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Communication

Concrete using waste oil palm shells as aggregate

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Abstract

Concrete with oil palm shells (OPS) as coarse aggregate was investigated for its workability, density, and compressive strength development over 56 days under three curing conditions. The effect of fly ash as partial cement replacement was also studied. Fresh OPS concrete was found to have better workability while its 28-day air-dry density was 19–20% lower than ordinary concrete. Compressive strength after 56 days was found to be 41–50% lower than ordinary concrete. These results were still within the normal range for structural lightweight concrete. Fly ash was found to lower the compressive strength of OPS concrete, which was the opposite of its effect on normal concrete.

Keywords: Concrete; Oil palm shells; Fly ash; Compressive strength

The oil palm industry in Malaysia accounts for over half of the world's total palm oil output and is set to grow further with the global increase in vegetable oil demand. However, it is also the main contributor to the nation's pollution problem, which includes the annual production of 2.6 million tonnes of solid waste in the form of oil palm shells (OPS) [1]. OPS is the hard endocarp that surrounds the palm kernel. The vast availability of this resource is still unutilised commercially. The current waste disposal practice of incineration within the industry is normally done in an uncontrolled manner and contributes significantly to atmospheric pollution.

OPS are light and naturally sized; they are ideal for substituting aggregates in lightweight concrete construction. Being hard and of organic origin, they will not contaminate or leach to produce toxic substances once they are bound in concrete matrix. OPS concrete can potentially be utilised in lightweight concrete applications that require low to moderate strength such as pavements and infill panel for floorings and walls.

This paper reports the results of an investigation into the compressive strength of OPS concrete under three curing conditions over a 56-day period. The influence of fly ash as a cement replacement admixture (pozzolan) on the concrete strength was also investigated. Fly ash as a pozzolan has been established to have several enhancing effects on normal concrete, including improving its compressive strength.

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1. Materials and experimental procedures

1.1. OPS as aggregate

The thickness of OPS depends on the species of the palm tree from which the nut was obtained, ranging from 0.50–8.00 mm. They were collected from a local factory, and were freshly discarded. In practice, the fruits of different species are processed together, hence shells are commonly of varying thicknesses. In this investigation, most of the shells were within the thickness range of 1.5–2.5 mm. The shells were flaky and irregularly shaped (depending on the breaking pattern of nut). The surface texture of the shell was fairly smooth for both concave and convex faces. The broken edges were rough and spiky.

OPS and crushed stone aggregate used were in saturated surface dry condition. The measured physical properties of OPS compared with crushed stone (used as aggregate for the control concrete samples) are shown in Table 1.

1.2. Other concrete mix components

Malaysian ordinary portland cement (OPC) and Malaysian fly ash (Class F) were used as binder, and mining sand was used as fine aggregate. The mining sand used had a fineness modulus of 2.56. The chemical constituents of Malaysian fly ash [2] and OPC [3] are shown in Table 2.

1.3. Test samples

All samples were cast in cube moulds ($100 \times 100 \times 100$ mm^3) and covered with plastic sheeting for 24 hours. The

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Table 1
Physical properties of OPS and crushed stone

Physical property	OPS	Crushed stone
Specific gravity (saturated surface dry)	1.17	2.61
Water absorption (24 h)	23.32%	0.76%
Aggregate abrasion value (Los Angeles)	4.80%	24.00%
Bulk density (compacted)	592 kg/m^3	1472 kg/m^3
Fineness modulus	6.24	6.33

Table 2
Chemical constituents of Malaysian fly ash [2] and OPC [3]

Constituent	Malaysian fly ash (class F)	ASTM C618 requirement for fly ash (class F)	Malaysian OPC
SiO_2 + Al_2O_3 + Fe_2O_3	51.4 + 27.5 + 7.2 = 86.1	Minimum = 70	—
SiO_2	51.4	—	21.54
Al_2O_3	27.5	—	5.32
Fe_2O_3	7.2	—	3.63
CaO	4.3	—	63.33
MgO	2.8	Maximum = 5.0	1.08
Na_2O	—	—	0.16
K_2O	0.8	—	1.06
SO_3	0.2	Maximum = 5.0	2.18
LOI	4.3	Maximum = 6.0	—

cement content of the concrete samples was set at 480 kg/m^3, which was within the range for lightweight-aggregate concrete (285 kg/m^3 to 510 kg/m^3). Cube samples of OPS concrete with three values of fly ash content, i.e., 0%, 10%, and 15% cement replacement, were prepared. (These values are commonly used for research in Malaysia.) A similar set of concrete samples using crushed stone aggregate instead of OPS was used as control. Table 3 shows six different types of mix proportions for the test samples. They were chosen after a series of trial mixes to establish the mix with optimum strength.

1.4. Testing

Workability of fresh concrete and the 28-day air-dry density (in accordance with ASTM C567-91) were measured for all sample batches. Compressive strengths were measured using an automatic compression testing machine with a maximum capacity of 3000 kN (Wykeham Farrance Engineering Ltd, Slough, UK). For all tests, each value was taken as the average of three samples. Compressive strength tests were performed at 3, 7, 28, and 56 days after casting. The tests were carried out under three curing conditions as shown in Table 4, i.e., (1) 55-day water curing (to BS8110), (2) six-day water curing, and (3) 55-day plastic curing where two layers of plastic film, as used for food wrapping, were applied on the samples [4].

Table 4
Curing conditions (at 26 ± 2°C)

Curing type	In mould	In water	Covered in plastic film	In room (RH at 60%)
55-day water curing	1 day	55 days	0 days	0 days
6-day water curing	1 day	6 days	0 days	49 days
55-day plastic curing	1 day	0 days	55 days	0 days

Table 5
Workability and 28-day air-dry density

Sample type	Slump (mm)	Compaction factor	28-day air-dry density (kg/m^3), at 26 ± 2°C, RH 60%
OPS concrete	7	0.82	1856
OPS concrete with 10% fly ash	7	0.82	1817
OPS concrete with 15% fly ash	7	0.82	1801
Control concrete	3	0.79	2301
Control concrete with 10% fly ash	3	0.79	2279
Control concrete with 15% fly ash	3	0.79	2246

2. Results and discussion

2.1. Workability and density

The results for workability and density are presented in Table 5. Slump values and compaction factors for all OPS concrete samples were higher than the control. The reason for OPS concrete having better workability was the smooth surfaces of the shells. This trend was also reported elsewhere [5]. The low slump values for control concrete was due to the low water-cement ratio without the use of superplasticiser, resulting in low free-water content.

Table 3
Mix proportions of concrete samples

No.	Mix description	Proportion by weight: Water	OPC	Fly ash	Fine aggregate	Coarse aggregate
1	OPS concrete	0.41	1.00	0.00	1.71	0.77
2	OPS concrete with 10% fly ash	0.41	0.90	0.10	1.71	0.77
3	OPS concrete with 15% fly ash	0.41	0.85	0.15	1.71	0.77
4	Control concrete	0.41	1.00	0.00	1.71	1.71
5	Control concrete with 10% fly ash	0.41	0.90	0.10	1.71	1.71
6	Control concrete with 15% fly ash	0.41	0.85	0.15	1.71	1.71

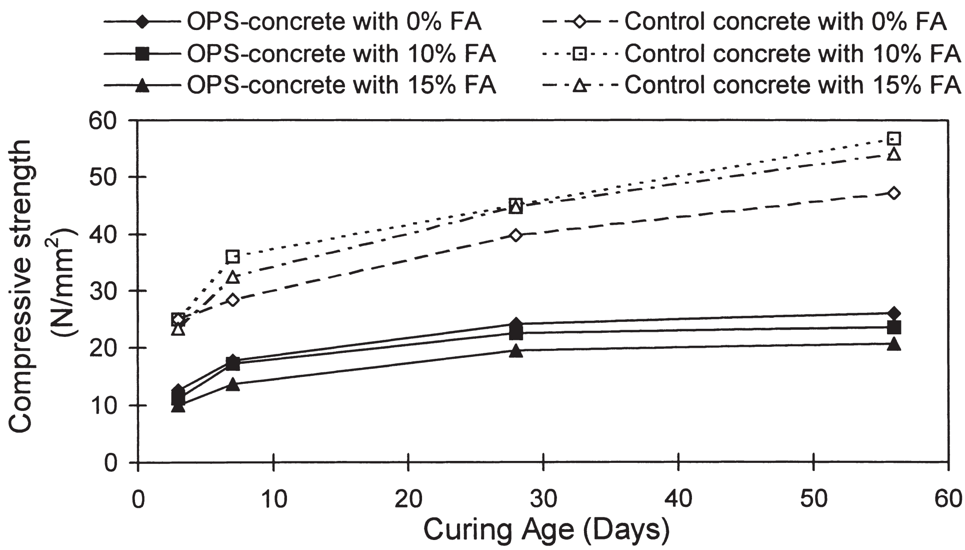

Fig. 1. Development of compressive strength under 55-day water curing.

The 28-day air-dry densities of OPS concrete were 19–20% lower than ordinary crushed stone concrete. Their values were within the range for structural lightweight concrete (1,450–1,900 kg/m^3) [6].

2.2. Compressive strength

The development of the compressive strengths of the six types of concrete cube samples under three curing environments are shown in Fig. 1 (56-day water curing), Fig. 2 (six-day water curing), and Fig. 3 (55-day plastic curing).

The compressive strengths of OPS concrete were found to be lower than ordinary concrete by 42–55% after 28 days and by 41–50% after 56 days, depending on the curing environment. Their values were within the normal range for structural lightweight concrete (17–35 N/mm^2) [6]. Curing underwater for 55 days produced the highest OPS concrete strength, followed by plastic film curing for 55 days, and then by six-day water curing. An examination of the failure surfaces showed breakage of the OPS aggregate, indicating that the individual shell strength had a strong influence on the resultant concrete strength.

2.3. Influence of fly ash on compressive strength

Fly ash as cement replacement has been known to enhance the compressive strength of concrete [7] by reacting with calcium hydroxide in the presence of moisture to form

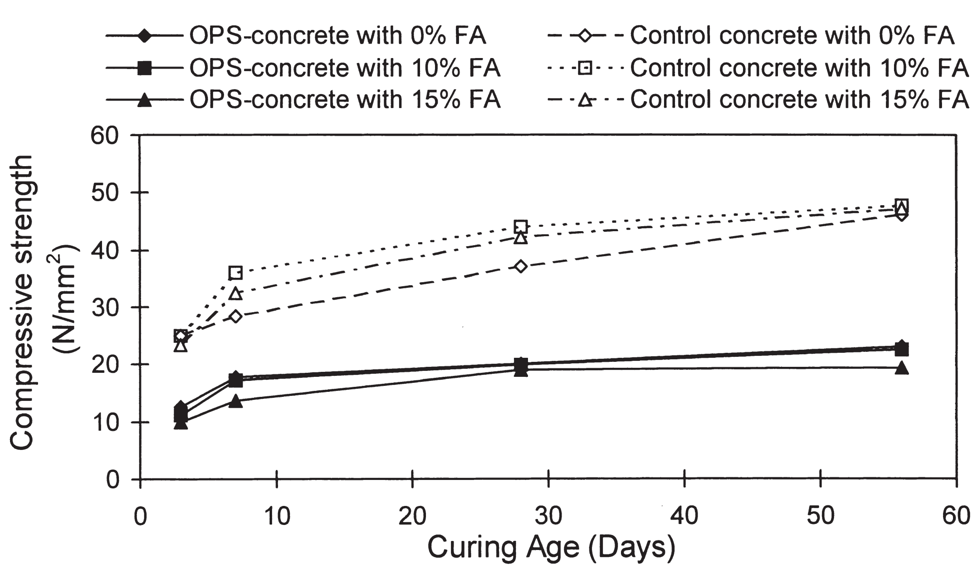

Fig. 2. Development of compressive strength under six-day water curing.

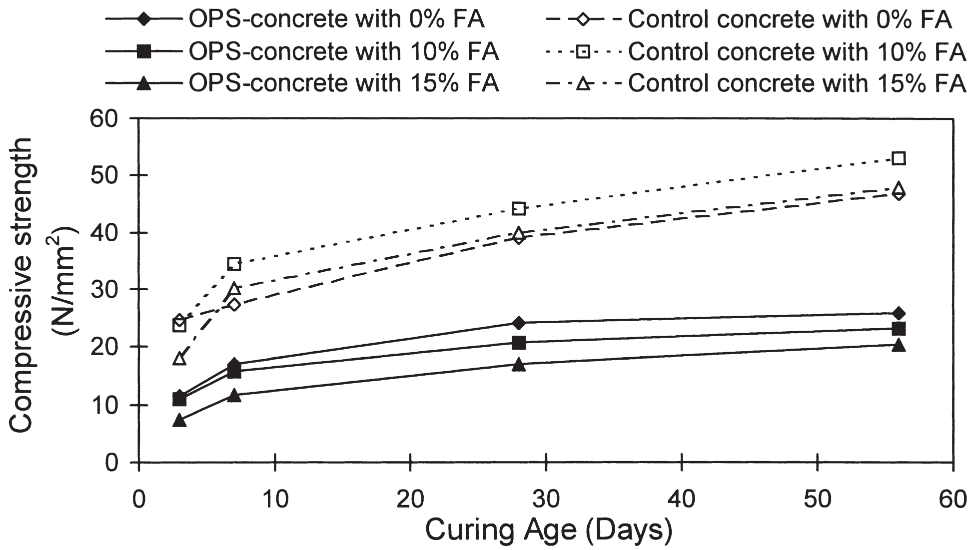

Fig. 3. Development of compressive strength under 55-day plastic curing.

a cementitious material. Tests on the concrete control samples confirmed this for all three curing environments, and further showed that the strength increased greater at 10%, as compared to 15% fly ash replacement of cement. As is usually the case, the strengths of control concrete showed initial reductions (as registered at three days) with fly ash replacement. However, for OPS concrete, the compressive strength was found to decrease when the fly ash content increased. With 10% fly ash, the 56-day strength was reduced by 7–15% compared with OPS concrete with no fly ash, and with 15% fly ash the reduction was as much as 23–29%. A possible explanation for this strength loss is that the presence of fly ash prevented proper contact between the OPS surfaces and the cement matrix. This interfered with the development of bonding strength between them, causing the compressive strength to be reduced. In crushed stone concrete, fly ash enhanced the strength by filling up micro voids created within the cement-stone matrix which increased the resistance to the formation of failure-inducing cracks. This void-filling function that enhanced the overall matrix strength might not be present in the case of OPS concrete because of the smoother shell surfaces.

3. Conclusions

The following conclusions can be drawn from this investigation.

1. The 28-day air-dry density of OPS concrete was within the range for structural lightweight concrete and was about 20% less than ordinary concrete.
2. The compressive strength of OPS concrete was within the range for structural lightweight concrete and was about 50% less than ordinary concrete.
3. Fly ash as cement replacement for OPS concrete had a negative effect on its compressive strength with a reduction of up to 29%.
4. OPS concrete attained the highest strength under 56-day water curing compared with six-day water curing and plastic film curing.

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