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ORIGINAL RESEARCH ARTICLE

STRUCTURAL EFFICIENCY OF CONCRETE CONTAINING CRUSHED BONE AGGREGATES

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ABSTRACT

The indiscriminate dumping of animal waste, especially cow bones in abattoir has brought about the need for adequate safe disposal and recycling of such waste. This study investigated the use of crushed bones as a partial substitute for fine aggregate and its efficiency in concrete structures. Sieve analysis test was conducted on the crushed bone and used as partial replacement of fine aggregate in concrete at 0, 25, 50, 75, and 100% by weight. Slump test on the fresh concrete was investigated, while the density, compressive strength test and structural efficiency of the hardened concrete were also determined. The sieve analysis result revealed that the crushed bone was poorly graded, and the slump test showed that the 25% of crushed bone concrete has a low slump. The density was 2370 kg/m^3, the compressive strength was 17.10N/mm^2 at 28 days, while the structural efficiency was 7.22. The 50, 75 and 100% samples has compressive strength of 16 N/mm^2, 6.10N/mm^2 and 4 N/mm^2 at 28 days respectively and these values are far below expectations. The work concluded that crushed bones could partially replace fine aggregate in lightweight concrete at not more than 25% by weight. This test is limited to a short-term test of 28 days.

1.0 Introduction

The use of waste material as a partial replacement of aggregates in concrete has been investigated in recent years by many researchers (Igba et al., 2019). Materials such as rice husk, groundnut and palm kernel shell, Corncob, sawdust etc. have been successively used in concrete to replace either cement or coarse and fine aggregates (Sada et al., 2013; Otunyo et al., 2011). The use of both plant and animal waste in building materials has helped in the recycling of these waste materials for the benefit of the environment, most of these materials have resulted in the production of lightweight concrete (Akinyele et al., 2016a).

The combination of coconut shell and grained palm kernel shell was investigated as lightweight aggregate in concrete production by Tukiman and Sabarudin (2009). Otunyo et al., (2014) also studied the use of crushed periwinkle shell as a partial replacement for fine aggregates in lightweight concrete, the concrete produced from the research was proposed for use in the support of light loads. The outcome of all these researches showed that agricultural waste materials are good substitutes to aggregates in light weight concretes. Akinyele et al. (2016b) also used waste tire rubber, a non-biodegradable material to replace fine aggregate in the production of lightweight concrete, the mechanical test carried out on the concrete samples showed that 16% waste tire rubber in concrete will conveniently produce a grade 15 concrete.
Falade (1990) used sawdust ash as partial replacement of cement in bricks and found out that the addition of this material reduces the compressive strength of bricks. In another study, Raheem and Sulaiman (2016) investigated the partial replacement of cement with sawdust and Saw Dust Ash (SDA) in sandcrete blocks. Hollow blocks were moulded and cement was partially replaced with 5% to 25% by weight of SDA, using vibrating block moulding machine. The blocks produced were tested to determine their density, compressive strength and water

absorption rate. The results indicated that compressive strength of Sandcrete hollow blocks at 28 days were 2.16 N/mm^2, 1.94 N/mm^2, 1.64 N/mm^2, 1.59 N/mm^2, 1.39 N/mm^2, and 1.25N/mm^2 for 0%, 5%, 10%, 15%, 20% and 25% SDA contents respectively. At 56 days, the compressive strength of blocks with 5% and 10% SDA replacement were 2.33 N/mm^2 and 2.04 N/mm^2 respectively, both of which surpassed the required standard of 2.00 N/mm^2 specified by the National Building Code (2006).

Cow bones constitute a big nuisance in abattoirs all over the world where cattle are slaughtered for human and industrial consumption. Heaps of cow bones are usually worm-infested and developed foul odour wherever they were dumped. Thousand tons of waste animal bones are produced annually providing scope for its small-scale utilization in the construction industry. Therefore, an effort has been made by this work to utilize these bones (crushed) to study the effect of animal bones on the production of lightweight concrete.

Opeyemi and Makinde (2012) have studied the replacement of cement by Rice Husk Ash (RHA) and Bone Powder (BP) in concrete structures. The replacement of cement with these materials varied from 5% to 20% in a mix of 1:2:4. Cubes were casted, and the results showed that workability was consistent within the described values for lightweight concrete. The substitution of cement with the mixture should not be more than 10% in the production of concrete structures.

Akinyele et al., (2016b) partially replaced cement in concrete at 5, 10, 15, 20 and 25% with both bone and wood ashes. Chemical analyses were carried out on both the wood and bone ashes to determine their pozzolanic properties while the compressive strength test was conducted on the concrete obtained from both cement replacements. The chemical analysis revealed that the bone ash is a better pozzolana when compared to the wood ash. The compressive strength test showed that wood ash is not a good material for replacing cement in concrete, while 10% of bone ash can partially replace cement in concrete at 28 days compressive test.

The structural efficiency of engineering materials is the ratio of the applied load at the failure to the density of the material (Akinyele et al., 2019). The structural efficiency of some engineering materials has been investigated before now; the structural efficiency of burnt bricks made from the use of waste glass, polyethylene terephthalate (PET) and polypropylene granules was investigated by Akinyele et al. (2020a, and 2020b,). These materials were found to perform better at a certain percentage. The advantage of determining the structural efficiency is to get a material that can support loads at a very low density.
This study aims to determine the structural efficiency of concrete containing crushed bones that have been used to partially replace fine aggregates.

2. Experimental Analysis

2.1 Materials

The bone was collected from Odo-Eran abattoir in Abeokuta. The cow bones were washed, cleaned and sun-dried in open field for three weeks 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 Agricultural and Bio-resources workshop at FUNAAB where it was crushed to fine aggregates using a locally fabricated hammer mill machine. The sieve analysis test was carried out on the crushed bones to determine its particle size distribution. The coefficient of uniformity (C_u) and coefficient of curvature (C_c) were determined using equations 1 and 2 respectively from a plotted graph.

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$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}} \quad (2)$$

The D_{10}, D_{30}, and D_{60} are the tenth, thirtieth and sixtieth percentiles on the graph respectively. Limestone Portland Cement (LPC), grade 42.5R locally available in Nigeria in 50 kg bags was used for the experiment. Potable water from the Civil Engineering Laboratory of the Federal University of Agriculture was used to prepare the concrete. Crushed granite stone was obtained from a quarry in Abeokuta, Ogun State, Nigeria. The fine aggregate used was quarry stone dust. The BS 1881 - 108 (1983) was adopted in the preparation of concrete cubes.

2.2. Casting of Concrete

The crushed bone aggregates were used as partial replacement of fine aggregates in concrete at 0, 25, 50, 75 and 100%, and these samples were designated as C_0, C_{25}, C_{50}, C_{75} and C_{100} respectively, the Concrete target strength of 20 N/mm^2, with a water/cement ratio of 0.65 was used.

The process of casting started by measuring and weighing the concrete aggregates in their various proportions by weight. The aggregate was mixed thoroughly by hand on a sampling tray and segregation of the aggregates was strictly avoided. The 150 mm x 150 mm 150mm mould was primed with oil and placed on a flat surface and filled with the freshly prepared concrete. Pouring was in layers and each layer tamped with compacting bar with 35 strokes for the 150mm cubes. The test cubes were removed from moulds after 24 hours and cured in water at room temperature of about 23 + 20C. Each cube was marked for identification and submerged immediately into the water at room temperature. The casting of the concrete followed the procedures of BS 1881 108 (1983).

2.3 Workability of the concrete

Workability is the amount of useful internal work required for full compaction. It highlights the case of working and ease of handling concrete from mixing point to compaction level.

The slump test is the most commonly used method to determine the workability of concrete. The slump test was carried out on a freshly prepared concrete to determine its workability. Equipment used for the work are slump cone, tamping rod, hand trowel, sampling tray, shovel, and rule graduated from 0 to 300 mm.

The inner surface of the slump cone was cleaned, dried and the bottom of the cone was placed on a clean, smooth and horizontal surface. While holding the cone, it was filled with fresh concrete within two minutes after mixing. The slump cone was filled in three layers with each layer at approximately one-third of the total height of the cone when tamping. Each layer of the concrete was uniformly tamped with a tamping rod with 25 strokes each. The concrete above the slump cone was heaped before the top was tamped. After tamping the top, the concrete level was stripped off with stamping rod. With the slump cone still held down, the surrounding of the slump cone was cleaned. The slump cone was removed vertically, slowly and carefully within 5 to 10 seconds. The slump was measured immediately after removal to determine the difference between slump cone and specimen. This test was carried out following BS EN 12350 (2000).

2.4 Compressive strength of concrete cube

The compressive test was done following BS 1881:108 (1983) standard and the objective of the test is to determine the specific strength of concrete. The equipment used for the test are compression testing machine (compact machine) and weighing balance with a minimum of 10kg capacity. The process began by weighing the concrete cube and recording the dimension of the concrete cube. The cube was carefully centered in between the upper and lower plate of the machine to ensure that the load is applied to the two opposite cast faces of the cube.

The calibrated screen of the machine was zeroed and the load was applied until no load can be sustained by the concrete cube and failure began to show. The density of the concrete cube was also determined from the average weight of the concrete cube weighed with the weighing balance.

3. Results and Discussion

3.1. Particle size analysis of crushed bone.

Figure 1 shows the particle size distribution for the crushed bone. The particle size distribution curve for the crushed bone has a semi-steep curve, indicating a type of aggregate containing particles of almost the same size. Any clean aggregate with less than 5% fines, with grading requirements of C_u (coefficient of uniformity) greater than 6 and C_c (coefficient of curvature) greater than 1 but less than 3 is a well or uniformly graded aggregate. From the results obtained in equations 1 and 2, the crushed bone particles have C_u of 4.4 and a C_c of 1.88. The C_c value is within the recommended range, but the C_u is less than the recommended value of 6, ASTM D2487 (2006). Hence, it can be concluded that the crushed bone particles are poorly graded and this type of graded materials are good for aggregates in concrete.

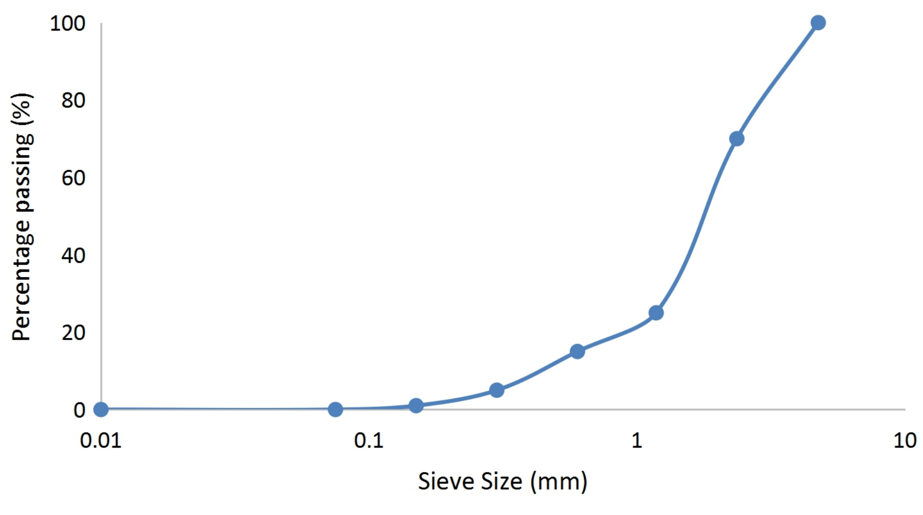

Figure 1: Sieve analysis result for crushed bone.

3.2 Slump of concrete samples

Result for the slump carried out is shown in Figure 2 which comprises the workability for the varying additions of bone and fine aggregate in concrete. It was observed that all the concrete samples slump evenly. That is they had a true slump during the test period, indicating that that the entire sample had good consistency properties. But from Figure 2, the slump value decreased as the percentage of crushed bone increased in the concrete mix. The C_0 concrete mix gave a slump of 35 mm, while the C_{25}, C_{50}, C_{75} and C_{100} gave slump values of 27 mm, 14 mm, 9 mm and 7mm, respectively.

The implication of this is that the C_0 and C_{25} concrete samples had a low slump. If the concrete is to be transported to a distant site, the water-cement ratio would have to be increased so that the slump and workability can be increased before pouring. This is a very good result as a low slump is good for hand-vibrated machines for rigid pavement in road construction and good for mass concrete foundations without vibration or lightly reinforced section with vibration.

The C_{50} – C_{100} mix showed a very low slump of between 14 and 7 mm. This type of concrete will require power operated vibration machine, and transportation to a distance site may not be advisable. The very low slump, especially in all the crushed bone samples, can be attributed to the absorption of water by the bone particles in the concrete mixture; since the crushed bone was dry, its affinity with water was high within the concrete environment hence the almost dry concrete obtained.

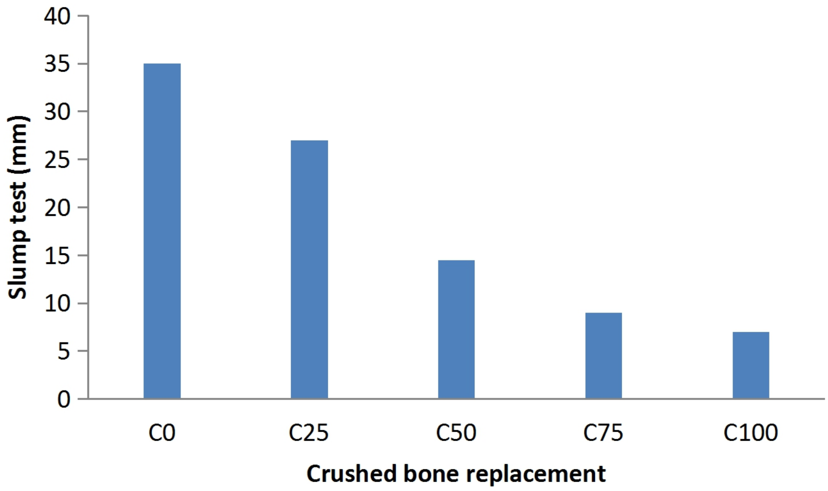

Figure 2: Variation of slump values with crushed bone replacement

3.3 Compressive strength

The variation of compressive strength with crushed bone percentage for each concrete sample is shown in Figure 3. The general trend is that the compressive strength reduces as the percentage of crushed bone increases in the concrete mix. The ultimate strength for Control specimen (C_0) is more than that of the C_{25} specimens by over 6 N/mm^2 at 28 days, while the C_{50} mix is lower than the control by 7 N/mm^2. However, for total crushed bone concentrations greater than 50%, the ultimate strength results were much lower than the half of the strength for the control samples at 28 days. The systematic reduction of ultimate strength in crushed bone concrete might restrict the use of the concrete, with bone concentrations exceeding 50%, in structural applications. The reduction in compressive strength can be attributed to the decrease in the bonding between the bone particle and cement, also the absorption of water by the crushed bone contributed to this trend. The pattern of reduction of strength as bones were added to concrete in this research is similar to what was obtained by Fapohunda et al., (2016), where the strength characteristics of varying water-cement ratio in concrete mixed with crushed bones was investigated. ACI 213 (1999, 2003) recommended a minimum 28 days compressive strength of 7 N/mm^2 for lightweight concrete (LWC), while BS 8110 (1997) required a minimum 28 days compressive strength of 15 N/mm^2 for concrete to be used as reinforced concrete and a minimum 7 N/mm^2 for plain concrete and these were confirmed by Akinyele et al., (2016) when they produced lightweight concrete from waste tire rubber crumb. The results from the entire test specimen showed that crushed bone can be used to replace fine aggregate in lightweight concrete by up to 50%, since the least 28 days compressive strength obtained was 16 N/mm^2, which is greater than the recommended values.

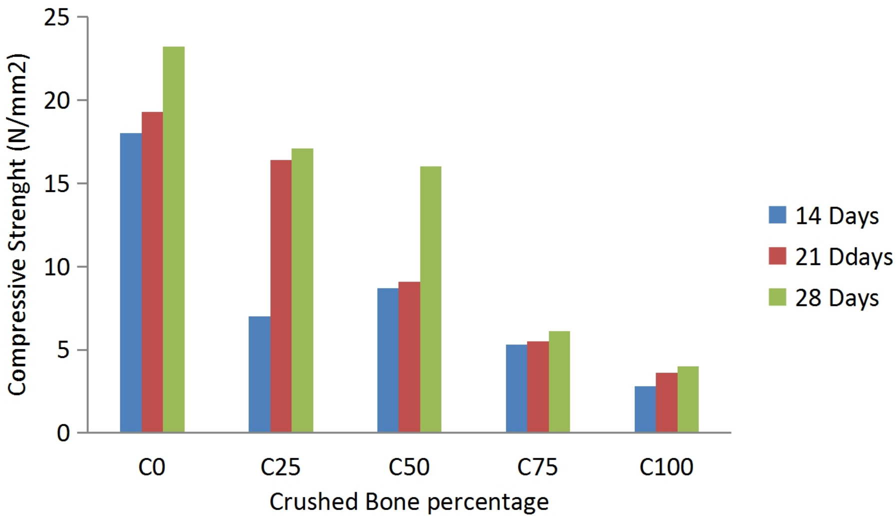

Figure 3: Variation of compressive strength with crushed bone percentage

3.4 Density and structural efficiency

The structural efficiency of the control was used to determine the efficiency of other materials, the efficiency of the control will be taken as the ultimate value. If the efficiency of any other samples is not less than 70% of the control, then that particular sample can be said to be structurally efficient (Akinyele et al., 2020a). The densities of each concrete mix were determined on each day of the compressive strength test, Figure 4 showed the variation in concrete densities. All the concrete samples showed a decrease in bulk density with increase in bone particles. All the concrete samples maintain a varying density of between 1985–2400 kg/m^3 which qualifies those above 2300 kg/m^3 as normal-weight concrete, while those below this value can be classified as lightweight concrete. The density of concrete also depends on the degree of compaction of the samples during casting. The values of the structural efficiency of each concrete sample are shown in Table 1. Structural efficiency is the ratio of compressive strength to density, and this determines how effective a structural member will perform during its lifetime. The efficiency of the control sample was compared with all the samples, the C_{25} and C_{50} samples were very close at about 74.97% and 74.76% respectively, while samples C_{75} and C_{100} gave 29.69% and 20.97% respectively, these are very low values for the last two sample. The results showed that samples C_{25} and C_{50} has structural efficiency greater than 70% benchmark, hence the two samples are structurally good, for engineering purpose.

Table 1: Structural efficiency of concrete samples

Concrete Sample	Density (kg/m^3)	Structural Efficiency (x 10^{3}m)
C_0	2400	9.63
C_{25}	2370	7.22
C_{50}	2222	7.20
C_{75}	2133	2.86
C_{100}	1985	2.02

4. Conclusion

The use of crushed bone particles as partial replacement (at 5%) of fine aggregate could improve some properties of the concrete. The particle size distribution revealed that the particles are not uniformly distributed which is an advantage for aggregate in concrete production. The slump and compressive strength tests showed that the concrete could perform well as lightweight concrete.

The structural efficiency of the C_{25} and C_{50} samples achieved good results above the 70% benchmark.

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