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Mix design for oil palm shell concrete

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Abstract

The mix design of lightweight concrete using oil palm shell (OPS) as aggregate differs widely from the procedure of mix proportioning for conventional concrete with crushed stone aggregate. The mix design depends on the properties of aggregates. The 28-day compressive strengths of OPS concrete designed according to the ACI method for conventional concrete and methods mentioned in references [A. Short, W. Kinniburgh, Lightweight Concrete, third ed., Applied Science Publishers, London, 1978; M.S. Shetty, Concrete Technology, S. Chand, India, 1993] for lightweight aggregate concrete have been found to be very much less than the targeted design strength of OPS concrete. It is confirmed that the mix design method of ACI and methods mentioned in the above references fail for the design of mix for OPS aggregates. A trial mix design for concrete with OPS as coarse aggregate has resulted in acceptable strength of 24 N/mm^2 for 28-day. Fly ash as mineral admixture and calcium chloride as an accelerator have also been used to study the improvement in strength.

Keywords: Mix proportion; Aggregate; Lightweight concrete; Compressive strength

1. Introduction

The requirement of mix design is to produce concrete with the required physical properties by selecting the most suitable materials and the most economical proportions of cement, various sizes of aggregates and water.

The mix design of lightweight concrete differs widely from that used for normal weight concrete mix because it depends upon the grading and the characteristics of the aggregates employed. The mix design for lightweight concrete used for structural purposes is more complicated because it depends on the type of lightweight aggregate [2]. A large number of artificial lightweight aggregates are available worldwide. The use of a local product depends on its specific properties and the requirements for a particular job. The mix design is done taking into account the strength required, density and workability requirement for the specific uses of lightweight concrete.

The same considerations of strength and workability do not always apply for different types of lightweight concrete.

Table 1
Properties of OPS and sand aggregates

Property	OPS aggregate	Sand
Specific gravity (saturated surface dry)	1.17	2.60
Water absorption (24 h), %	23.32	0.95
Aggregate abrasion value (Los Angeles), %	4.80	–
Bulk density (compacted), kg/m^3	592	–
Fineness modulus	6.24	2.56
Aggregate impact value (AIV), %	7.86	–

Table 2
Mix design for OPS concrete according to ACI mix design [OPS aggregates of saturated surface dry (ssd), cement content = 370 kg/m^3 and w/c ratio = 0.53, mix proportion by weight, C = cement, S = sand, OPS = oil palm shell]

				28-Day compressive strength (N/mm^2)	
Mix order	Mix proportion C:S:OPS	Demolded density (kg/m^3)	Fresh property (slump, mm)	Obtained strength	Targeted design strength
A1	1:2.73:0.85	1870	00	13.65	28
A2[a]	1:2.73:0.85	–	04	6.30	28
A3[b]	1:2.73:0.85	1884	00	13.15	28

[a] A2 mix with Superplasticizer Sika NN at 3.5 l/m^3.
[b] A3 mix with Superplasticizer Sika NN at 1.5 l/m^3.

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Table 3
Mix design for OPS concrete according to the method mentioned in Ref. [1] [w/c ratio = 0.60, OPS aggregate with ssd condition, mix proportion by weight]

					28-Day compressive strength (N/mm^2)	
Mix order	Mix proportion C:S:OPS	Cement content (kg/m^3)	Demolded density (kg/m^3)	Fresh property (slump, mm)	Obtained strength	Targeted design strength
B1	1:1.28:0.55	555	1791	collapse	11.80	25
B2	1:0.85:0.56	630	–	collapse	14.35	25

Even in the design of concrete mixes with gravel or crushed stone as coarse aggregates, the methods used are aimed at producing only a trial mix that may or may not fully meet the specified requirements. The grading of lightweight aggregates is more restricted as their physical properties vary considerably for different types of aggregates. These properties include particle shape, surface texture, bulk density, absorption and hardness or inherent strength.

The objective of this paper is to investigate the mix design procedure suitable for oil palm shell (OPS) concrete for structural purpose.

2. Materials and curing method

The materials used are ordinary Portland cement (ASTM, Type I), sand and OPS. The concrete samples have been cured in water for 28 days. Properties of materials are given in Table 1 [3].

3. Mix design procedure for OPS concrete

In the preliminary investigation of OPS concrete mix proportion, the three procedures followed were the ACI mix design method for normal weight concrete and the mix design methods for lightweight concrete as mentioned in Refs. [1,4].

As mentioned in Table 2, the mix orders A1, A2 and A3 were based on the ACI mix design. However, the results obtained for OPS concrete were far below the targeted designed strengths. Though the superplasticizer, Sikament NN was used in the mixes of A2 and A3, it could not increase the strength of OPS concrete.

In Table 3, the mix orders B1 and B2 of OPS concrete were based on the mix design for lightweight concrete [1]. The targeted design strengths for mixes of B1 and B2 could not be achieved as shown in this table. Basically, the mix design procedure for lightweight concrete as shown in Ref. [1] is meant for concrete with lightweight aggregates such as Leca, foamed slag, Aglite and Lytag.

The mix design method suggested by Shetty [4] was employed for the mixes of C1 and C2 of OPS concrete (Table 4). The targeted design strengths at the age of 28 days for mixes C1 and C2 were considered as 25 and 22 N/mm^2, respectively. However, the results obtained were much less than the targeted design strength as shown in Table 4.

Actually, the ACI mix design method is for normal weight concrete and the methods mentioned in Refs. [1,4] are for lightweight aggregate concrete. The OPS aggregate is of natural organic material and its properties are different from those of lightweight aggregates such as Leca, foamed slag, Aglite and Lytag, in that the texture is smooth and the shapes are of different types. The targeted designed strengths of OPS concrete could not be achieved by employing these established methods. Hence, it is concluded that the established method such as ACI method for normal weight concrete and the methods in Refs. [1,4] for lightweight concrete could not be applied to the mix design of OPS concrete.

In addition to the above, a large number of trial mixes (Table 5) were attempted to obtain the best strength for OPS concrete. In these trial mixes, different variations were considered such as mix proportion, cement content, w/c ratio, concrete density and stage of OPS aggregate (saturated surface dry/dry condition). For lightweight concrete, the amount of cement content specified is in the range of 285–510 kg/m^3 [5].

3.1. Acceptable mix proportions for OPS concrete

Finally for OPS concrete, the acceptable mix proportions with different ingredients are presented in Table 6. The cement content of 480 kg of cement per cubic meter of concrete used in this study is within the usual range of values used in the mix design of lightweight concrete [5]. The free water–binder ratio was 0.41 for all the mixes. The sand/OPS ratio was 2.22 by weight. In Table 6, fly ash was

Table 4
Mix design for OPS concrete according to the method mentioned in Ref. [4] [OPS of ssd condition and mix proportion by weight]

						28-Day compressive strength (N/mm^2)	
Mix order	Mix proportion C:S:OPS	Cement content (kg/m^3)	w/c ratio	Demolded density (kg/m^3)	Fresh property (slump, mm)	Obtained strength	Targeted design strength
C1	1:1.13:0.92	480	0.50	1781	–	14.40	25
C2	1:1.41:1.15	400	0.60	1704	collapse	9.65	22

Table 5
Mix design for OPS concrete based on trial-and-error method (mix proportion by weight)

Mix order	Mix proportion C: S: OPS	Cement content (kg/m^3)	w/c ratio	Stage of OPS	Demolded density (kg/m^3)	Fresh property (slump, mm)	Compressive strength (N/mm^2), 28-day
D1	1:1.70:1.70	325	0.65	ssd	1680	0	7.30
D2	1:1.59:1.59	340	0.62	ssd	1655	0	9.90
D3	1:1.24:0.99	465	0.55	air dry	1780	5	11.85
D4	1:1.10:1.06	465	0.55	air dry	1755	10	11.50
D5	1:1.20:0.98	480	0.54	ssd	–	–	10.40
D6	1:1.24:0.79	500	0.55	air dry	1825	30	15.70
D7	1:1.24:0.86	520	0.38	ssd	1830	5	20.00
D8	1:1.07:0.98	520	0.36	ssd	1815	0	18.75
D9	1:0.82:0.79	545	0.55	air dry	1725	44	14.75
D10	1:1.24:0.50	555	0.60	air dry	1850	Collapse	10.00
D11	1:0.82:0.79	560	0.50	air dry	1770	30	12.70
D12	1:0.82:0.89	565	0.38	ssd	1780	20	18.60
D13	1:1.24:0.50	585	0.50	air dry	1870	20	18.80
D14	1:0.82:0.73	600	0.41	ssd	1805	25	20.25
D15	1:1.24:0.62	600	0.45	air dry	1910	40	18.45
D16	1:0.82:0.42	630	0.60	air dry	1790	Collapse	11.50
D17	1:0.82:0.42	675	0.50	air dry	1845	125	19.10

Table 6
Acceptable mix proportions of OPS concrete with different ingredients

	Proportions by weight of cement (cement = 480 kg/m^3), w/c = 0.41					Demolded density (kg/m^3)	Fresh property (slump, mm)	28-Day compressive strength (N/mm^2)
Mix order	Cement	Fly ash	$CaCl_2$	Sand	OPS			
E1	1.00	0.00	0.00	1.71	0.77	1890–1905	7	24.20
E2	0.90	0.10	0.00	1.71	0.77		8	22.60
E3	0.85	0.15	0.00	1.71	0.77		9	19.50
E4	1.00	0.00	0.5%	1.71	0.77		6	23.45
E5	1.00	0.00	1.0%	1.71	0.77		7	29.40
E6	1.00	0.00	1.5%	1.71	0.77		8	24.50

mixed as partial cement replacement and $CaCl_2$ was used as an admixture. In the acceptable mix design, air-dry sand was used. However, the required correction was made to adjust the free water content.

4. Conclusions

To attain a 28-day compressive strength of 24.20 N/mm^2 a mix proportion using OPS as coarse aggregate has been determined using cement content of 480 kg/m^3 and free w/c ratio of 0.41. Fly ash up to 10% as partial cement replacement is recommended, whereas 15% fly ash results in reduction of compressive strength. The use of an accelerator like calcium chloride results in higher strength up to 29.40 N/mm^2.

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