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A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates

E.A. Olanipekun, K.O. Olusola, O. Ata*

Department of Building, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria

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Abstract

The high cost of conventional building materials is a major factor affecting housing delivery in Nigeria. This has necessitated research into alternative materials of construction. This paper presents the results of an investigation carried out on the comparative cost analysis and strength characteristics of concrete produced using crushed, granular coconut and palm kernel shells as substitutes for conventional coarse aggregate in gradation of 0%, 25%, 50%, 75% and 100%. Two mix ratios (1:1:2 and 1:2:4) were used. A total of 320 cubes of size $100 \times 100 \times 100$ mm were cast, tested and their physical and mechanical properties determined. The results of the tests showed that the compressive strength of the concrete decreased as the percentage of the shells increased in the two mix ratios. However, concrete obtained from coconut shells exhibited a higher compressive strength than palm kernel shell concrete in the two mix proportions. The results also indicated cost reduction of 30% and 42% for concrete produced from coconut shells and palm kernel shells, respectively. Considering the strength/economy ratio, it was concluded that coconut shells were more suitable than palm kernel shells when used as substitute for conventional aggregates in concrete production.

Keywords: Coconut shells; Compressive strength; Cost analysis; Palm kernel shells

1. Introduction

Palm kernel shell (PKS) and coconut shell (CS) are not commonly used in the construction industry but are often dumped as agricultural wastes. However, with the quest for affordable housing system for both the rural and urban population of Nigeria and other developing countries, various proposals focussing on cutting down conventional building material costs have been put forward. One of the suggestions in the forefront has been the sourcing, development and use of alternative, non-conventional local construction materials including the possibility of using some agricultural wastes and residues as construction materials.

PKS and CS, both of which belong to the family of palm shells, are agricultural waste products obtained in the processing of palm oil and coconut oil, respectively, and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and America. In Nigeria, both are available in large quantities in the southern part of the country. Previous studies by Ogedengbe [1], Nuhu-koko [2], Olateju [3], Falade [4], Omange [5], and Ayangade et al. [6] have shown that PKS is suitable as granular filter for water treatment, as a suitable aggregate in plain, light and dense concretes and as a road building material. Apart from its use in production of fibre-roofing material, the other possibility of using CS as an aggregate in concrete production has not been given any serious attention. However, Adeyemi [7] investigated, for one mix ratio (1:2:4) the suitability of CSs as substitute for either fine or coarse aggregate in concrete production. It was concluded that the CSs were more suitable as low strength-giving lightweight aggregate when used to replace common coarse aggregate in concrete production.

*Corresponding author. Tel.: +234 8033 883127.
E-mail address: gbenga_ata@yahoo.com (O. Ata).

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This paper presents the results of an investigation carried out on the comparative cost analysis and strength characteristics of concrete produced using crushed, granular coconut and PKSs as substitutes for conventional coarse aggregate. The main objective is to encourage the use of these 'seemingly' waste products as construction materials in low-cost housing. It is also expected to serve the purpose of encouraging housing developers in investing in house construction incorporating these materials.

2. Experimental

2.1. Material investigations

PKSs: PKSs were obtained from a local palm mill in Tonkere, a village near Obafemi Awolowo University, Ile-Ife in Ife Central Local Government Area of Osun State of Nigeria. It was obtained in the already cracked and oil-extracted form, the fibrous outer parts of the nut already removed. It was kept indoors in sacks for 2 months. It was washed and graded in accordance with the British Standard methods of sampling, testing and sieve test of lightweight aggregates for concrete. The particle sizes range from 5 to 15 mm.

CSs: The CSs were obtained from a local coconut oil mill located in Badagry in Lagos State of Nigeria. They were sun dried for 1 month before being crushed manually. The crushed materials were later transported to the laboratory where they were washed and allowed to dry under ambient temperature for another 1 month. The particle sizes of the CS range from 5 to 20 mm. Washed gravel obtained locally was used as the main coarse aggregate. The particle size ranges from 5 to 20 mm.

Fine aggregate: The fine aggregate used was stone dust obtained from a local quarry few kilometres from Ile-Ife. The maximum particle size used was 2.36 mm.

Cement and water: The cement used as the binding agent was the Ordinary Portland Cement (OPC) and the water was obtained from a nearby flowing stream.

2.2. Experimental procedure

2.2.1. Preparation of the test samples

Two nominal mix ratios (1:1:2 and 1:2:4) involving crushed, granular coconut and PKSs as substitutes for gravel in gradation of 0%, 25%, 50%, 75% and 100% were used in each case. A water/cement ratio of 0.75 and 0.50 were used, respectively, for mix ratios 1:2:4 and 1:1:2. Slump test values showed concretes of workabilities ranging from low (less than 25 mm) to medium (25–50 mm). At 0% replacement level (normal concrete), the slump values obtained were 62 mm for mix proportion 1:1:2 and 37 mm for mix proportion 1:2:4, indicating high and medium workabilities. These values decrease progressively as percentage shell substitution increases; however, for CSC, they remain fairly constant for 1:2:4 mix ratio. The concrete mixes and cubes were prepared in accordance with the provisions of BS1881 [Part108, 1983]. A total of 320 cubes of size $100 \times 100 \times 100$ mm were cast and tested and their compressive strength and water absorption properties determined. In all cases, batching was done by volume.

2.2.2. Tests applied to the samples

The physical properties—moisture content, water absorption capacity, durability, density and specific gravity of the CS and PKS were first determined following standard laboratory procedures.

3. Results and discussion

3.1. Moisture content and water absorption capacity

The moisture contents of the coconut and PKSs used were found to be 5.13% and 4.35%, respectively. These were allowed for in the calculation of batched quantities and of the total water requirement of the concrete mix. The water absorption capacity of the CS was found to be 6.17% while that of the PKS was 8.15%. The absorption capacity is a measure of the porosity of an aggregate. Since the values obtained are low, it is reasonable to conclude that the shells absorb very little amount of mixing water during concrete production. These values are also within the range of absorption capacity of lightweight aggregates which have been put at 5–20% (Portland Cement Association [8]).

3.2. Unit weight and specific gravity

The unit weight (density) and the specific gravity of the shells are 1738 kg/m^3 and 1.74, respectively, for CSs, 1462 kg/m^3 and 1.46, respectively, for PKSs. These figures fall below the 2.5–3.0 range of specific gravity for normal weight aggregates. The CSs and PKSs can therefore be classified as lightweight aggregates, the CSs having higher density and specific gravity. The clear differences in specific gravities of the shells (1.74 and 1.46), stone dust (2.35) and cement (3.15) explained why it was necessary, as done in this investigation, for the material quantities to be computed by the method of absolute volume.

3.3. Durability

Durability of an aggregate is a measure of its resistance to wear, moisture penetration, decay and disintegration. The hardness of the CSs and PKSs was measured by the durability test using the Los Angeles

abrasion method. The test results indicated high values of 98.6% for CSs and 96.4% for PKSs. This implies that concrete made from these two types of aggregate will possess a high degree of resistance to wear and can be used in the production of concrete intended for floors and pavements expected to be subject to heavy human traffic.

3.4. Density of concrete

In all cases, the density of the concrete produced decreased with increase in the percentage replacement of conventional coarse aggregate (gravel) with CSs and PKSs as shown in Fig. 1. At 0% level of CS and PKS substitution, the density of the concrete at 28-day curing age was 2450 and 2440 kg/m^3 for mix ratios 1:1:2 and 1:2:4, respectively. At 75% and 100% levels of CS substitution, the density decreased, respectively, to 1900 and 1760 kg/m^3 for mix ratios 1:1:2; and 1840 and 1680 kg/m^3 for mix ratio 1:2:4. At 75% and 100% levels of PKS substitution, the density decreased to 1850 and 1700 kg/m^3, respectively, for mix ratio 1:1:2, while at 50%, 75% and 100% levels of shell substitution for mix ratio 1:2:4, the concrete density decreased to 1860, 1790 and 1630 kg/m^3, respectively. Neville [9] observed that lightweight concrete has a density in the range of 300–1850 kg/m^3. This density range was obtained when 75% of the CSs were used to replace gravel as coarse aggregate for mix ratios 1:1:2 and 1:2:4. This was also true for palm kernel shell concrete (PKSC) made from mix proportion 1:1:2. However, for the other mix ratio (1:2:4), lightweight concrete density range was achieved when 50% of the PKSs were used to replace gravel. The coconut shell concrete (CSC) exhibited higher density than PKSC. For both shells and for the two mix ratios, the density of the concrete decreased as the percentage of shells increased.

3.5. Compressive strength of concrete

The results showed that the compressive strength of the concrete decreased as the percentage of the shells increased in the two mix ratios (Figs. 2–5). It was observed that the concrete compressive strength of the cube specimens increases with increasing age. The results further showed that grades 20 and 15 lightweight concretes can be obtained if the percentage replacement levels of the conventional coarse aggregate with either PKS or CS do not exceed 25% and 50%, respectively, for both mix ratios tested. Figs. 6 and 7 showed that concrete obtained from CSs exhibited a higher compressive strength than PKSC in the two mix proportions.

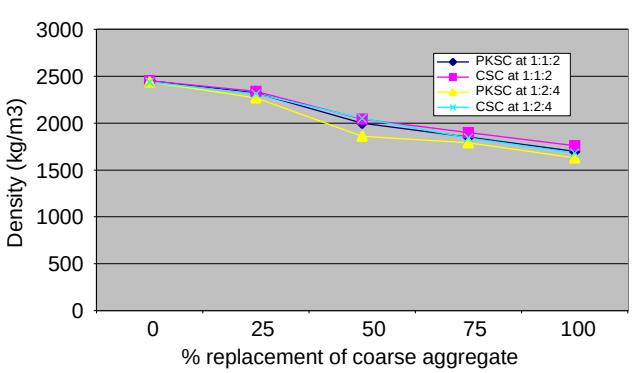

Fig. 1. Density vs. % replacement at 1:1:2 and 1:2:4 mix proportions.

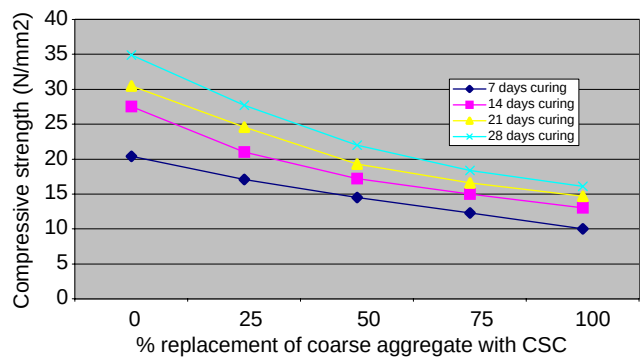

Fig. 2. Compressive strength of CSC of mix proportion 1:1:2.

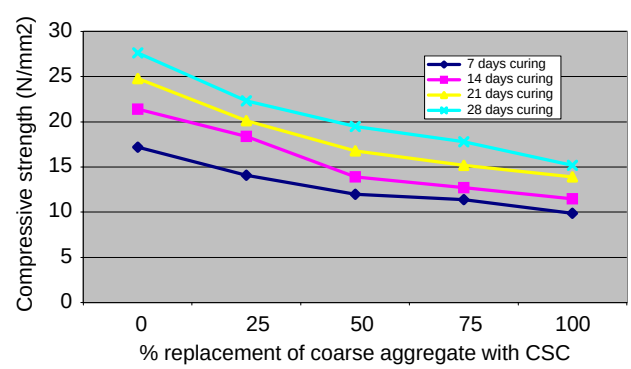

Fig. 3. Compressive strength of CSC of mix proportion 1:2:4.

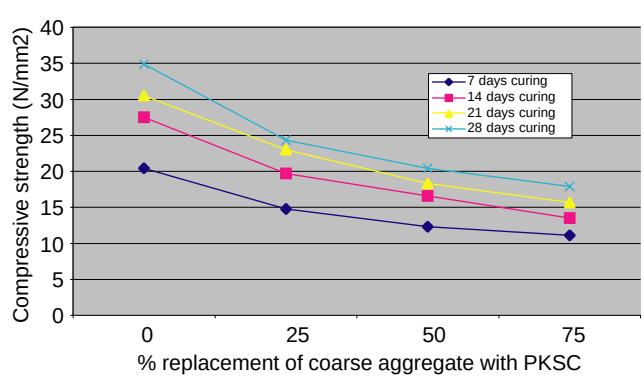

Fig. 4. Compressive strength of PKSC of mix proportion 1:1:2.

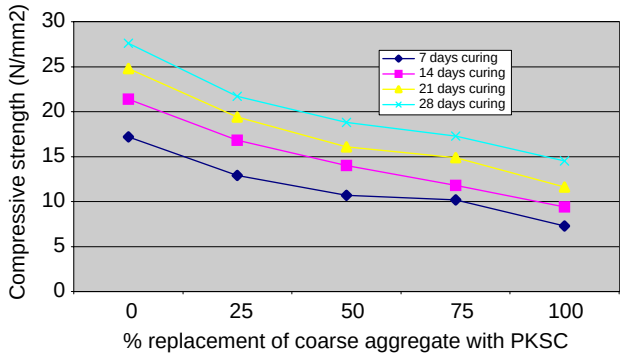

Fig. 5. Compressive strength of PKSC of mix proportion 1:2:4.

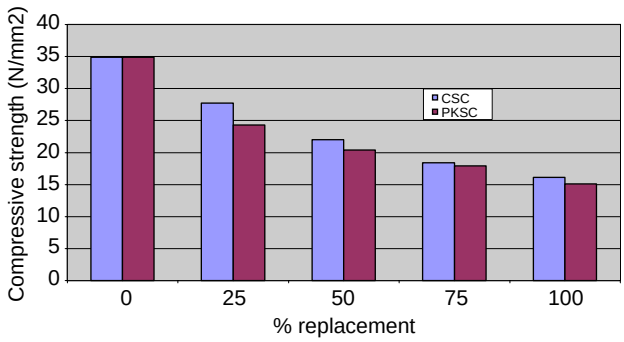

Fig. 6. Comparison compressive strength of CSC and PKSC of mix proportion 1:1:2 at 28 days curing.

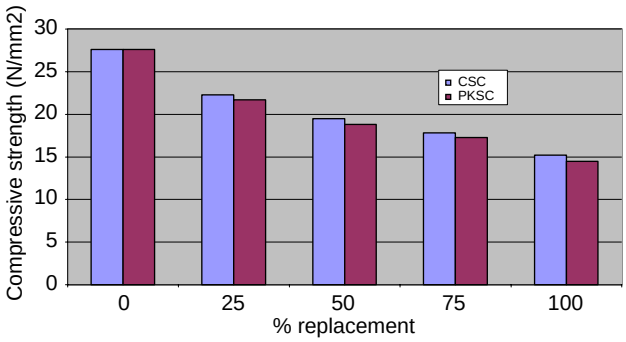

Fig. 7. Comparison compressive strength of CSC and PKSC of mix proportion 1:2:4 at 28 days curing.

3.6. Water absorption capacity

The water absorption tests showed that the percentage water absorption increases with increase in the percentage replacement level of coarse aggregate with PKS and CS. For mix ratio 1:1:2, the values range from 0.41% to 3.98% and 0.41% to 5.88% for CSC and PKSC (10–100% replacement levels), respectively. For mix ratio 1:2:4, the values range from 0.82% to 13.10% and 0.82% to 10.41% for CSC and PKSC, respectively. Higher values were obtained for the PKSC. This might be due to the higher water absorption capacity of the PKSs. However, for mix ratio 1:2:4 at the given water/cement ratios, it appears that PKSC performed better (at substitution level over 50%) with respect to its water absorption capacity (Fig. 8).

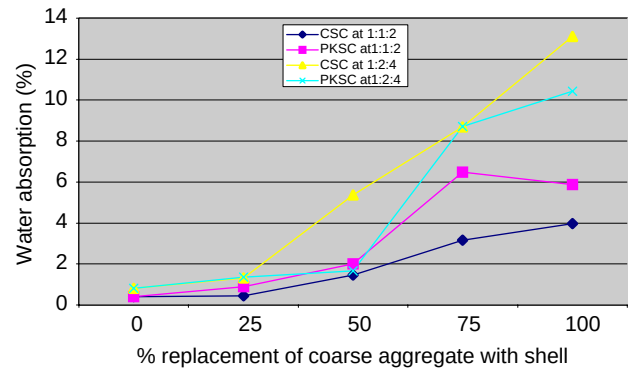

Fig. 8. Comparison of water absorption capacity of CSC and PKSC.

Table 1
Cost/m^3 of concrete (Naira: ₦)[a]

Concrete type	Mix ratio	
	1:1:2	1:2:4
Gravel concrete	10,985	9685
Coconut shell concrete (100%)	7670	6685
Palm kernel shell concrete (100%)	7215	5655

[a] 1$(US) = ₦150.

3.7. Cost analysis

The results of the comparative cost analysis is shown in Table 1. The results showed that between 30% and 42% cost reduction could be achieved if concrete is produced with coconut and PKSs as coarse aggregates. However, it is cheaper to produce concrete from PKSs than CSs.

4. Conclusion and recommendations

A comparative study of concrete properties using CS and PKS as coarse aggregates has been carried out. Generally the compressive strength of the concrete decreased as the percentage shell substitution increased. In all cases, the CSC exhibited a higher compressive strength than PKSC in the two mix proportion tested. Both types of concrete performed fairly equally well in terms of their water absorption capacities. In terms of cost, the PKSC appears to be cheaper. However, considering the strength/economy ratio and expecting further studies on the durability performance of both types of shell concrete, it could reasonably be concluded that CSs would

be more suitable than PKSs when used as substitute for conventional aggregates in concrete production.

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