Chapter 8

Mixture Proportioning for Oil Palm Kernel Shell

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.75601

Abstract

Oil palm kernel shell (OPKS) is an organic lightweight aggregate (LWA) used as coarse aggregate in tropical countries for concrete in low-cost buildings. Concrete mixture proportioning is used to calculate the quantities of different constituents required to achieve different properties. For LWA concrete with mineral aggregate, there exist mix design methods that follow rigorous sequence of steps that consider performance specifications. However, no such method exists for concrete using organic coarse aggregate, namely, OPKS. The methods that exist for OPKS concrete that satisfy technical specifications for structural lightweight concrete (LWC) are based on trial and error or empirical methods. With 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. The present topic presents a structured method for trial mix proportioning of structural LWC using OPKS as coarse aggregate. Based on the principle of the absolute volume method in ACI 213, the method is presented, following the below headings: (1) properties of constituents of OPKS concrete; (2) mix design procedure; and (3) results and discussion. Technicians in tropical oil-palm-producing countries for low-cost buildings can use the presented method.

Keywords: lightweight concrete, mix proportioning, compressive strength, oil palm kernel shell, Benin

1. Introduction

The oil palm sector in the Republic of Benin is experiencing a revival since the last 10 years with a production estimated to be more than 505,000 tons in 2015 [1]. This production, according to the Ministry in charge of agriculture, is expected to increase to reach 800,000 tons by 2030. From the industrial and artisanal transformation of this product, we obtain among others, oil palm kernel shells (OPKSs), considered as vegetable waste. In areas of production, traditionally near rural populations, OPKS is often used in the building of houses with and without multiple storeys. The OPKSs are used as coarse aggregate for the concrete of structural elements (**Figure 1**). To date, it is permissible to note the apparent good record of service of most of these buildings, constructed more than 30 years back. However, despite the wide availability of OPKSs, the lack of reliable technical information behind OPKS concrete making has led to reluctance by conventional professionals. For the moment, in Republic of Benin as in other oil-palm-producing countries, these materials have little commercial value, despite their technical qualities: (1) they have a relatively low weight and are naturally sized; (2) they are hard enough to break and are of organic origin; and (3) once embedded in the cement matrix of concrete, they do not have any toxic effects on the concrete because they are imputrescible [2]. Moreover, in some of the production areas, the OPKSs are recovered and burned in the cement industry under conditions that do not necessarily satisfy the requirements relating to good management of air pollution. As in Benin, OPKSs are available in large quantities in almost all tropical countries and the problem of managing OPKSs is posed almost in the same way. In such countries as Malaysia and Nigeria, several studies have been undertaken in the past 30 years with success in studying the mix design of structural lightweight concrete using OPKSs as aggregate [2–9]. Most mix design methods for OPKS concrete that satisfy the requirements of technical specifications for structural lightweight concrete were based on trial and error or on empirical methods because the methods based on the proven structured methods for normal and lightweight structural concrete with mineral aggregates had failed. With the trial and error method, it is not always possible to predict the value of specific properties of the concrete, whereas an engineer is mainly concerned with obtaining these specific properties in the process of proportioning a concrete mixture. To lead to that, one of the ways consists of the determination of ranges of values for the ratios of water/cement, cement/aggregates, coarse aggregate/fine aggregate, as well for the cement content that can permit to get the targeted specifications. Some results are available [10], but it is still necessary to work to further refine the range of values of the coarse/fine aggregate ratio in the process of designing structural lightweight concrete using OPKSs as coarse aggregate.

In the present study, a trial mix is proposed for a structural lightweight concrete using OPKSs of Benin as coarse aggregate, based on the principle of absolute volume methodology of ACI 213.

a) b)

Figure 1. An example of a one-storeyed house in Missérété, constructed in 2014 with the use of OPKS concrete for the supporting elements. (a) Overview of the ongoing building. (b) Zoom on the columns of the main facade, showing on their surface the oil palm kernel shells in the cement matrix.

This approach is conducive to recommending mix proportions of concrete that allow its use for structural elements in low- and moderate-cost buildings in tropical countries and in earthquake-prone areas.

2. Properties of constituents of OPKS concrete

OPKS concrete (OPKSC) is a judicious mix of cement, sand, OPKSs, and water. As the mechanical properties of OPKSC are largely influenced by the physical properties of OPKS, in the present chapter, the emphasis is on the study of the properties of OPKS. OPKSs used as coarse aggregate in OPKSC are one of the wastes produced during the process of obtaining palm oil. For that six stages are necessary: sterilization, threshing, pressing, depericarping, separation of kernel and shell, and clarification [11]. For the present study, the OPKSs used were collected from an artisanal mill at Missérété 6°35′43.4″N; 2°35′26.9″E and were freshly discarded (**Figure 2**).

They were thoroughly rinsed with potable water and dried in the sun for 4 h, in order to remove impurities, present on the shells. Then, they had been stored in containers. After the pretreatment, OPKS aggregate needs to be treated before using in concrete [12]. Various treatment processes are mentioned in the literature to remove the impurities (dust and oil coating) from aggregates [13–18].

In this study, the treatment method used consists of the following:

- Put 30 kg of OPKS in an aqueous solution of potassium hydroxide with a mass concentration of 7.4 g/l for 2 h.
- Wash the shells with potable water in the sun, until the shells surface became dry.

Figure 2. OPKS waiting for a transaction at Missérété.

Figure 3. Different size of Oil Palm Kernel Shell for the concrete mixing.

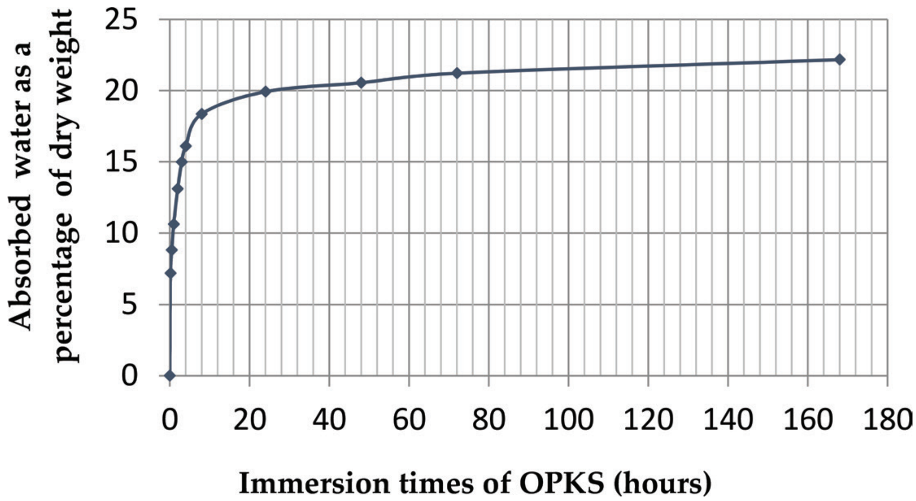

Figure 4. Curve of water absorption of the used OPKS.

Figure 5. Draining of OPKSC after imbibition to obtain saturated surface dry (SSD) status.

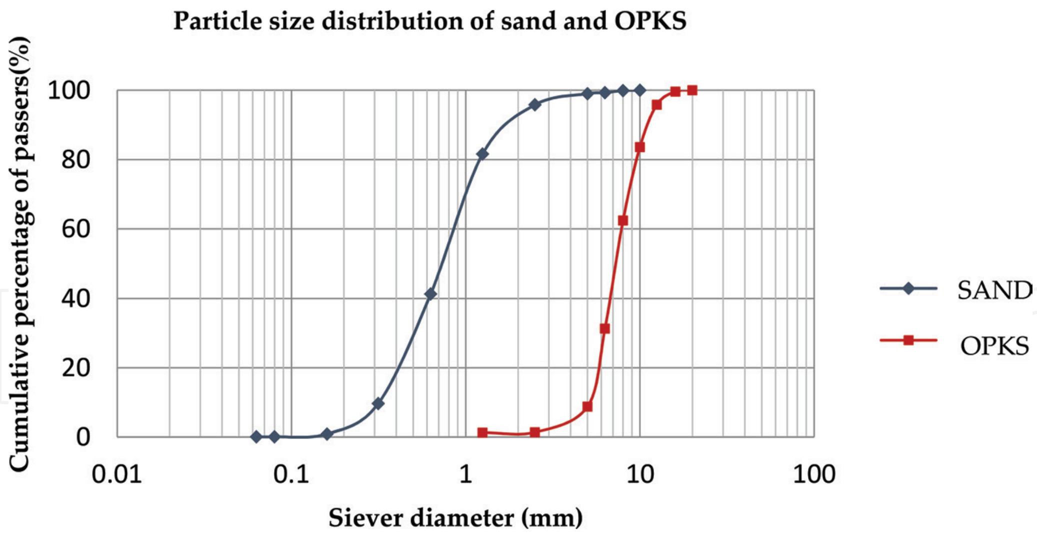

Figure 6. Particle size distribution of sand and OPKS.

Properties	Constituents of OPKS concrete from Benin		Constituents of OPKS concrete used elsewhere [10]	
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	

Table 1. Physical properties of constituents of OPKS concrete.

Most of the shells were within the thickness range of 2.00–6.00 mm. The shape of the OPKS aggregate varies irregularly as flaky shaped, angular, or polygonal as shown in **Figure 3**. The surface texture of the shell was fairly smooth for both concave and convex faces. The broken edges were rough and spiky. To take into account the fact that the shells absorb water (**Figure 4**), we used them in saturated surface dry condition as shown in **Figure 5**. Particle size distribution for OPKS and sand are shown in **Figure 6**. The other measured physical properties of OPKS were compared with those obtained by previous authors and are shown in **Table 1**.

3. Mix design procedure for OPKS concrete

3.1. Trial mixture proportions

The lightweight concrete (LWC) mix design is usually established by trial mixes [19]. In the preliminary investigation of OPKS concrete mix proportion, the procedure followed was the method for lightweight concrete proposed by Georges Dreux [20]. As mentioned in **Table 2**, the obtained cylindrical compressive strength was far below the targeted designed strength, and what that means is that the method is not appropriate for the mixing of structural lightweight concrete using OPKS.

According to [21], the best approach to making a first trial mixture of lightweight concrete, which has given properties and uses a particular aggregate from a lightweight aggregate source, is to use proportions previously established for a similar concrete using aggregate from the same aggregate source. Based on the similarity of the physical properties of the constituents of OPKS concrete (**Table 1**), in a second approach, the mix proportions proposed by Mannan [3] was used. The obtained results were presented in **Table 3**. The 28-day cylindrical compressive strength of 23.50 MPa obtained is greater than the 17 MPa required by ACI [22]. This shows that the said method of mix proportioning is suitable for mix design of structural lightweight concrete, using OPKS from Benin, and therefore can be recommended. Though effective, the method proposed by Mannan is a trial and error method. It does not give the flexibility to vary the mix ratio in order to change the technical specifications of the concrete in the event of need.

3.2. Experimental method of mix proportioning

According to ACI 213 [23], the absolute volume method considers that the volume of fresh concrete, produced by any combination of materials, is considered equal to the sum of the absolute volumes of cementitious materials, aggregate, net water, and entrapped air. The approach proposed by ACI 213 is based on the use of the indications of the ACI 211 [24], which is a method of mix proportioning, often used for concrete of normal weight aggregates. Mannan [3] has proven that this approach does not give good results for the mix design of structural lightweight OPKS aggregate. In this study, we agree to use the principle defined by said method, through its definition, that is to say:

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

Using the specific gravity, the formula (Eq. (1)) can be rewritten:

$$\frac{C}{\rho_C} + \frac{S}{\rho_S} + \frac{W}{\rho_W} + \frac{OPKS}{\rho_{OPKS}} + V_{Air} = 1 \tag{2}$$

By applying $\frac{W}{C} = k_W$ and $\frac{OPKS}{S} = k_{OPKS}$ we have:

$$C\left(\frac{1}{\rho_C} + \frac{k_W}{\rho_W}\right) + S\left(\frac{1}{\rho_S} + \frac{k_{OPKS}}{\rho_{OPKS}}\right) + V_{Air} = 1$$

$$S = \frac{(1 - V_{Air}) - C\left(\frac{1}{\rho_C} + \frac{k_W}{\rho_W}\right)}{\left(\frac{1}{\rho_S} + \frac{k_{OPKS}}{\rho_{OPKS}}\right)} \tag{3}$$

				28-Day compressive strength (N/mm²)	
Mix order	OPKS/Sand Ratio (by absolute volume)	Mix proportion C:S:OPKS	Demoulded density (kg/m³) (NF EN 12350-6)	Obtained strength (EN12390-3)	Targeted design strength
A1	2.1	1:1.05:1.21	1570.59	4.67	25.00
A2	1.6	1:1.26:1.09	1766.52	7.27	25.00
A3	1.0	1:1.64:0.89	1826.65	8.11	25.00
A4	0.8	1:1.82:0.79	1881.30	9.25	25.00
A5	0.6	1:2.04:0.67	1893.16	10.65	25.00

Table 2. Mix design for OPKS concrete according to Dreux [OPKS aggregates: saturated surface dry (SSD) conditions, bulk density = 0.53, specific gravity = 1.43; cement: CPJ 35 (type CEM II, 32.5), Density = 3.10, genuine class = 450 bar, content = 530 kg/m³; sand: Bulk density = 1.41, specific gravity = 2.63; w/c ratio = 0.48; wished slump = 5 cm; mix proportion by weight, C = cement, S = sand, OPKS = oil palm kernel shell].

	Proportion by weight of cement (cement = 480 kg/m³), w/c = 0.41			Demoulded density (kg/m³)	Fresh property (slump, mm)	28-Day compressive strength (N/mm2)
	Cement	Sand	OPKS			
B1	1.00	1.71	0.77	1890–1905	7	24.20[a]
B2	1.00	1.71	0.77	1889–1941	9	23.50[b]

[a]Compressive strength obtained by Mannan [3].
[b]Compressive strength obtained by authors.

Table 3. Mix design for OPKS concrete according to [3].

where S denotes the sand content in kg/m^3 of concrete, V_{Air} denotes the entrapped air content in $litres/m^3$ of concrete, C denotes the cement content in kg/m^3 of concrete, ρ_C denotes the density (specific gravity) of the cement in kg/m^3 of concrete, ρ_S denotes the mean particle density (specific gravity) of the sand in kg/m^3 of concrete, and ρ_{OPKS} denotes the mean particle density (specific gravity) of the OPKS in kg/m^3 of concrete.

As the specific gravity of all constituents of the mix were known (see Section 2), the entrapped air volume V_{Air} and the ratio k_W were fixed, taking into account the values obtained by most of previous authors [10, 25]. Thus, the only unknown quantities in the formula (Eq. (3)) were the cement content, C, and the k_{OPKS} ratio. Knowing that, according to Basri et al. [26], the cement contents range from 285 to 510 kg/m³; we agreed in this study to vary the cement content classes from 400 to 550 kg/m³ with a step of 50 kg/m³. For each class of cement, we varied the k_{OPKS} ratio from 0.50 to 0.75. Indeed, according to the practice of traditional use of OPKS concrete in Benin, the average value of this ratio is 0.6 for the mix proportion of structural lightweight concrete. The obtained results were presented in **Table 4**.

Mix order	Cement content	OPKS/Sand ratio	Mix proportion	Demoulded density	Fresh property	Average Cylindrical 28-day Compressive strength
	(kg/m^3)		C:S:OPKS	(kg/m^3)	(Slump, mm)	(N/mm^2), 28-day
		0.45	—	—	—	—
C1		0.50	1:2.10:1.05	1872.63	8.5	8.35
C2	400	0.55	1:2.00:1.10	1875.44	7.92	6.14
C3		0.60	1:1.91:1.15	1838.74	6.23	8.91
C4		0.65	1:1.83:1.19	1829.82	5.1	11.22
C5		0.70	1:1.75:1.23	1811.33	4.7	12.03
C6		0.75	1:1.68:1.26	1789.50	3.86	10.70
		0.40	—	—	—	—
		0.45	—	—	—	—
C7	450	0.50	1:1.76:0.88	1859.40	34.50	10.80
C8		0.55	1:1.67:0.92	1876.81	30.35	13.54
C9		0.60	1:1.60:0.96	1840.09	26.98	15.19
C10		0.65	1:1.53:0.99	1843.79	22.01	18.63
C11		0.70	1:1.47:1.03	1790.92	16.38	9.58
C12		0.75	1:1.41:1.06	1759.35	16.25	9.44
		0.40	—	—	—	—
C13		0.45	1:1.56:0.70	1895.35	47.07	12.38
C14	500	0.50	1:1.48:0.74	1887.08	42.36	18.27
C15		0.55	1:1.41:0.78	1901.31	51.12	12.21
C16		0.60	1:1.35:0.81	1879.85	52.67	12.09
C17		0.65	1:1.29:0.84	1849.70	48.16	13.50
C18		0.70	1:1.24:0.86	1798.10	27.07	10.03
		0.75	—	—	—	—
C19	550	0.40	1:1.40:0.56	1920.86	86.84	14.91
C20		0.45	1:1.32:0.60	1857.09	125.01	15.36
C21		0.50	1:1.26:0.63	1892.48	80.4	17.54
C22		0.55	1:1.20:0.66	1893.12	80.60	12.28
C23		0.60	1:1.14:0.69	1866.81	77.15	12.21
C24		0.65	1:1.09:0.71	1851.51	83.09	12.21
		0.70	—	—	—	—
		0.75	—	—	—	—

Table 4. Mix design for OPKS concrete based on the variation of the OPKS/Sand ratio and the cement content [w/c=0.45; Stage of OPKS=saturated surface dry; Mix proportion by weight].

4. Results and discussion

4.1. Workability

The workability increased with increasing cement content and sand content but not for all cement classes. The cement contents of 400 and 450 kg/m^3 gave for each OPKS/sand ratio, more than 70% in weight for the solid part of the concrete mix, and in the same moment, for cement contents of at least 500 kg/m^3, the said quantity was lower than 70%. For 400 and 450 kg/m^3 of concrete, the workability decreases with the increase in the quantity of OPKSs, that is to say, more the quantity of OPKSs is, the lower is the workability. This is due to the increase of the specific surface because of the increase in the quantity of OPKSs, thus requiring more water to make the specimens workable. This trend was mentioned elsewhere [5].

Slump values for cement content of 450, 500, and 550 kg/m^3 were included mostly in the range of recommended values for structural lightweight concrete according to ACI 211. 2–98 [24], that is to say, 25.4–101.6 mm. The low value of the workability (slump less than 10 mm) for the cement content of 400 kg/m^3 could be because the quantity of mortar that penetrates the cavities and the pores of OPKSs no longer permits to have the needed quantity of cement paste, which allows for good workability. On the other hand, for cement contents higher than 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 according to the decrease of the OPKS quantity as proven also by [5, 27].

Therefore, the optimal cement content relative to the workability would be 450 kg/m^3, and the recommendable range values of OPKS/sand ratio could be in the range of 0.50–0.65 by weight.

Thus, to obtain the minimum recommendable values of slump for various types of constructions according to Table 3.1 of [24], the mix ratios designated by C7, C8, C9, and C10 in **Table 4** could be the suitable ones. Note that the ratio of water/cement was 0.45.

4.2. Density

In this investigation, we determined the 28-day air-dry density of the specimens, which were kept in ambient laboratory conditions (RH of 74–88%; temp. of 27 ± 2°C). The results were shown in **Table 4**. Note that all densities obtained are less than 2000 kg/m^3, which allows saying that all the mix proportions were those for lightweight concretes. From **Table 4**, it can be seen that, in each cement content class, the density decreases as the proportion of shells increases, with a maximum value of almost 1880 kg/m^3 for cement content of 400 and 450 kg/m^3. Mixtures with cement content equal to or higher than 500 kg/m^3 had a maximum density of more than 1900 kg/m^3, which is above the maximum value of the density for structural lightweight concrete, according to Mindess [16]. Thus, it appears that except the sand, the cement content is also a parameter influencing the density of OPKS concrete. Taking into account the results of workability (Section 4.1) and the maximum value of 1900 kg/m^3, we could recommend the mix proportions of C7, C8, C9, and C10, with cement content of 450 kg/m^3 and w/c = 0.45 to achieve a density which corresponds to the requirements of structural lightweight concrete.

4.3. Compressive strength

From the results presented in **Table 4**, it can be noted that for every class of cement content, the 28-day cylindrical compressive strength increased to attain a maximum value, before it decreased, depending on the quantity of shells in the concrete mix. The cement content of 400 kg/m^3 showed a maximum of 28-day cylindrical compressive strength of 11.22 MPa for OPKS/sand ratio equal to 0.65, corresponding to almost 27% of OPKS in the rigid part of the concrete. For 450 kg/m3, we recorded the greatest value of the 28-day cylindrical compressive strength of 18.63 MPa, corresponding to 447.36 kg of OPKS in 1 m^3 of concrete. This content is in the rangeof values (290–450 kg) for OPKS in structural lightweight concrete, as reported by [25]. The value of 18.63 MPa is higher than the specified cylindrical compressive strength of 17 MPa given by ACI. Relative to cement contents of 500 and 550 kg/m^3, the maximum values of the 28-day cylindrical compressive strength were, respectively 18.27 and 17.54 MPa, and the corresponding OPKS/sand ratio was 0.5, which corresponds to almost 20% of OPKS in the rigid part of the concrete.

The developing of the compressive strength of the concrete with cement content less than 500 kg/m^3 was influenced by the amount of OPKS in the concrete mix, with a maximum value of up to 27% of the rigid part of the concrete. For these cement contents, the compressive strength is controlled by the strength of the shells [28]. During the compressive strength test, it is observed that the cement matrix failed first, which is to say that, the cracks path passed around OPKS aggregates. For cement contents of 500 and 550 kg/m^3, the compressive strength was influenced by the strength of the cement matrix and contrary to 400 and 450 kg/m^3, the cracks path passed through the shells of the concrete.

Thus, to produce economically structural lightweight concrete using OPKS as coarse aggregate and taking into account the recommended mix proportions for good workability and acceptable density, the mix ratios of C9 and C10 could be suggested. They could give the possibility to an engineer to fix efficiently the targeted values of specific properties in the mix proportioning of lightweight concrete, using OPKS as coarse aggregate.

4.4. OPKS concrete mixing proportioning process

Taking into account the results obtained earlier, we could recommend a general mixture proportioning procedure as follows [9]:

1. Establish the specific properties of the lightweight OPKSC for structural elements in low-cost buildings: slump [24], density [10], and 28-day compressive strength [29].

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 [10], as presented in **Table 5**.

Author (year) as cited by [10]	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 5. 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 [10], for concrete without admixture.

4. Determine the cement content [10] 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 [12] in the range from 4.8 to 5.1

7. Calculate the sand content for 1 m^3 of concrete, based on the principles of the absolute volume method of ACI 213:

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

8. Determine the OPKS content for 1 m^3 of concrete, using the OPKS/sand ratio and sand content determined earlier.

9. Make a test mixture with sufficient volume to perform the "slump test" coming to 0.008 m^3, that is to say 8 l. If the slump is smaller than the one specified above, then increase the amount of cement and water between 5% and 15%, while respecting the ratio w/c as indicated earlier. If the slump is larger than indicated in the data, then increase the amount of sand and OPKSs by 5–15% without changing the ratio of OPKS/sand.

   If despite all the operator does not obtain the results, then review the calculations and obtain precisely again the characteristics of the materials constituting the concrete.

10. Calculate the final mix proportion

5. Conclusion

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 450 kg/m^3 and $w/c = 0.45$ had resulted in obtaining appropriate values for workability ($\geq 20mm$), density ($1800 \leq d \leq 1900kg/m^3$), and cylindrical compressive strength ($\geq 15MPa$), 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.

Acknowledgements

We would like to thank the managers of the Djaouley Consulting Engineers (DIC-BTP) for the logistical, material, and financial support we received during the various laboratory experiences and office works.

Conflict of interest

There is no conflict of interest in this submission.

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