

Optimum Compressive Strength of Structural Concrete Containing Coarse Aggregates and Crushed Cow Bones

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Abstract:

An exploratory study was carried out on the suitability of crushed cow bones (CCB) as a partial replacement for coarse aggregates in the production of structural concrete. The physical properties of CCB and locally available aggregates (fine and coarse) were determined and compared. The properties investigated are specific gravity, bulk density, sieve analysis, water absorption and compressive strength. The slump test is used to determine the workability of the fresh concrete. The CCB was used to replace coarse aggregates from 0% to 25% in steps of 5%. A total number of 54 concrete cubes of size 150×150×150 mm with different percentages by weight of coarse aggregate to CCB as coarse aggregate in the order 75:25, 80:20, 85:15, 90:10, 95:5 and 100:0 were cast, cured and crushed at 7, 21 and 28 days. Compressive strength tests showed that 5% replacement of coarse aggregates with CCB in concrete production was quite satisfactory for structural application, producing concretes in the M20-25 grades, as this results in strengths that are not significantly different from the control at various curing ages. From the outcome of this study, 5% CCB can be used as a partial replacement for granite in concrete production for structural uses.

Keywords

Crushed cow bone, coarse aggregate, concrete, density, compressive strength,

1. Introduction

Concrete is the most extensively used construction material worldwide, with billions of tons produced yearly (Meyer, 2009; Qi et al., 2024). It is an artificial composite material typically made of natural aggregates (lime rock, sand and gravel) or crushed rock bound together by binders (cement, lime) and water to form a dense semi-homogenous mass (Collivignarelli et al., 2020). Relatively, by-product aggregates such as fly ash, cinders and burnt furnace slag can be employed where suitable, to improve/reduce the properties to achieve a desired or targeted strength.

Concrete is favoured in the construction industry because, as a fluid material, it can be moulded into a nearly limitless range of shapes and has a relatively low maintenance cost. Nonetheless, studies have shown that concrete production requires abundant natural resources compared to other construction materials (Bala et al., 2015). Moreover, in some developing countries, the need for affordable houses has increased in recent years, leading to research on using by-products and local building materials as construction materials (Abdullahi et al., 2017). Hence, the partial replacement of non-replaceable aggregates with waste materials has been discovered as a remedy to these problems, and their usage is highly encouraged (Arum et al., 2013; Collivignarelli et al., 2020; Edmund et al., 2019; Koganti et al., 2017; Mo et al., 2016; Prusty et al., 2016).

About 23.3 gigatonnes (Gt) of resources are consumed yearly in producing ordinary concrete consisting of 3.8 Gt of cement, 2 Gt of water and 17.5 Gt of aggregates (Miller et al., 2018). In Nigeria, river sand (fine aggregates) and crushed stones (coarse aggregates) are the most common aggregates used in concrete production. However, viable alternatives for replacing these popular aggregate forms are being researched and sourced. The materials used as possible alternatives in partially or fully replacing aggregates include coconut shells, broken bricks, reclaimed asphalt, broken concrete, broken ceramic tiles and recycled glass bottles for coarse aggregate, while pumice, rice husk, manufactured sand, slag sand, powdered glass, fly ash, Quarry dust, processed crushed rock fines, sugarcane bagasse ash, groundnut shell, cork, tobacco waste have been used to replace

fine aggregates ([Adegbemileke et al., 2025](#); [Olorunfemi et al., 2025](#); [Oparinde et al., 2024](#); [Rilwan et al., 2025](#)).

This research investigates some properties of concrete with crushed cow bone (CCB) as a partial replacement substitute for coarse aggregates. Cow bone is an organic waste material freely obtained from Nigerian abattoirs. However, large quantities are produced yearly across Nigeria without any properly defined means of sustainable and environmentally friendly disposal. Its abundance has led to severe environmental concerns and could be readily used to partially replace the coarse aggregate constituent of concrete.

A lot of studies have been carried out by researchers to investigate the use of cow bones and their derivatives to replace the constituent materials of concrete in concrete production. Pulverised cow bone was used as a pozzolanic material to replace cement in concrete production by [Falade et al. \(2012\)](#). [Subrahmanyam and Sri \(2016\)](#) used silica fume, animal bone and fly ash to investigate the partial replacement of coarse aggregate and cement in concrete production and discovered that silica fume increases the mechanical properties of the concrete. [Ogarekpe et al. \(2017\)](#) investigated the suitability of burnt crushed cow bone (BCCB) as a partial replacement for fine aggregate. They discovered that the BCCB could replace fine aggregate by up to 50% of the weight in structural works. [Oluborode and Ayeni \(2019\)](#) investigated the compressive strength of concrete using cow bones to partially replace coarse aggregate using a 1:2:4 mix ratio. They recommended that cow bones could be used to replace coarse aggregate up to 20% in normal-weight concrete. However, their study focused on the production of an M15 grade concrete, which is mostly used as plain cement concrete. This study aims to evaluate the compressive strength of a structurally applicable concrete (in the region of a grade M20-25) produced from a different mix ratio (1:1.35:2.51) by partially replacing coarse aggregates with manually crushed cow bone. The properties to investigate are workability, density and compressive strength.

2. Methodology

2.1 Materials

The material used for this research includes cement, fine aggregate, coarse aggregate, crushed cow bone and water. The Ordinary Portland cement (Grade 42.5) produced in conformity with [BS EN 197-1:2011 \(2011\)](#) was used in this study. Fine river sand with a smooth texture and rounded shape, obtained from Gidan Kwano, Minna, Niger State, satisfying [PD 6682-1:2009+A1 \(2013\)](#) requirements, was used as fine aggregate. The coarse aggregates (crushed granite) with a rough surface texture and angular shape, having a size range of 5mm – 20mm and conforming to [PD 6682-1:2009+A1 \(2013\)](#), were obtained from local vendors along Kpakungu - Gidan Kwano - Bida road in Minna, Niger State.

The CCB used for this research study was acquired from an abattoir in Minna, Niger state. The bones were cleaned (by removing all the attached flesh, muscles, tissue, and fats) and dried, after which they were manually crushed in the laboratory (using a mechanical vice) to achieve the size range of 5 - 20mm (**Figure 1**).



Figure 1: Sample of Crushed Cow Bone (CCB)

The potable mixing water for the concrete was obtained from the borehole within the vicinity of the Civil Engineering laboratory of the Federal University of Technology, Minna, Niger state. This conformed to [BS EN 1008:2002 \(2002\)](#) specifications. The constituents were mixed using a mix ratio of 1:1.35:2.51 (Cement: Fine aggregate: Coarse aggregate) by weight and the water-cement ratio of 0.52. The coarse aggregates were replaced with CCB between 0 – 25% in steps of 5%.

2.2 Experimental Investigations

Preliminary tests were carried out on the aggregates and CCB to determine their properties and suitability for use in concrete production. The properties investigated include sieve analysis, specific gravity, bulk density, moisture content and water absorption test.

- i. Particle size distribution (sieve analysis): This test, commonly referred to as the gradation test, can be summarised as dividing a sample of aggregate into fractions of the same particle size. The test was carried out on the aggregates and the CCB in accordance with [BS EN 933-1:2012 \(2012\)](#) guidelines.
- ii. Specific gravity (G_s): This is the ratio of the mass of a unit volume of material to the mass of the same volume of water at the same temperature. It was carried out on the CCB and aggregates following the [BS EN 1097-6:2022 \(2022\)](#) specifications. The specific gravity was determined using equation (1):

$$G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (1)$$

where, M_1 = mass of vessel (g), M_2 = Mass of vessel + sample (g), M_3 = Mass of vessel + sample + water (g), M_4 = mass of vessel + water only (g)

- iii. Bulk density: This measures the sample's relative compactness and is expressed as the weight of a given material needed to fill a given volume of a container. It

depends on the particle size distribution and shape of the particles, and could either be compacted or un-compacted (loose). The test was carried out on the aggregates and the CCB following the [BS EN 1097-3: 1998 \(1998\)](#) guidelines. It was obtained using Equations 2 and 3.

$$\text{Compacted Bulk Density} = \frac{W_3 - W_1}{V} \quad (2)$$

$$\text{Loose Bulk Density} = \frac{W_2 - W_1}{V} \quad (3)$$

where, W_1 = weight of mould (g), W_2 = Weight of mould + un-compacted sample (g), W_3 = weight of mould + compacted sample (g), V = volume of mould

- iv. Moisture content (Mc): This is the quantity of water above the saturated dry condition of the sample. It shows a relationship between the water in the sample and the weight of the thoroughly dried sample and is expressed on a volumetric or gravimetric (mass) basis. It is measured using the guideline in [BS EN 1097-5:2008 \(2008\)](#) and is computed as follows:

$$Mc = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \quad (4)$$

where, M_1 = weight of empty can (g), M_2 = Weight of can + sample (g), M_3 = weight of can + dry sample (g)

- v. Water Absorption: This is the increase in aggregate mass due to the penetration of water into the pores during a period. It is determined by measuring the decrease in mass of a saturated and dry sample after oven drying for 24 hours. The test was carried out in accordance with [BS EN 1097-6:2022 \(2022\)](#) guidelines and was obtained using Equation 5:
- vi.

$$\text{Water Absorption} = \frac{W_3 - W_2}{W_4 - W_1} \times 100 \quad (5)$$

where, W_1 = weight of container (g), W_2 = Weight of container + sample (g), W_3 = weight of container + wet sample (g), W_4 = weight of container + oven-dry sample (g)

- vii. Slump test. This measures the degree of workability of the fresh concrete mix and was carried out following [BS EN 12350-2:2019 \(2019\)](#).
- viii. Compressive strength test. This measures the strength of the hardened concrete, and was obtained for the hardened concrete in this study using the guidelines in [BS EN 12390-2:2019 \(2019\)](#) and [BS EN 12390-3: 2019 \(2019\)](#).

2.3 Specimen Preparations

The concrete specimens were prepared by partially replacing the coarse aggregate with CCB using a mix ratio of 1:1.35:2.51 (obtained from the mix design using the Council for the Regulation of Engineering in Nigeria (COREN) Concrete Mix Design Manual ([COREN, 2017](#)) and a water-cement ratio of 0.52. The coarse aggregate (granite) was progressively replaced with CCB between 0 – 25% in steps of 5% (Table 1). A total of 54 concrete cubes were cast using the 150mm x 150mm x 150mm steel moulds and allowed to set and harden for 24 hours before demoulding and immersion into curing tanks filled with water. This allowed the curing to take place for the ages of 7, 21 and 28 days, respectively, with the crushing tests taking place after each of the curing ages.

Table 1: Material Proportioning Using 1:1.35:2.51 Mix Ratio

Percentage Replacement (%)	Cement (kg)	Water (kg)	Fine aggregate (kg)	Granite (kg)	CCB (kg)
0	15.46	8.04	20.87	38.81	0.00
5	15.46	8.04	20.87	36.87	1.94
10	15.46	8.04	20.87	34.93	3.88
15	15.46	8.04	20.87	32.99	5.82
20	15.46	8.04	20.87	31.05	7.76
25	15.46	8.04	20.87	29.11	9.70

3. Results and Discussion

The results of the physical properties of the CCB, coarse aggregates and fine aggregate, as well as the workability tests on the fresh concrete and compression tests on the hardened concrete at 7, 21 and 28 days, are presented.

3.1 Physical Properties of fine aggregates, CCB and Granite

The CCB aggregate was manually crushed and sieved into the 5mm - 20mm size ranges, as shown in Figure 1. The CCB aggregate is greatly calcareous and can bind easily with cement. However, the properties of CCB significantly differ from conventional aggregates used in concrete production due to its high organic nature. The physical properties of CCB, granite and fine aggregates used for this study are shown in Table 2.

Table 2: Physical Properties of CCB, Granite and Fine Aggregate

Properties	CCB	Granite	Fine aggregates
Maximum aggregate size (mm)	20	20	5
Specific gravity	2.40	2.64	2.62
Loose bulk density (kg/m ³)	768.16	1553.13	1388.27
Compacted bulk density (kg/m ³)	821.23	1670.60	1449.72
Ratio of uncompact bulk Density to compacted bulk density	0.935	0.930	0.958
Water absorption (%)	6.73	0.07	2.41

From Table 2, it is observed that the specific gravity values obtained for all the CCB, coarse (granite) and fine aggregates are 2.40, 2.64 and 2.62, respectively. The values for the fine and coarse aggregates fall within the standard limits specified by [Neville and Brooks \(2010\)](#), while the value for the CCB follows very closely.

Furthermore, the ratios of loose bulk density to compacted bulk density of CCB (Table 2), coarse (granite) and fine aggregates are 0.935, 0.93 and 0.958, respectively. Therefore, the obtained ratio conforms to the specified range by [Neville \(2011\)](#), who specifies that the ratio of uncompacted bulk density to compacted bulk density of aggregates for concreting should be between 0.87 and 0.96.

It is further observed from Table 2 that the water absorption of CCB aggregate is higher at a value of 6.73% than that of both the fine aggregate (2.41%) and granite (0.07%), indicating that the CCB aggregate tends to absorb more water than the other aggregates. Therefore, with a uniform water-cement ratio, the available water for the strength-forming hydration process of the concrete mix with a higher CCB aggregate content is reduced [Neville \(2011\)](#). At the same time, the formation of C-S-H gel, which is widely known to be responsible for the strength development in concrete, slows down with insufficient water. Meanwhile, the water absorption values of both the fine and coarse aggregates are within the limit specified by [BS EN 1097-6:2022 \(2022\)](#). The high water absorption of the CCB results in the reduction of the compressive strength of the concrete as the percentage of CCB content in the mix increases ([Golewski, 2023](#)).

The particle size distributions of the CCB, coarse (granite) and fine aggregates are presented in Figure 2, showing a well-graded particle size distribution for the fine aggregate. In contrast, the CCB and granite are medium-graded. The result of the percentage passing BS sieves shows that the fine aggregates satisfy the grading requirement for overall and medium grading as specified in [BS EN 933-1:2012 \(2012\)](#). This implies that the sand can conveniently be used for concrete work without much mixture proportioning adjustment. **Figure 2** shows smooth curves, which indicate that the aggregates contain particles of different sizes in good proportion.

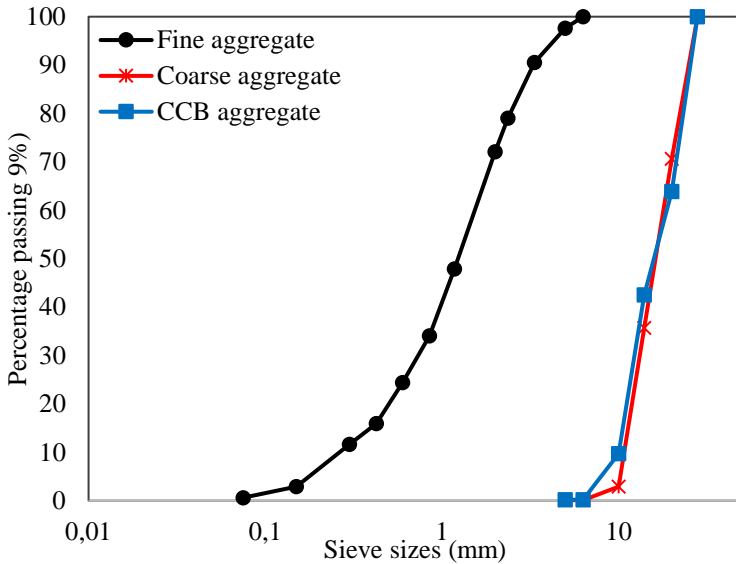


Table 3: Workability Test Result of Concrete Mix containing Crushed Cow Bone

Replacement (%)	Water-Cement Ratio	Mix Ratio	Slump (mm)
0	0.52	1:1.35:2.51	140
5	0.52	1:1.35:2.51	60
10	0.52	1:1.35:2.51	40
15	0.52	1:1.35:2.51	32
20	0.52	1:1.35:2.51	28
25	0.52	1:1.35:2.51	21

3.3 Tests on hardened concrete

The density of the hardened concrete increases as the curing days increase, but reduces with the increase in the CCB content as the age of the concrete increases (Figure 3).

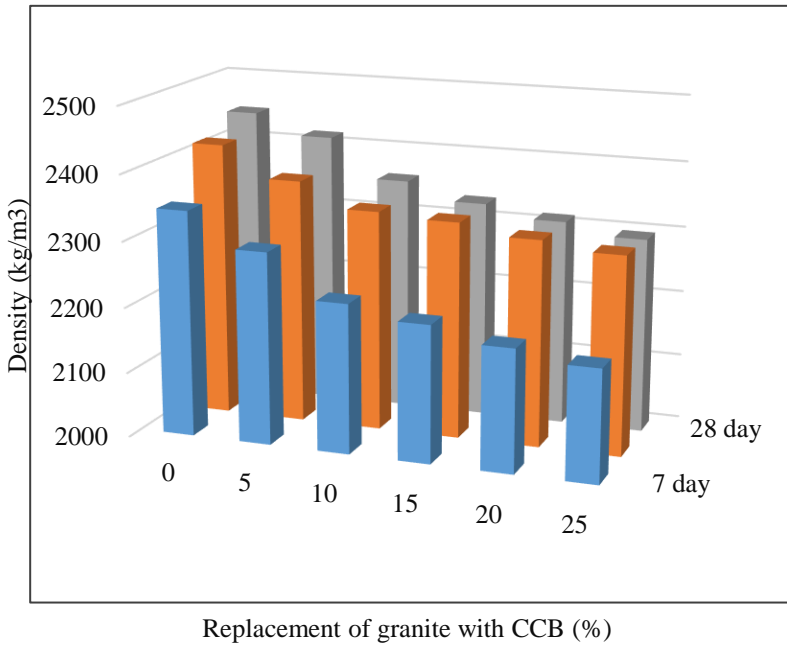


Figure 3: Density of concrete at different percentage replacements of granite with CCB

The average density of the concrete cube increased with an increase in the curing days of the cube, but reduced with each replacement level of the granite with CCB, as presented in Figure 3, until about 20 - 25% replacement, where the increase in density became insignificant at 28 days of curing.

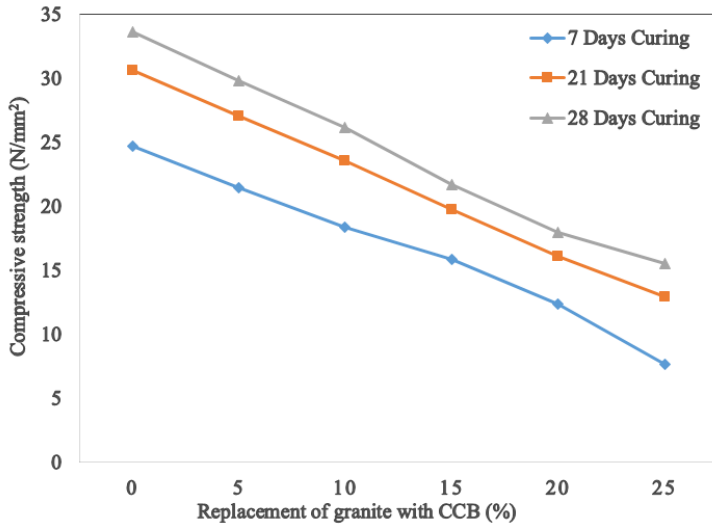


Figure 4: Effect of Replacement of Granite with CCB on Compressive Strength

It is observed that the compressive strength of the concrete specimens decreases with an increase in crushed cow bone content (as the percentage of granite reduces). As expected, at 0% (i.e., no granite replacement with CCB), the compressive strength is maximum, while at 25% CCB aggregate replacement, the compressive strength is minimum. At 28 days of curing, the compressive strength reduces from 33.60N/mm² for samples with 0% CCB aggregates to 15.55N/mm² for 25% CCB content (**Figure 5**). This trend was also observed at other curing ages.

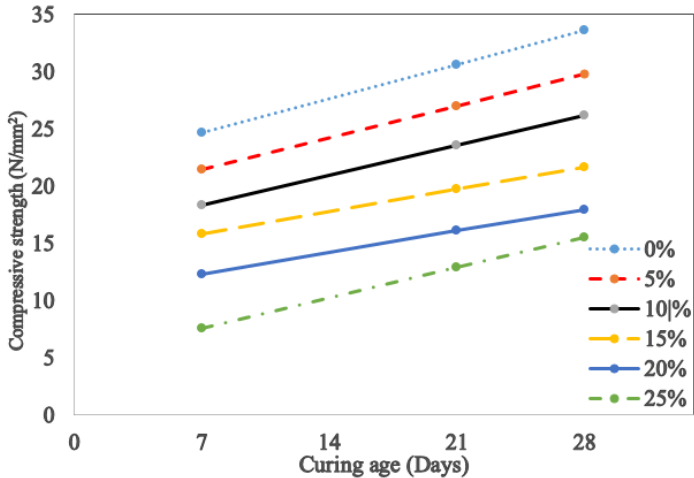


Figure 5: Effect of Curing Ages on the Compressive Strength

It was also further observed that the compressive strength of the concrete cubes increased with curing age, with all granite replaced with CCB. This is in agreement with most work on the effect of curing on the compressive strength of concrete (Akinwumi & Gbadamosi, 2014; Okonkwo & Nwokike, 2015), showing that the longer a concrete specimen is allowed to undergo curing, the higher the generation of hydration products and hence the strength of the concrete.

4. Conclusions and Recommendations

The properties of concrete having a partial replacement of crushed granite (coarse aggregates) with CCB on the workability and compressive strength of 1:1.35:2.51 concrete with a water/cement ratio of 0.52 have been examined. Based on the results achieved in this study, the workability of concrete reduces with an increase in the percentage replacement of granite with crushed cow bone. In addition, the weight of the concrete specimen decreased as the percentage replacement of granite with CCB increased.

For every percentage replacement of granite with CCB, the compressive strength increased from a minimum at the curing age of 7 days to a maximum at 28 days. Compressive strength values of concrete cubes produced with crushed cow bone at 28 days of curing age are comparable to the compressive strength values of granite between 0 – 5%, making the concrete so produced a good candidate for structural applications. However, beyond 5% replacement, the compressive strength development of CCB concrete cubes reduces noticeably at all the examined curing ages. While this does not preclude the use of the concrete so produced for structural purposes, the ensuing compressive strengths obtained for respective replacements should be noted vis-à-vis the use to which they are to be put.

Based on the foregoing paragraph, the use of crushed cow bone as a partial replacement of granite up to 5% by weight in concrete production results in the production of structurally sound concretes that are lightweight and economic, thereby leading to the achievement of safe, economic and environmentally friendly constructions for civil engineers and other professionals in the industry.

It is worthy of note that this research primarily focused on the compressive strength of the concrete produced from the use of CCB in replacing coarse aggregates, as compressive strength is the only measure of concrete quality (Wright and McGregor, 2009). However, a further check on how the durability of this concrete can be extended and guaranteed would get the research community closer to the widespread adoption of this very promising prospect.

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