-waste ashes shown in Figure 5 can help one predict how the ashes would behave when mixed with concrete.

Figure 5: SEM micrographs of crushed bones at (a) 100 µm (b) 200 µm

Table 1. Particle sizes of crushed cow bone (Sieve Shaker Machine) Department of Civil Engineering, Covenant University, Ota, Oct. 11, 2022)

Particle Sizes (mm)	10.25 mm	6.55 mm	4.75 mm	2.36 mm	1.00 mm
Weight (g)	50g	135g	405g	1215g	3515g
Particle Sizes (mm)	850 µm	600 µm	425 µm	300 µm	150 µm
Weight (g)	473g	807g	665g	503g	644g

Table 2. Weight of bone and sand substitute

Level of Substitute (%)		Cement: sand ratio	Mixing ratio of sand and bone		Ratio of water/binder
			Sand (kg)	Bone(kg)	
Sand 100%	Bone 0%	1:6	120	0	0.42
Sand 95%	Bone 5%	1:6	114		0.84
Sand 90%	Bone 10%	1:6	108	12	1.26
Sand 85%	Bone 15%	1:6	102	18	1.68
Sand 80%	Bone 20%	1:6	96	24	2.1
Sand 75%	Bone 25%	1.6	90	32	2.1

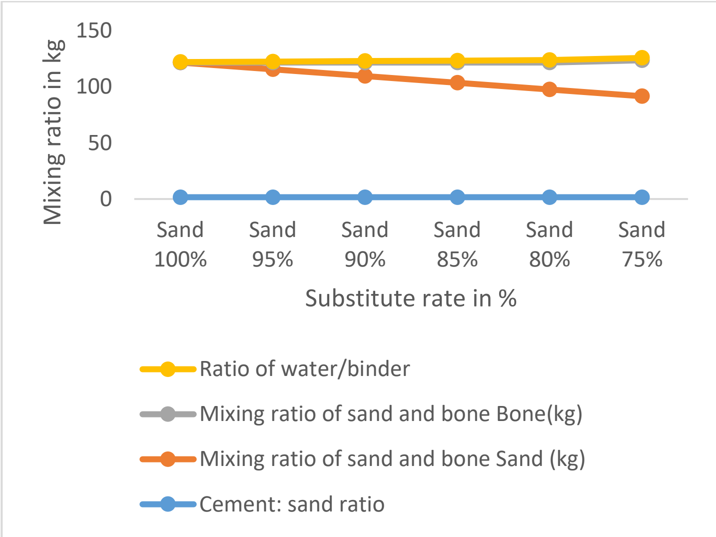

Figure 6: Weight of bone and sand substitute

4 Results

4.1 Compressive Strength

As the compression machine is linked to the primary and the indicator, the perusing alignment scale is changed in accordance with the zero checks. The weight of the metallic sheet placed on the square (to distribute the load) is increased by the compressive strength prediction made by the machine, which is detailed as the compressive strength prediction of the block molded. The block was measured, noted, spread with bolts, handled into the pressure region, and bolted with the block brought together inside the pressure region after being gauged and noted. By turning the control (knob) and applying electric pressure to the block, the compressive load is applied. The indicator monitoring the compressive strength estimation in kilo-Newton (KN) rapidly rises until it reaches a maximum value. The most extreme worth not long before the indicator starts to fall or the indicator perusing when obvious breaks are clear on the block is recorded as the compressive strength of the block which is demonstrated by an alternative pointer in the previous case. To release the compressed block, the red control (knob) ii was pressed after the compression was turned off. The compression was then turned off by pressing the control device (knob) in order to discharge the squashed block.

The relationship below was used to calculate the compressive strength (Eq.1):

$$\boldsymbol{CS} = \boldsymbol{F}/\boldsymbol{A}[N\ /mm2]\ (1)$$

where: F - failure force, in N;

A - Net area of crashing, in mm2.

Table 2 displays the assessment outcome of the compressive strength of wood cement of this research work. The mean compressive strength of one hundred percent (100%) of sand and zero percentage (0%) of bone substitute was (2.80N/mm^2). This was done sequentially by having (1.59N/mm^2) 95% sand and 5% bone substitute; (0.55N/mm^2) for 90% sand and 10% bone substitute; (0.43N/mm2) for 85% sand and 15% bone substitute; (0.24N/mm^2) for 80% sand 20% bone substitute and (0.20N/mm^2) for 75% sand 25% bone substitute. Fig 8 shows the compact machine in use while Fig 9 displays blocks produced using 75% sand and 25% bone substitute while Fig 10 displays blocks made using 100 percent sand and 0 percent bone substitute and Fig 11 represents the stacked cured blocks.

Table 3. Compressive strength assessment findings

Unit of Substitute (%)	Block Number	Block Net area (mm^2)	Load Crushing (kN)	Compressive strength of block (N/mm^2)	Block Mean compressive strength (N/mm^2)
0	1	36900	114	3.09	2.80± 0.20
	2	36900	112	3.04	
	3	36900	108	2.93	
	4	36900	108	2.93	
	5	36900	104	2.82	
	6	36900	100	2.71	
5	1	36900	62	1.68	1.59 ± 0.08
	2	36900	60	1.63	
	3	36900	58	1.57	
	4	36900	58	1.57	
	5	36900	56	1.51	
	6	36900	56	1.51	
10	1	36900	18	0.49	0.55 ± 0.02
	2	36900	18	0.49	
	3	36900	16	0.43	
	4	36900	16	0.43	
	5	36900	15	0.41	
	6	36900	12	0.33	
15	1	36900	16	0.43	0.43 ± 0.06
	2	36900	15	0.41	
	3	36900	14	0.38	
	4	36900	14	0.38	
	5	36900	8	0.22	
	6	36900	8	0.22	
20	1	36900	16	0.43	0.24 ± 0.09
	2	36900	15	0.41	
	3	36900	14	0.38	
	4	36900	14	0.38	
	5	36900	8	0.22	
	6	36900	8	0.22	
25	1	36900	15	0.41	0.20 ± 0.12
	2	36900	14	0.41	
	3	36900	14	0.38	
	4	36900	8	0.38	
	5	36900	8	0.22	
	6	36900	6	0.22	

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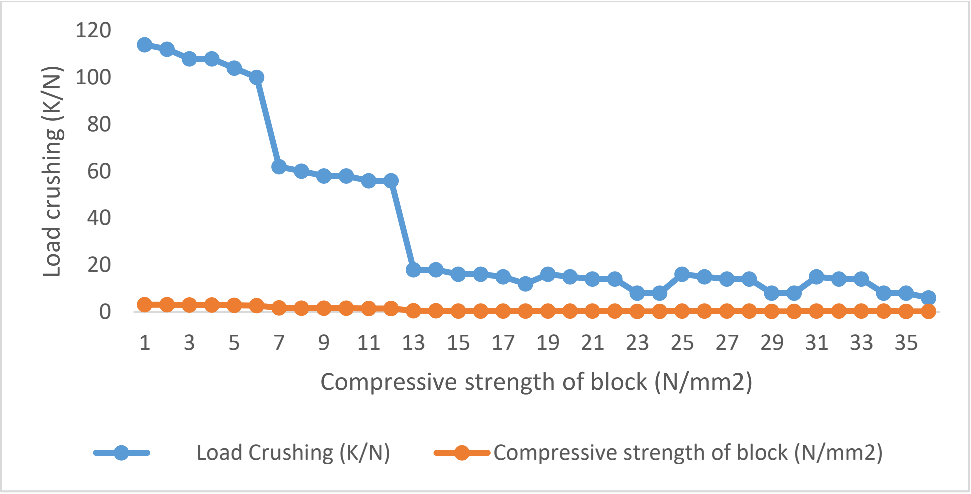

Figure 7: Load crushing against the compressive strength of the blocks

Figure 8: Machine Compact

Figure 9: Curing section of the blocks made with bone and Block produced from 100% sand

Figure 10: Stacked cured blocks

The assessment showed that at the twenty-eight days wetting stage, the compressive strength of blocks molded with 100 (%) percent sand and 0 (%) bone from the outcome obtained is in accordance to the lowest specification for load-bearing parapets of 2.0N/mm2. Also, in accordance to National Building Code (2006) and 2.75N/mm2 (Building code of Ghana (1989) [27] [28]. In one hundred percentage (100%) sand and 0% bone substitute there was an improvement in compressive strength recorded as a result of the tougher combination ratio of 1:6 (cement:sand) utilised with the absence of bone. The assessment showed that a rise in bone content lowers compressive strength as displayed in Fig 9. Therefore, the production of affordable and lightweight sandcrete blocks is achievable using bone as a composite

5 Conclusion

The available local content materials were utilised for the making of blocks as part of an on-going research for the production of sandcrete blocks. The cost of production was also reduced due to the application of locally available materials used. The use of agro waste like bone will be embraced by Nigerian block producers for the availability of the local materials or low cost of making or acquirement, simplicity of manufacture and maintenance, minimal cost of maintenance of the fabricated block machine joined with a rise in the quality and number of block. However, a 1:6 proportion of cement/sand ratio measured by volume was used to cast the sandcrete block to ensure quality, unlike most block makers who normally use a ratio of 1:8. It was observed that a rise in the percentage substitute of bone for sand increases the water ratio. The assessment showed that an increase in bone content lowers compressive strength. The inappropriate mix proportions used by the producers will usually lead to a reduction in the quality of the blocks. The low quality of blocks is due to some factors like poor curing and bad production techniques.

6 Recommendation

The price of cement should be subsidized to encourage the block producers so as to desist from the act of cutting corners and be honest with their production activities. The use of other agro waste like bone and rice husk for production of low cost sandcretes block should be encouraged. This on the other hand will allow substitute of cement with rice husk ash (RHA) which will encourage reduced cost of production. Control production processes and quality of the blocks must be controlled by the regulatory and enforcement bodies which have been authorised to endorse certified producers to properly ascertain the quality of these blocks before they are sold. Producer found selling blocks of low quality which has not met up with the minimum required standards should be sanctioned.

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