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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 ($1800 \leq d \leq 1900\ kg/m^3$) 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,

$$V_{OKPS} + V_{Sand} + V_{Cement} + V_{Water} + V_{Air} = 1 \tag{1}$$

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

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

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			

Table 3
Mix proportions for OPKS concrete according to the proposed method [w/c = 0.45; OPKS = SSD; Mix proportion by weight].

Mix order	Cement content (kg/m^3)	OPKS/sand ratio	Mix proportion C:S:OPKS
		0.40	–
		0.45	–
C1	400	0.50	1:2.10:1.05
C2		0.55	1:2.00:1.10
C3		0.60	1:1.91:1.15
C4		0.65	1:1.83:1.19
C5		0.70	1:1.75:1.23
C6		0.75	1:1.68:1.26
		0.40	–
		0.45	–
C7	450	0.50	1:1.76:0.88
C8		0.55	1:1.67:0.92
C9		0.60	1:1.60:0.96
C10		0.65	1:1.53:0.99
C11		0.70	1:1.47:1.03
C12		0.75	1:1.41:1.06
		0.40	–
C13	500	0.45	1:1.56:0.70
C14		0.50	1:1.48:0.74
C15		0.55	1:1.41:0.78
C16		0.60	1:1.35:0.81
C17		0.65	1:1.29:0.84
C18		0.70	1:1.24:0.86
		0.75	–
C19	550	0.40	1:1.40:0.56
C20		0.45	1:1.32:0.60
C21		0.50	1:1.26:0.63
C22		0.55	1:1.20:0.66
C23		0.60	1:1.14:0.69
C24		0.65	1:1.09:0.71
		0.70	–
		0.75	–

- Determine the OPKS content using the OPKS/sand ratio and sand content determined above.
- Determine the trial mix proportion and adjust the value based on the slump value.
- Calculate the final mix proportion.

To test the proposed method, taking into account the values obtained by most previous authors [12], we fixed V_{Air} and k_W in formula 2, the cement content C and the k_{OPKS} ratio. Based on [11], we varied C in the range of 400 to 550 kg/m^3 with a step of 50 kg/m^3. For all values of C, k_{OPKS} was within the range of 0.40–0.75. According to the traditional practices regarding OPKS concrete in Benin, the most common value of k_{OPKS} is 0.6 for structural LWC. The obtained mix proportions are presented in Table 3.

4. Results and discussion

We found that the slump increases as cement content increases, regardless of the value of the OPKS/sand ratio, with a difference

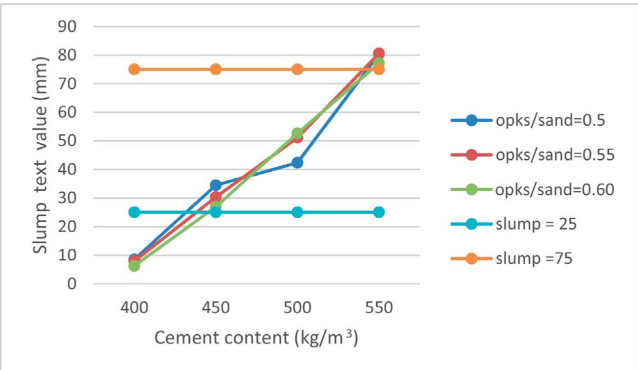

Fig. 1. Slump vs Cement content.

Table 4
Recommended cement content ranges based on OPKS/sand ratio for suitable workability of OPKSC for structural elements.

No	OPKS/sand ratio	Range for cement content in kg/m^3
1	0.50	432–467
2	0.55	438–485
3	0.60	445–520
4	0.65	458–520

of 95% between minimum and maximum values (Fig. 1). Because the water/cement ratio is constant and equal to 0.45, the increase in the cement content is equivalent to the increase in free water, and consequently, the cement paste. Moreover, for a cement content of 400 and 450 kg/m^3 and for all OPKS/sand ratios, it is observed that the slump decreases as the quantity of shells increases, which is caused by the specific surface area of the shells increasing with the quantity of shells, and therefore, more water would be required. Conversely, for *C*above 450 kg/m^3, the variation of the slump value versus OPKS/sand ratio does not follow the logic of the growth of the slump value based on the decrease of the OPKS quantity, as demonstrated by [11]. Taking into account the physical properties of the ingredients of OPKSC, the recommended values of the slump, based on ACI 211 for LWC in structural elements (25–75 mm), and the principles that the workability of fresh OPKSC decreased with an increase in the volume of OPKS (see Fig. 1), for suitable OPKS/sand ratios, the recommended range of values for cement content would be as follows: For each OPKS/sand ratio, the lower limit is equal to the cement content corresponding to the point in Fig. 1 at which the slump value is equal to 25 mm given by the corresponding curve of OPKS/sand ratio; the upper limit is equal to the cement content corresponding to the first point at which the slump decreased with an increase in OPKS (additionally, at the same point, the slump was lower than 75 mm). The results are presented in Table 4 below.

For each OPKS/sand ratio the recommended cement content range is within the range of values proposed by [15]. The corresponding mix proportions are C7, C8, C9, and C10 based on suitable slump for structural elements.

For each class of cement, it is observed that the obtained densities of OPKSC were between 1800 and 1900 kg/m^3, and thus, fell within the range of values allowed for structural LWC according to Mindess and Young, as cited by [16]. Moreover, note that the density of the OPKSC decreased as the percentage of shells increased for class cement at 400 and 450 kg/m^3. This trend was also observed by [11], [17], and [18]. Based on the results of workability and the maximum value of 1900 kg/m^3 [19], we recommend mix proportions C7, C8, C9, and C10.

For every class of cement, the 28-day compressive strength increased to a maximum value before decreasing, with the specific trend dependent on the quantity of shells in the concrete mix (see Figs. 2–5). At a density of 450 kg/m^3, we recorded the greatest value of 28-day cylindrical compressive strength at 18.63 MPa, corresponding to 447.36 kg of OPKS in one cubic metre of concrete. This content is in the range of values (290–450 kg) for OPKS in structural LWC, as reported by [20]. At densities of 500 and 550 kg/m^3, the compressive strength was influenced by the strength of the cement matrix. With regard to strength, the mix proportions of C9 and C10 were chosen for good workability and acceptable density.

None of the previous authors who used rigorous mix design methods such as those of ACI [21], the specific gravity method [22], or traditional mixes of 1: 2: 4 [7] obtained the specific properties required for structural LWC. The use of admixtures was necessary in some cases. The proposed method, which does not use an admixture, is based on i) the general approach followed in the mix design of concrete using conventional aggregates and ii) the results of numerous studies carried out over several years relating to the mix

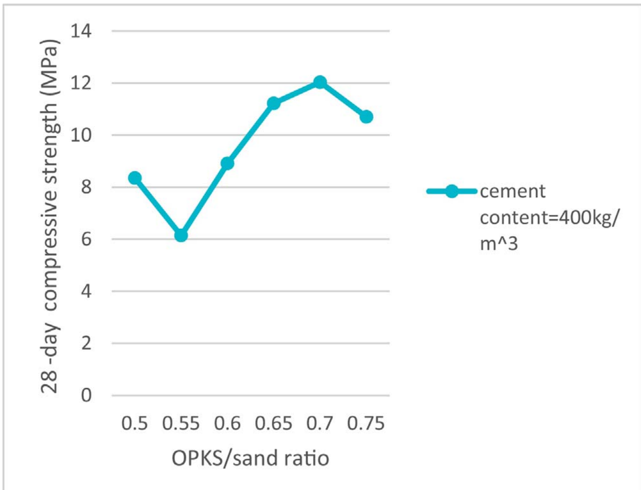

Fig. 2. Cylindrical compressive strenght vs OPKS/sand, for cement content = 400 kg/m^3.

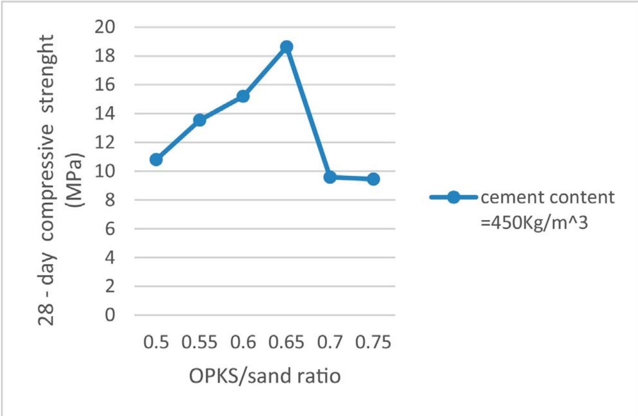

Fig. 3. Cylindrical compressive strength vs OPKS/sand, for cement content = 450 kg/m^3.

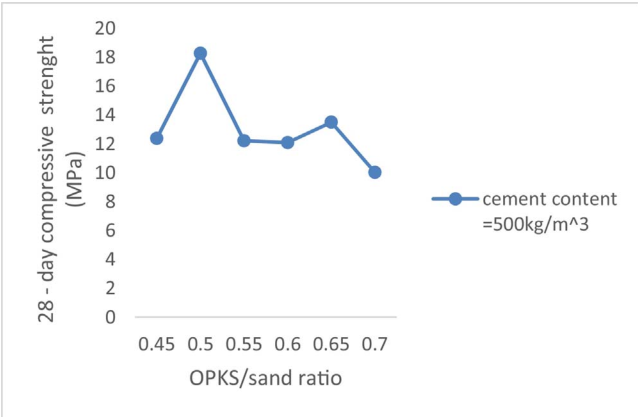

Fig. 4. Cylindrical compressive strength vs OPKS/Sand, for cement content = 500 kg/m^3.

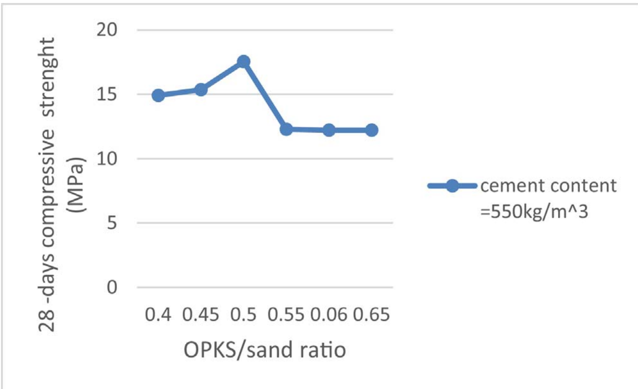

Fig. 5. Cylindrical compressive strength vs OPKS/sand, for cement content = 550 kg/m^3.

design of concrete based on oil palm kernel shells. One of the limitations of the proposed method is that the parameters that had been obtained by previous authors were not experimentally verified before their use in comparing the physical properties of the constituents of the studied OPKSC. The proposed method is a step toward the codification of OPKS as a coarse aggregate in concrete for structural elements in low cost buildings in tropical, oil-palm-producing countries, as was suggested by researchers like [9].

5. Conclusions

The mix proportions of C:S:OPKS in weight of 1:1.60:0.96 and 1:1.53:0.99 with cement content of 450kg/m^3 and $w/c = 0.45$ had resulted in obtaining appropriate values for workability (≥20 mm), density ($1800 \leq d \leq 1900\ kg/m^3$) and cylindrical compressive strength (≥ 15 MPa), recommended by ACI and British Code for structural lightweight concrete. This study, as part of efforts to develop a structured method of proportioning of eco-friendly composite, demonstrates the possibility of linking mix proportions to properties of lightweight OPKS concrete and therefore makes the use of locally available materials in developing countries more feasible.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cscm.2017.04.004.

References

[1] MAEP, Plan Stratégique de Relance du Secteur Agricole, (2011) 116 pages. http://www.inter-reseaux.org/IMG/pdf/PSRSA_version_finale.pdf (31 08 2016).
[2] D.C.L. Teo, M.A. Mannan, V.J. Kurian, Structural concrete using oil palm shell (OPS) as lightweight aggregate, Turk. J. Eng. Environ. Sci. 30 (2006) 251–257.
[3] U.J. Alengaram, N.H.W. Mohottige, C. Wu, M.Z. Jumaat, Y.S. Poh, Z. Wang, Response of oil palm shell concrete slabs subjected to quasi-static and blast loads, Constr. Build. Mater. 116 (2016) 391–402, http://dx.doi.org/10.1016/j.conbuildmat.2016.04.103.
[4] P.A. Claisse, Civil engineering materials, Elsevier B.H., 2016. http://www.sciencedirect.com/science/book/9780081002759 (accessed March 4, 2017).
[5] B. Basri H, M.A. Mannan, M.F.M. Zain, Concrete using waste oil palm shells as aggregate, Cem. Concr. Res. (1999) 619–622.
[6] M.A. Mannan, C. Ganapathy, Mix design for oil palm shell concrete, Cem. Concr. Res. 31 (2001) 1323–1325, http://dx.doi.org/10.1016/S0008-8846(01)00585-3.
[7] E.A. Olanipekun, K.O. Olusola, O. Ata, A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates, Build. Environ. 41 (2006) 297–301, http://dx.doi.org/10.1016/j.buildenv.2005.01.029.
[8] D.C.L. Teo, M.A. Mannan, V.J. Kurian, C. Ganapathy, Lightweight concrete made from oil palm shell (OPS): Structural bond and durability properties, Build. Environ. 42 (2007) 2614–2621, http://dx.doi.org/10.1016/j.buildenv.2006.06.013.
[9] D.Y. Osei, E.N. Jackson, Experimental study on palm kernel shells as coarse aggregates in concrete, Int. J. Sci. Eng. Res. 3 (2012) 1–6.
[10] M. Yong, J. Liu, U.J. Alengaram, M. Santhanam, M. Zamin, K. Hung, Microstructural investigations of palm oil fuel ash and fly ash based binders in lightweight aggregate foamed geopolymer concrete, Constr. Build. Mater. 120 (2016) 112–122, http://dx.doi.org/10.1016/j.conbuildmat.2016.05.076.
[11] S.M.Z, E. Serri, O.M.A. Mydin, M. Suleiman, The influence of mix design on mechanical properties of oil palm shell lightweight concrete, J. Mater. Environ. Sci. 6 (2015) 607–612.
[12] U.J. Alengaram, B. Abdullah, A. Muhit, M. Zamin, Utilization of oil palm kernel shell as lightweight aggregate in concrete–A review, Constr. Build. Mater. 38 (2013) 161–172, http://dx.doi.org/10.1016/j.conbuildmat.2012.08.026.
[13] S.G. Barton, L.W. Bell, G.R.U. Berg, J.E. Cook, R.A. Cook, W.J. Costa, K.W. Day, S.H. Lee, G.R. Mass, J.S. Pierce, H.C. Robinson, D.A. Crocker, J.A. Scherocman, M.A. Taylor, S.J. Virgalitte, J.W. Weber, D.J. White, Standard Practice for Selecting Proportions for Structural Lightweight Concrete (ACI 211. 2–98) Reported by ACI Committee 211, (1998) 1–18.
[14] M.A. Mannan, C. Ganapathy, Concrete from an agricultural waste-oil palm shell (OPS), Build. Environ. 39 (2004) 441–448, http://dx.doi.org/10.1016/j.buildenv.2003.10.007.
[15] S.M.Z, E. Serri, M.A. Othuman, The effect of mix design on mechanical and thermal properties oil palm shell (OPS) lightweight concrete, J. Mater. Environ. Sci. 4 (2014) 203–207, http://dx.doi.org/10.5923/c.jce.201402.34.
[16] M.A. Mannan, C. Ganapathy, Mix design for oil palm shell concrete, Cem. Concr. Res. 31 (2001) 1323–1325, http://dx.doi.org/10.1016/S0008-8846(01)00585-3.
[17] D.Y. Osei, E.N. Jackson, Experimental Study on Palm Kernel Shells as Coarse Aggregates in Concrete, Int. J. Sci. Eng. Res. 3 (August 8) (2012) 1–6 ISSN 2229-5518.
[18] D.O. Oyejobi, T.S. Abdulkadir, I.T. Yusuf, M.J. Badiru, Effects of Palm Kernel Shells Sizes and Mix Ratios on Lightweight Concrete, USEP: J. Res. Inform. Civil Eng. 9 (2), 2012.
[19] S. Mindess, J.F. Young, Concrete, Prentice H, Englewood Cliffs, NJ, 1981.
[20] P. Shafigh, M.Z. Jumaat, H. Mahmud, Mix design and mechanical properties of oil palm shell lightweight aggregate concrete: a review, Int. J. Phys. Sci. 5 (2010) 2127–2134.
[21] M.A. Mannan, C. Ganapathy, Engineering properties of concrete with oil palm shell as coarse aggregate, Constr. Build. Mater. 16 (2002) 29–34, http://dx.doi.org/10.1016/S0950-0618(01)00030-7.
[22] U.J. Alengaram, M.Z. Jumaat, H. Mahmud, Ductility behaviour of reinforced palm kernel shell concrete beams, Eur. J. Sci. Res. 23 (2008) 406–420 http://www.scopus.com/inward/record.url?eid = 2-s2.0-65449171264 & partnerID = 40 & md5 = 0188422c38f6f2089d4977a30af926ff\nhttp://www.eurojournals.com/ejsr.htm.