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Case study

# Structured mixture proportioning for oil palm kernel shell concrete

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ABSTRACT

Proportioning based on the principles of absolute volume method was used to obtain specific properties of lightweight concrete of oil palm kernel shells (OPKS). The sand content was determined depending on the cement content and OPKS/sand ratio. The trapped air volume of 5% and Water/cement ratio of 0.45 were fixed according to previous authors' works. The cement content ranged from 400 to 550 kg/m$^3$, and the OPKS/sand ratio ranged from 0.4 to 0.75. The mixture proportions of C:S:OPKS in weight of 1:1.60:0.96 and 1:1.53:0.99 with cement content of 450 kg/m$^3$ resulted in values for workability (≥20 mm), density ($1800 \le d \le 1900\ kg/m^3$) and cylindrical compressive strength (≥ 15 MPa), which are recommended by ACI and British Code for structural lightweight concrete. This study, as part of efforts toward a structured method of proportioning of eco-friendly composite, demonstrates the possibility of linking mix proportions to properties of lightweight OPKS concrete.

## 1. Introduction

In Benin, more than 300,000 t of oil palm kernel shells (OPKSs) are produced each year [1]. In areas of production, traditionally near rural populations, OPKSs are often used as coarse aggregate for concrete in structural elements in houses (both with and without multiple storeys), which is the case in several tropical countries [2]. Moreover, [3] the established high resistance to blast load of OPKS concrete (OPKSC) structures, as compared to normal weight concrete (NWC) structures, indicates the possibility of efficient use of OPKSC in buildings with potential threats of bombs attack, specifically, as caused by terrorist activities. Despite the usefulness of OPKSC, few papers have been devoted to mix design using OPKSC, which could be used by the majority of the population of tropical, oil-palm-producing countries. Concrete mixture proportioning is used to calculate the quantities of different constituents required to achieve different physical properties [4].

For light-weight aggregate concrete (LWAC) with mineral coarse aggregates, there exist mix design methods that follow a rigorous sequence of steps that consider performance specifications. However, no such methods exist for concrete using organic coarse aggregates, namely, OPKSs [5]. In Malaysia and Nigeria, several studies have been undertaken over the past 30 years to study the mix design of structural LWC using OPKS as an aggregate [6–11]. Most mix design methods for OPKS concrete that satisfy technical specifications for structural LWC were based on trial and error or empirical methods. With the trial and error method, it is not always possible to predict the value of specific properties of the concrete; however, engineers are mainly concerned with obtaining specific properties when proportioning a concrete mixture. Some work has been conducted to determine the ranges of mix ratios that result in desired values of concrete properties. Some experimental results are available [12]; however, it is still necessary to further refine the range of values of the coarse/fine aggregate ratio in the process of designing structural LWC using OPKS as a coarse aggregate.

In the present study, we proposed a structured method for trial mix proportioning of structural LWC using OPKS from Benin as a coarse aggregate. This method was based on the principles of the absolute volume method in ACI 213. This approach is conducive to

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**Table 1**
Physical properties of constituents of OPKS concrete.

| Properties | Constituents of OPKS concrete from Benin | | Constituents of OPKS concrete used elsewhere [12] | |
|---|---|---|---|---|
| AGGREGATES (SAND = Fine, OPKS = Coarse) | | | | |
| | Sand | OPKS | Sand | OPKS |
| Specific gravity | 2.59 | 1.31 | 2.60 | 1.17 |
| Loose bulk density (kg/m$^3$) | 1410 | 530 | – | 500–600 |
| Water absorption, 24 h, (%) | – | 19.93 | – | 23.32 |
| Fineness modulus | 2.4 | – | 2.56 | – |
| Aggregate abrasion value (Los Angeles),% | – | 5.02 | – | 4.80 |
| Type of cement | CEM II 32.5 | | CEM I 42.5 | |

recommending mix proportions of concrete that allow its use for structural elements in low cost buildings in tropical countries and in earthquake prone areas.

## 2. Properties of constituents of OPKS concrete

The OPKS used were collected from an artisanal mill at Missérété 6°35′43.4”N; 2°35′26.9”E and were freshly discarded. The shells were thoroughly rinsed with potable water and dried in the sun for 4 h. Next, the shells were stored in containers. Most of the shells were within a thickness range of 1.50 to 2.50 mm. The shape of the OPKS aggregate varied between irregularly flaky shaped, angular, and polygonal. The surface texture of the shell was fairly smooth. The broken edges were rough and pointy. The shells used were in the saturated surface dry (SSD) condition. The particles size of sand and OPKS were in the range between 0 and 10 mm, and 1 −and 16 mm, respectively. The other measured physical properties of OPKS were compared with those obtained by previous authors, as shown in Table 1.

## 3. Mixture proportioning for OPKS concrete

The mixture proportioning procedure is as follows:

1. Establish the specific properties of the lightweight OPKSC for structural elements in low cost buildings: slump [13], density [12], and 28-day compressive strength [4].
2. Determine the physical properties of constituents of concrete based on the applicable codes. For sand, we consider specific gravity, loose bulk density, fineness of modulus, and grading curve. For OPKS, we consider specific gravity, loose bulk density, water absorption after 24 h, aggregate abrasion value, and grading curve.
3. Choose the water/cement ratio based on the targeted 28-day compressive strength using the data from previous authors [12], as presented in Table 2.
4. Determine the cement content [12] in the range of 400 to 550 kg/m$^3$ based on the slump value and the 28-day compressive strength.
5. Determine the OPKS/sand ratio depending on the targeted slump value and the 28-day compressive strength.
6. Determine the air content ratio [14] in the range of 4.8–5.1
7. Calculate the sand content, based on the principles of the absolute volume method of ACI 213,

$$V_{OKPS} + V_{Sand} + V_{Cement} + V_{Water} + V_{Air} = 1 \quad (1)$$

Using the specific gravity and by applying $W/C = k_W$ and $OPKS/Sand = k_{OPKS}$, we have:

$$S = \frac{(1 - V_{Air}) - C\,(1/\rho_C + k_W/\rho_W)}{(1/\rho_S + k_{OPKS}/\rho_{OPKS})} \quad (2)$$

**Table 2**
Water/cement ratio for compressive strength (≥15 MPa), recommended by ACI and British code for structural LWC, obtained from the data of previous authors as reported by [12], for concrete without admixture.

| Study | Mix proportion | Water/cement | 28-day compressive strength (MPa) |
|---|---|---|---|
| Abdullah (1984) | 1:2:0.6 | 0.40 | 20.50 |
| Okafor (1988) | 1:1.70:2.08 | 0.48 | 23.00 |
| Okpala (1990) | 1:1:2 | 0.50 | 22.30 |
| | 1:2:4 | 0.50 | 18.90 |
| Teo and Lew (2006) | 1:1.12:0.80 | 0.41 | 22.00 |
| Range for water/cement ratio is from 0.40 to 0.50 | | | |