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RESEARCH ARTICLE

MECHANICAL PROPERTIES OF COCONUT SHELL AS COARSE AGGREGATE IN LIGHTWEIGHT CONCRETE

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ABSTRACT

Coconut shell is an agricultural waste from the processing of coconut, the knowledge of it's engineering properties can boost the usage and the confidence of the designer in utilizing it as an alternative material of application in civil engineering construction. Therefore, the focus of this experimentation is to provide laboratory results of the mechanical properties of coco nut shell aggregate that can establish its potential for usage as light weight aggregate in concrete production. The basic engineering properties of coconut shell investigated includes the specific gravity, bulk density, impact value, crushing value, abrasion value, water absorption capacity, elongation and flakiness test. Coconut shell aggregate exhibits low impact, crushing, and abrasion values of 1.3%, 1.16% and 2.23% respectively compared with normal aggregate with 19.23%, 25.60% and 27.67% respectively. Coconut shell, however, has high percentage of water absorption capacity, elongation index and flakiness index of 23.72%, 26.69% and 86.12% respectively as compared with that of normal aggregate of 1.80%, 8.78% and 36.89% respectively. It has a bulk density of 630Kg/m3 which is classified as lightweight aggregate. With these properties coconut shell aggregates can be an alternative material for consideration as coarse aggregate in lightweight concrete.

INTRODUCTION

Global attention has been focused on environmental preservation due to alarming depletion of ozone layer as a result of pollution resulting from manufacturing processes. It was reported by Mehta (2001) that "cement production, coarse aggregate mining, processing and transportation operations accounts for about 7% of the global loading of carbon dioxide into the atmosphere due to considerable amount of energy consumed, thereby affecting the ecology of the forested areas and river beds. In an attempt to reduce environmental degradation, close attention is now being paid to material recycling and the use of agricultural and industrial wastes in concrete production. In civil engineering practice and construction works, large volumes of coarse aggregates are usually used in the production of concrete. Gambhir (2005) reported that coarse aggregate constitutes about 75% to 85% of the concrete matrix. Concrete being one of the major building materials that is used virtually in all aspects of construction, it is easily delivered to the job site, and could be molded in situ or pre-cast to any form or shape.

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These qualities distinguished it as a material of choice in construction. The basic constituents of concrete are cement, fine aggregate (sand), coarse aggregate (granite chipping) and water. Since coarse aggregate constitute an average 80% of every volume of concrete. The significance and relevance of coarse aggregate in concrete production in all areas of civil engineering practice and building construction cannot be ignored. Nigeria being a developing country is faced with inadequate provision of physical infrastructure; shelter and related amenities, which are typical factors of under development that need to be addressed through provision of alternative, cheap and affordable materials. In these areas development require the use of cement and other related materials such as coarse aggregate. Technologies which can provide means of upgrading shelter within the scope of the socio economic and cultural environment need to be developed (Elinwa, 2003). Currently, research efforts have been geared towards sourcing, development and the use of local alternative construction materials including the possibility of using some agricultural wastes and residues as construction materials. Some investigations made shown that it is possible to produce concrete using agricultural, urban and industrial wastes material, (Gambhir, 2005). Hence the focus of this research is to investigate the engineering properties of coconut shell as

an aggregate in lightweight concrete through experimental investigation. The growing concern of resource depletion and global pollution has challenged many engineers to seek and develop new materials relying on renewable resources (Teo *et al*, 2006). These include the use of by-products and waste materials in building construction. In developing countries where abundant agricultural and industrial wastes are discharged, these wastes can be used as potential material or replacement material in the construction industry. This will have the double advantage of reduction in the cost of construction material and also as a means of disposal of wastes. Therefore, the use of alternative materials to normal aggregate in concrete is of paramount importance. Hence the agricultural and industrial wastes which constitutes nuisances both to our health and environment can be converted into useful materials by either burning them into ashes, converting them from the original state and used in various proportions with cement, and thus reduce the cost for concrete works (Elinwa, 2003).

Tay (1990) and Toress et al (1999) also reported that waste materials generated from industrial and agricultural activities can be recycled into new building materials, because they reduce carbon dioxide (CO_2) emission and used less energy consumption in processing or they can be used directly as aggregate in their natural or processed states. Payam et. al, (2010) observed that to build environmentally sustainable structures, especially in developing countries, the possibility of using some agricultural wastes and industrial by- products from different industries as construction materials will be highly desirable and has several practical and economical advantages. Delsye *et. al* (2006) reported that exploitation of waste material from agricultural source lead to sustainable building material in construction industry which will help in preserving the natural resources and also helps maintain ecological balance. Coconut shell is one of the by-products from the processing of coconut, it is organic in nature and similar to hard woods in chemical composition though lignin content is higher and cellulose content is lower (*www.reade.com*). The shell composition is shown in Table 1.

Table 1. Chemical composition of Coconut Shell

COMPOUND	PERCENT
CELLULOSE	33.61
LIGNIN	36.51
PENTOSANS	29.27
ASH	0.61

Source: Jasper Guy woodroof (197"Coconuts: Production, processing, products" 2nd ed AVI publishing Co. Inc

Therefore, considering the high cost of conventional building materials in the country which affects housing delivery, concrete using coconut shell as coarse aggregate can be useful as a structural lightweight concrete. This will enhance the quest for low cost housing system for both the rural, urban population in Nigeria and in the developing countries. The use of the waste generated will also contribute toward a cleaner environment. These waste materials however must be tested to ascertain their properties – chemical, mechanical and their suitability for constructional purposes. According to Gambhir (2005) the suitability of a particular lightweight concrete is determined by the specified compressive strength and the density of concrete. Coconut tree as an agricultural crop is widely grown in the tropics, for decoration as used as for many culinary and non-culinary uses (Thampan, 1981). Traditionally found around hamlets in small stands. Although in the last century in larger plantations especially in the pacific, Asia, Caribbean and Africa. Plate III shows the regions where coco nut trees are predominantly grown. In Nigeria coconut trees are found in abundance in the West, East, Mid-West and part of middle belt region. Coconut trees are available in larger quantities and its supply is renewable compared with other materials. Adewuyi *et al*(2008) reports that Coconut plantation is gaining prominence in the Southern, Eastern and Western part of Nigeria, because of the economic importance to the rural dwellers. One of the significance problem according to his report is the large amount of waste generated in the processing of Coconut, which includes fibre and shell. It's in an attempt to find possible usage of this waste that this research has been embarked upon to see the possibility of using coconut shell as aggregate for the production of lightweight concrete. Owen (1993) stated that usually aggregates which have dry weights (of less than) 1200kg/m3 are classified as light weight aggregates. Coconut shell aggregates has a unit weight of 500-650kg/m^3 and this is approximately 60% lighter compared to the conventional crushed stone aggregates.

MATERIALS AND METHODS

Material

Coconut shell: The coconut shell used was obtained from the local hawkers of coconut (popularly called in Hausa "Kwakwa") in the central market area, Kaduna, located within latitude 10° 30′ N and longitude 7° 27′E.

Methods

Coco nut shell Processing: The coco nut shell was sun dried for two months before being crushed in the quarry. This is to ensure that the moisture content is reduced to the barest minimum. The crushed Coconut shell material was later transported to the laboratory where they were thoroughly cleaned and washed, then allowed to dry under ambient temperature. The coconut shells were available in various shapes, such as curved, flaky, elongated, roughly parabolic and other irregular shapes as shown in Plate v. Plate VI are the sizes obtained after crushing. In order to ascertain the properties of coconut shell aggregate the following tests was carried out which includes the specific gravity, bulk density, particle size distribution, aggregate impact value, aggregate crushing value, aggregate abrasion value, , porosity/water absorption capacity, elongation index and flakiness index. All these tests were performed in accordance to BS 812, part 101, 1984, BS 812, part 101, 1990, BS 812, part 105.1, 1990, BS 812, part 105.2, 1990,BS 812, part 109, 1990,BS 812, part 110, 1990, BS 812, part 112, 1990, BS 812, part 113, 1990 and BS 1330, part 2, 1995. The results are presented in tables 2-10.

Mechanical properties of Coco nut shell

Specific gravity of aggregates: The specific gravity of an aggregate is of importance in the calculation of the quantity of aggregate required for a given volume of concrete. The results of specific gravity of coconut shell aggregate is presented in table 2. This was conducted in accordance to BS 1330: Part 2: 1995. The specific gravity adopted in this research is the

apparent specific gravity. The apparent specific gravity is the ratio of the mass of the aggregate dried in an oven at 100 to 110°c for 24 hours to the mass of water occupying a volume equal to that of the solid including the impermeable pores. It is worthy of note that the apparent specific gravity of an aggregate depends on the specific gravity of the minerals of which the aggregate is composed and also on the amount of voids. The British standard BS 1330: part 2: 1995 stipulates the procedure for determining the specific gravity of an aggregate. It also gave the specific gravity of majority of natural aggregate to be between 2.6 and 2.7.

Specific gravity: Coconut shell aggregate

The results of the specific gravity tests carried out are as shown in Table 2. The results showed that coconut shell has an average specific gravity of 1.31. The average specific gravity value of 1.31 for coconut shell aggregate is about 50 percent lower than the specific gravity of naturally occurring aggregate as stated above. This implies that more aggregate is needed for concrete mix.

coconut shell aggregate have about 50% less weight compare with that of both fine and normal stone aggregate making it light weight aggregate.

Aggregate particle size distribution analysis

The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, often referred to as gradation. A good aggregate particle size distribution implies that a sample of aggregates contains all standard fractions. That is aggregate in required proportion, such that the sample contains minimum voids. The essence of particle size distribution analysis is to have well graded aggregate which have direct influence on producing workable concrete.

Coconut shell aggregate particle size distribution

The particle size distribution analysis was carried to ensure that the resulting concrete is workable, since good grading of aggregates is one of the factors in producing good concrete.

Table 2. Coconut shell specific gravity values

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
specific gravity value	1.35	1.33	1.37	1.31	1.30	1.29	1.29	1.31	1.27
Average specific gravity value	1.35			1.30			1.29		

Table 3. Coconut shell aggregate bulk density results

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
Bulk density Kg/m3	639.45	639.48	639.42	625.00	622.00	628.00	629.00	623.00	626.00
Average Bulk density Kg/m3	639.45			625.29			626.00		

Table 4. particle size distribution- coconut shell aggregate (16mm)

Sieve size	mm	28	20	14	10	6.30	5.0	3.35	Pan
% passing cumulative		99.50	96.86	17.36	2.06	0.84	0.52	0.26	0.00

Table 5. Coconut shell aggregate impact value results

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
Aggregate impact value %	1.32	1.31	1.33	1.29	1.30	1.29	1.31	1.30	1.29
Average Aggregate impact value %	1.32			1.29			1.30		

Table 6. Coconut shell aggregate crushing value results

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
Aggregate crushing value %	1.159	1.158	1.153	1.169	1.158	1.1.160	1.158	1.154	1.159
Average Aggregate crushing value %	1.157			1.162			1.157		

Aggregate bulk density

The bulk density gives information in respect of shape and grading of the aggregate. This is test was performed in accordance to BS 812: Part 2: 1990. The detail results are shown in Table 3.

Coconut shell aggregate bulk density

The coconut shell bulk density also ranges from 622kg/m^3 to 639.48kg/m^3 as shown in Table 3. This value is within the limit specified for light weight aggregate. The result shows that

The result is in table 4, while the graph showing the percentage passing against the various sieve sizes is shown in figure 1. The single aggregate size used in the analysis is reflected, as the highest percentage of the aggregate passing fell between size 14-20mm.

Aggregate impact value

The aggregate impact value test result is presented in table 5. This was done in accordance with BS 812: Part 112: 1990. The aggregate Impact value can be described as a standard hammer falling 15 times under its own weight upon the aggregate in a cylindrical container.

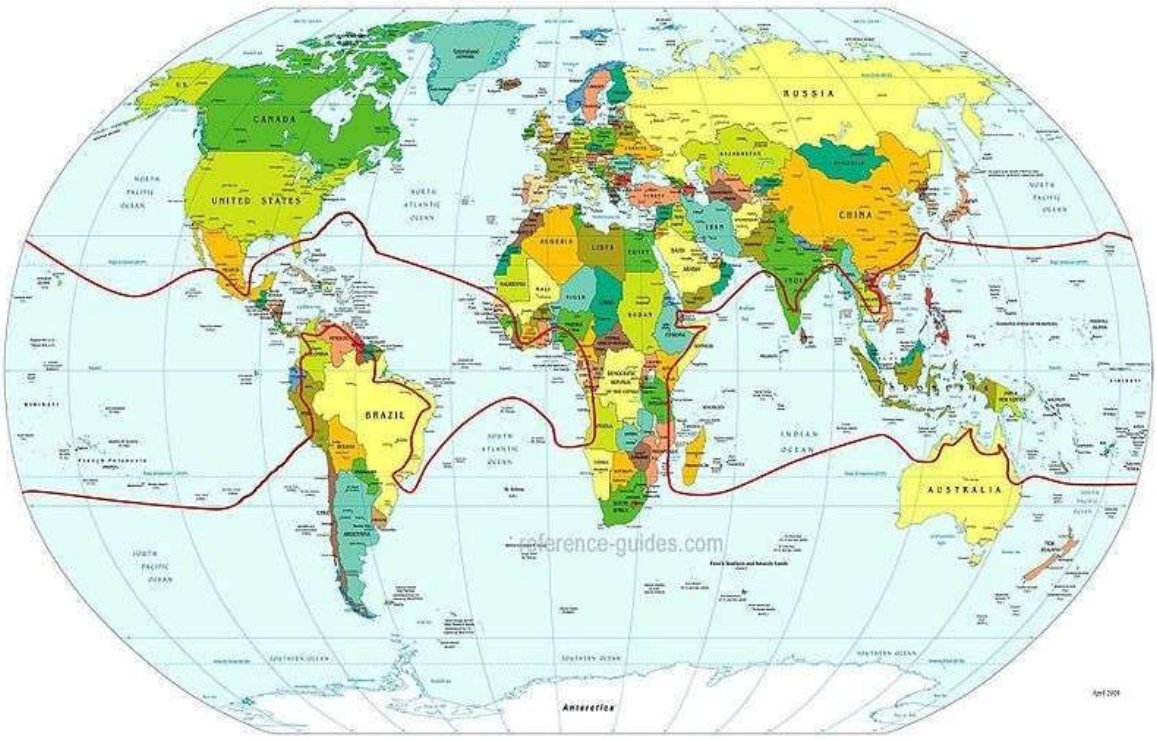

Plate I. The world map of Coco nut growing regions

Table 7. Coconut shell aggregate abrasion value results

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
Aggregate abrasion value %	2.26	2.25	2.27	2.24	2.26	2.22	2.19	2.16	2.22
Average Aggregate abrasion value %		2.26			2.24			2.19	

Table 8: Coconut shell aggregate water absorption capacity results

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
Aggregate Absorption capacity %	23.72	23.69	23.75	23.78	23.80	23.76	23.67	23.65	23.69
Average Absorption capacity %		23.72			23.78			23.67	

Table 9. Coconut shell aggregate Elongation index results

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
Enlongation index %	26.69	26.71	26.67	26.66	26.64	26.68	26.78	26.66	26.72
Average enlongation index %		26.69			26.66			26.72	

Table 10. Coconut shell aggregate flakiness index results

Samples	A1	A2	A3	B1	B2	B3	C1	C2	C3
Flakiness index	86.11	86.14	86.09	86.13	86.10	86.16	86.15	86.09	86.12
Average flakiness %		86.15			86.09			86.12	

This results in fragmentation in manner similar to that produced by the pressure of the plunger in aggregate crushing value. The British standard (BS 812: Part 112:1990 and BS 882: 1992) specified maximum value of 25 percent when the aggregate is to be used in heavy duty floors; 30 percent when the aggregate is to be used in concrete for wearing surfaces and 45 percent when it is to be used in the other concrete. Resistance to wear is an important property of concrete used in pavements, and in floor surfaces subjected to heavy traffic.

Coconut shell aggregate impact value

From Table 5, the impact values for coconut shell aggregate ranges from 1.29 to 1.32 percent.

This means that coconut shell aggregate is resistance to wear. Hence it can be used for all types of light weight concrete. The average impact value for Coconut shell aggregate is 1.32 percent which is far less than 25 percent allowed in BS 812: Part 112:1990 and BS 882: 1992. The Coconut shell aggregate impact value indicates that it can also be used as construction material.

Aggregate crushing value

This test was carried out in accordance with BS 812: Part 110: 1990. The details of the result is presented in Table 6. The test of aggregate crushing value is a measure of aggregate

resistance to pulverization. The British standard code of practice BS 812: part 110: 1990 specified that aggregate crushing value should not be more than 45% for aggregate used for concrete other than for wearing surfaces and 30% for concrete used for wearing surface such as runways, roads and air field pavements.

Plate II: Coco nut shell waste dump

Plate IV: Coconut Tree

Plate V: An Unopened Coconut Fruit

Plate V. Coconut shell before crushing

Plate VI. Machine crushed Coconut shell

Coconut shell aggregate crushing value

From table 6 the crushing value of coconut shell aggregate ranges from 1.153% to 1.169%. Hence the coconut shell aggregate can be used for other concrete work other than the ones mentioned above. The average of coconut shell aggregate crushing value is 1.16% which is lower than 30% maximum specified in the code. Therefore, the coconut shell aggregate crushing value shows that the material can be used as alternative coarse aggregate in construction.

Aggregate abrasion value

The aggregate abrasion value test result carried out is presented in table 7. The abrasion value test on aggregate particles was done as prescribed by BS 812: part 113:1990. The aggregate abrasion value is defined in terms of the percentage loss in mass on abrasion. The aggregate sample is subjected to abrasion in a standard machine, the grinding lap being turned 500 revolutions. High aggregate abrasion value denotes a low resistance to abrasion. The aggregate abrasion test is of great importance if the aggregate is to be used for road construction, warehouse floors and pavement constructions. The code specified that for aggregates to be used for above type of construction should have max abrasion value between 30% - 50%.

Coconut shell aggregate abrasion value

The coconut shell abrasion value ranges between 2.19 to 2.26 percent as shown in table 7. While the average abrasion value is 2.23% this is far less than 30%. Hence the coconut shell aggregate is a suitable material for construction as it satisfied the abrasion provision in the code. The implication of this result is that coconut shell aggregate have high resistance to wear.

Aggregate porosity /water absorption capacity

The standard procedures for assessing the porosity and water absorption of aggregate is prescribed in BS 812: Part 2: 1975 and BS 812: part 109: 1990. The presence of internal pores in the aggregate particles and the characteristics of these pores are of paramount importance in the study of its properties.

The porosity of aggregate, the permeability and the absorption influences such properties of aggregate as the bond between it, the hydrated cement paste, the resistance of concrete to freezing and thawing as well as its chemical stability and resistance to abrasion. Since aggregate represents three-quarters of the volume of concrete, it is clear that the porosity of aggregate materially contributes to the overall porosity of concrete. The water absorption of aggregate is determined by measuring the increase in mass of an oven dried sample when immersed in water for 24 hours. The ratio of the increase in mass to the mass of the dried sample expressed as a percentage is termed absorption.

Coconut shell aggregate porosity /water absorption capacity

The coconut shell aggregate porosity/water absorption capacity test result is presented in table 8. The value of coconut shell absorption capacity ranges from 23.65% to 23.80%. While the average coco nut shell absorption capacity is approximately 24%. This value is within the range for absorption capacity of light weight aggregates as stipulated by Portland cement association, which is between 5% and 30%. Hence the coconut shell aggregate can also be used or classified as light weight aggregate.

Aggregate elongation index

The test result is presented in table 9 and it was carried out in accordance with BS 812 section 105.2: 1990. and 9% elongation index respectively. Although BS 812 section 105.2: 1990 have no recognized limits but this result is acceptable for a light weight aggregate.

Coconut shell aggregate elongation index

The result shows that coconut shell aggregate have approximately 27%. Although, there is no recognized limits laid down, the presence of elongated particles in excess of 10 to 15% of the mass of coarse aggregate is generally considered undesirable.

Aggregate flakiness index

The results of the flakiness index tests are shown in tables 3.26 and 3.27 of chapter three. The flakiness index of an aggregate is the percentage by weight of particles whose least dimension (thickness) is less than three fifths of their mean dimension.

Coconut shell aggregate flakiness index

The coconut shell flakiness index test ranges from 86.09% to 86.16% as shown in table 10.
The result shows that coconut shell aggregate is a flaky material, based on BS 882:1992 which limits the flakiness index of the coarse aggregate to 50% for natural gravel and 40% for crushed coarse aggregate.

Conclusion and Recommendation

Conclusion

Experimental investigation of the properties of coconut shell aggregate has been carried out. The experimental results shows that coconut shell has good potential as coarse aggregate in lightweight concrete as well as a partial replacement of conventional coarse aggregate in concrete. Therefore, based on investigation the following conclusion can be drawn:

- More volume of coconut shell aggregate will be required for a concrete mix, because it has a low specific gravity of 1.31 compared with that of normal aggregate stone.
- Coconut shell aggregate can be classified as light weight aggregate because it has an average bulk density of 630Kg/m^3 as specified in BS 812: Part 2 : 1990.
- The coconut shell aggregate average impact value of 1.32 percent is below the maximum 25 percent allowed in BS12: part 112: 1990 and BS 882 ; 1992 . This indicates that it can be used as light weight construction materials.
- The crushing value of coconut shell aggregate ranges from 1.15 and 1.17%. This implies it has low crushing value. The BS812, Part 110: 1990 gave maximum allowable 45% crushing value for the application of any aggregate to be use as aggregate for wearing surface.
- The coconut shell aggregate abrasion value from table 7 is lower than the allowable maximum 30% given in the code of practice BS 812: Part 113: 1990.Which implies that coconut shell aggregate has high resistance to abrasion, which is a good mechanical prosperity of a any given aggregate.
- The porosity/water absorption capacity of coconut shell aggregate is however very high which means that high water cement ratio will be required to have a workable concrete as the water meant for the hydration of concrete will be absorbed by the aggregate. However the absorption capacity of 24% is within the stipulated value by Portland cement association, which is between 5% and 30%.
- The result of elongation index shows that coconut shell has high elongation index, although no recognized limits has been laid down, however the presence of elongated particles in excess of 10 to 15% of the mass of the coarse aggregate is generally considered undesirable.
- The experimental results show that coconut shell flakiness index is very high. Therefore, coconut shell is considered to be flaky material. It has flakiness index of 86% which is considered flaky based on BS882:1992 which limits the flakiness of coarse aggregate to 50% for natural gravel and 40% for crashed coarse aggregate.

Recommendations

Based on the scope and the results of this research the following are the recommendation for further investigation.

- A study of the shrinkage characteristics of Coconut shell is recommended.
- The use of coconut shell aggregate as a replacement in convectional concrete should be encourage in the locality where it is in abundance to enhance environmental cleanliness.

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