Turkish J. Eng. Env. Sci.
30 (2006) , 251 – 257.

Structural Concrete Using Oil Palm Shell (OPS) as Lightweight Aggregate

D. C. L. TEO, M. A. MANNAN, V. J. KURIAN
Universiti Malaysia Sabah, Civil Engineering Program, Sabah-MALAYSIA
e-mail: dtconc@yahoo.com.au

Received 27.02.2006

Abstract

This paper presents part of the experimental results of an on-going research project to produce structural lightweight concrete using solid waste, oil palm shell (OPS), as a coarse aggregate. Reported in the paper are the compressive strength, bond strength, modulus of elasticity, and flexural behaviour of OPS concrete. It was found that although OPS concrete has a low modulus of elasticity, full-scale beam tests revealed that deflection under the design service loads is acceptable as the span-deflection ratios ranged between 252 and 263, which are within the allowable limit provided by BS 8110. Laboratory investigations show encouraging results and it can be summarised that OPS has good potential as a coarse aggregate for the production of structural lightweight concrete, especially for low-cost housing construction and also for use in earthquake prone areas.

Key words: Low-cost housing, Solid waste, Lightweight concrete, Stress-strain curve, Prototype beam test.

Introduction

The growing concern of resource depletion and global pollution has challenged many engineers to seek and develop new materials relying on renewable resources. These include the use of by-products and waste materials in building construction. Many of these by-products are used as aggregate for the production of lightweight concrete. Although there has been much research conducted on the structural performance of lightweight aggregate concrete, these are mostly confined to naturally occurring aggregates, manufactured aggregates, and aggregates from industrial by-products.

Being the world's largest producer and exporter of palm oil, Malaysia is well known for its palm oil industry; however, one significant problem in the processing of palm oil is the large amounts of waste produced and this is one of the main contributors to the nation's pollution problem. At the mills, when the fresh fruit bunches (FFB) are processed and oil extraction takes place, solid residues and liquid wastes are generated. These by-products include empty fruit bunches, fibre, shell, and effluent. Currently, research efforts have been directed towards the potential use of oil palm shell (OPS) as aggregate for the production of lightweight concrete. In this respect, Universiti Malaysia Sabah (UMS) built a small footbridge [Figure 1(a)] of about 2 m in span in May 2001 and a low-cost house [Figure 1(b)] with a floor area of about 59 m^2 in 2003, both using OPS concrete. Both structures were constructed on the campus, which is located near the coastal area. This area has an annual rainfall of about 2500 mm, air temperature in the range of 22.9 to 32.2 °C, and relative humidity of 71.6% to 91.0%.

In Malaysia, there is an annual production of over 4 million tonnes of waste OPS. Figure 2 shows a photo of waste OPS being left at a mill area. Exploiting this waste material not only maximises the use of oil palm, but also helps preserve natural resources and maintain ecological balance. Currently, there is also an increasing demand for low-cost houses in Malaysia and therefore OPS can be used as an alternative to the conventional aggregates in fulfilling this demand.

Figure 1. Structures made from OPS concrete. (a) Footbridge and (b) Low-cost house.

Figure 2. Waste OPS left at an oil palm mill.

Aggregates having dry unit weights (of less than) 1200 kg/m^3 are classified as lightweight aggregates (Owens, 1993). OPS aggregate has a unit weight of 500-600 kg/m^3 and this is approximately 60% lighter compared to the conventional crushed stone aggregates. Consequently, the resulting concrete will be lightweight. Lightweight concrete using OPS as coarse aggregate is still a relatively new construction material and the structural performance of this concrete has not yet been fully investigated. Earlier investigations showed that OPS can be used as coarse aggregate in concrete (Mannan and Ganapathy, 2004; Teo et al., 2005). The behaviour of OPS concrete in a marine environment was also previously studied (Mannan and Ganapathy, 2001). The present paper endeavours to investigate these important characteristics of OPS concrete further, so as to create wider acceptance of OPS as a lightweight concrete alternative to be as used as building material for low-cost housing construction. The structural properties investigated in this paper include compressive strength, bond strength, modulus of elasticity, and flexural behaviour of reinforced OPS concrete beams.

Materials Used and Mix Proportions

The constituents of OPS concrete included ordinary Portland cement (ASTM Type 1), river sand as fine aggregate, OPS, and a Type-F naphthalene sulphonate formaldehyde condensate-based superplasticiser. The OPS aggregates were obtained from local oil palm mills. The species of oil palm tree normally found in Malaysia are oleifera, dura, psifera, and tenera. Except for the psifera species (which has virtually no shell to the kernel), the shell comprises approximately 10% to 50% of the total composition of the oil palm fruitlets. OPS is available in various shapes, such as curved, flaky, elongated, roughly parabolic, and other irregular shapes as shown in Figure 3. Usually, some oil coating is present on the surface of fresh OPS; therefore, pretreatment to remove any oil coating is necessary, which can be achieved by various methods, including natural weathering, boiling in water, and washing with detergent. In this investigation, weathered OPS was used. Before the OPS was used as aggregate, it was sieved and only aggregate passing through the 12.5 mm sieve and retained on the 4.75 mm sieve was used. The particle size distribution of the OPS aggregate is shown in Figure 4, whereas the properties of the river sand and OPS are shown in Table 1.

Figure 3. Various shapes of OPS aggregate.

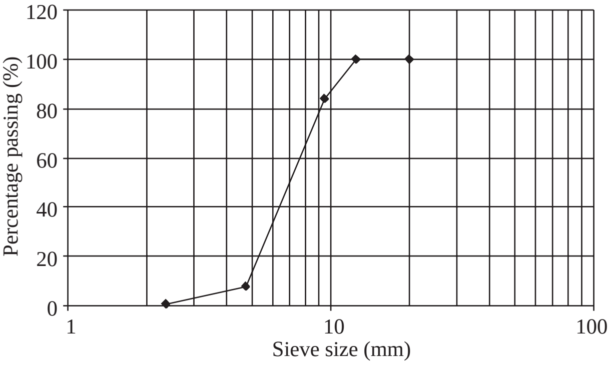

Figure 4. Particle size distribution of OPS aggregate.

Based on the properties of the available fine and coarse aggregate, the mix proportions were approximated, followed by the modification of trial mixes to achieve a practical end result. The acceptable mix comprised 510 kg/m^3 cement, 848 kg/m^3 sand, and 308 kg/m^3 OPS, with a free water/cement ratio of 0.38. The cement content used in this study was within the range for lightweight concrete (Mindess et al., 2003). The amount of superplasticiser used was 1.4 l/100 kg cement, which was within the recommended concentration range provided by the manufacturer. This mix proportion was used throughout the entire investigation. The OPS aggregate used was mixed at saturated surface dry (SSD) condition based on 24 h submersion in potable water.

Testing Programme

Several tests were conducted to determine the structural properties of OPS concrete. Compression tests on 100 mm cubes were performed according to BS 1881: Part 116, whereas the initial modulus of elasticity on 150 Ø x 300 mm cylinders was carried out as per ASTM C 469-87a. The bond strength of OPS concrete was determined by carrying out a series of pullout tests on 100 Ø x 200 mm cylinders. Flexural tests on full-scale prototype beams were also conducted. Except for the prototype beam tests, which used beams of 3 different tension reinforcements, triplicate specimens were prepared for each test and the results were reported as an average.

Mixing of concrete was carried out using a rotating drum mixer conforming to BS 1881: Part 125 (Clause 6.3 for SSD aggregates). To prevent excessive evaporation from the fresh concrete, a plastic sheet was placed on top of the moulds immediately after casting and left for 24 ± 3 h in the laboratory at ambient conditions (24-28 °C; relative humidity: 80% - 93%). Subsequently, all cube and cylindrical

Table 1. Properties of river sand and OPS.

Properties	River sand	Oil palm shell (OPS)
Maximum grain size, mm	1.18	12.5
Shell thickness, mm (Average shell thickness = 2.0 mm)	-	0.5 – 3.0
Specific gravity	2.45	1.17
Bulk unit weight, kg/m^3	1500-1550	500-600
Fineness modulus	1.40	6.08
Los Angeles abrasion value, %	-	4.90
Aggregate impact value, %	-	7.51
Aggregate crushing value, %	-	8.00
24-h water absorption, %	3.89	33.0

specimens were transferred into a 26-30 °C water tank until testing commenced. For the prototype beams, the specimens were moist cured continuously for another 6 days after which they were left in the same ambient laboratory conditions until the age of test.

The bond between the reinforcement and OPS concrete was investigated through the bond-slip relationship. The pullout test was conducted using deformed bars of 10, 12, and 16 mm diameter and tested at an age of 3, 7, 28, 56, 90, and 180 days. The bond strength was computed by the following formula:

$\tau \quad = F / (\pi \times d \times l)$

where τ = bond stress (MPa), F = applied load (N), d = nominal bar diameter, and l = embedment length (mm)

Three singly reinforced beams (S1, S2, and S3) were fabricated and tested. All test beams had rectangular cross-sections of 150 x 230 mm, with a total length of 3200 mm and an effective span of 3000 mm. The test beam dimensions were sufficiently large to simulate a real structural element. Tension reinforcement of 2Y10, 2Y12, and 3Y12 were provided for beams S1, S2, and S3, respectively. Two 8 mm diameter mild steel hanger bars were provided for each beam. Sufficient shear links were provided to avoid failure in shear and an all-round cover of 25 mm was maintained for each beam. The beams were tested under 4-point bending. Three plunger travel LVDTs (linear voltage displacement transducers) capable of reading to a maximum value of 100 mm were used to monitor the deflection of the beams in the pure bending region. The test set-up and beam details are illustrated in Figure 5.

Results and Discussions

The slump obtained in the OPS concrete was in the range of 50 to 70 mm. This showed that the OPS concrete had a medium degree of workability and was within the range of a workable concrete. The air content was in the range of 4.8% to 5.5% and this was relatively high. This could be attributed to the highly irregular shapes of the OPS, which prevented full compaction; however, the air content for OPS concrete is still within the stipulated values of 4% to 8% provided by ACI 213R-87. As for the fresh concrete density, it ranged from 2010 to 2065 kg/m^3.

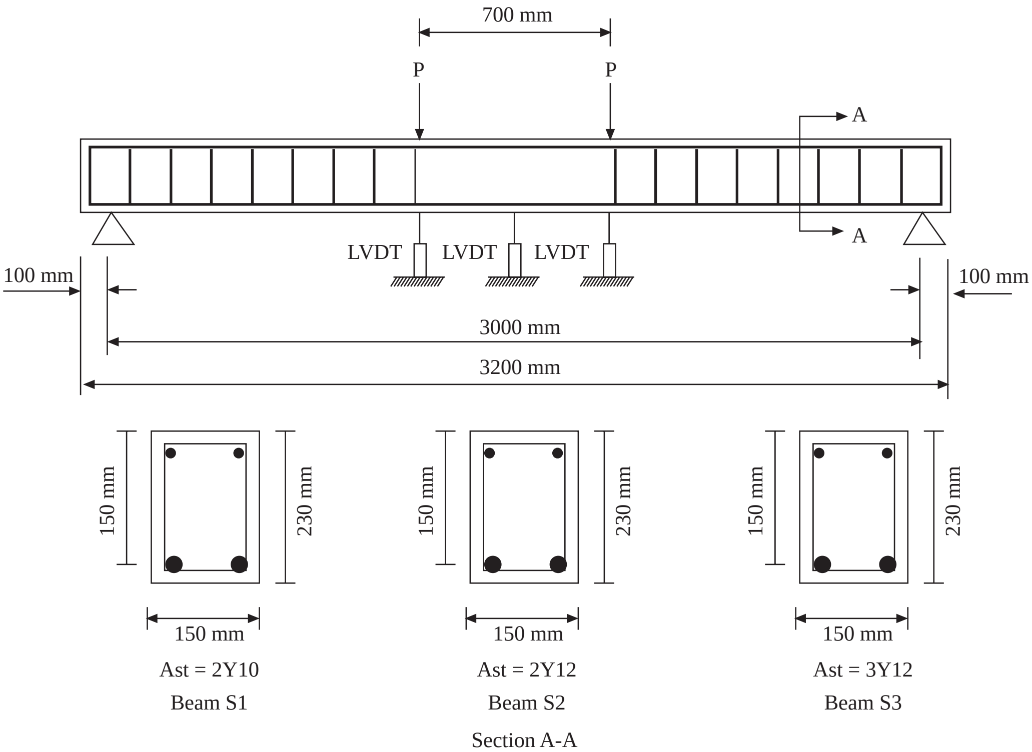

Figure 5. Beam testing setup and details.

The properties of the hardened OPS concrete tested at an age of 28 days are presented in Table 2.

Table 2. Properties of OPS concrete.

Air-dry density, kg/m^3	1963
Compressive strength, MPa	28.12
Modulus of elasticity, GPa	5.31
Pullout bond strength, MPa	7.18 – 9.36

Lightweight concretes normally have densities of less than 2000 kg/m^3 and the density of OPS concrete falls within this limit, thus making it lightweight. Compared to normal weight concretes of 2400 kg/m^3, OPS concrete is approximately 20% lighter. This shows that OPS concrete would decrease 20% dead load when used in construction. By reducing the weight of the structure, catastrophic earthquake forces and inertia forces that influence the structures can also be ultimately reduced, as these forces are proportional to the weight of the structure.

Cubes tested at an age of 28 days produced strengths of 28.1 MPa, which is approximately 65% higher than the minimum required strength of 17 MPa for structural lightweight concrete recommended by ASTM C330. Although OPS is an organic material, tests revealed that biological decay was not evident as the cubes gained strength even after 6 months. This can be observed from Figure 6. Similarly, existing structures constructed with OPS concrete (Figure 1) have not shown any sign of deterioration. At the earlier ages of testing (3 to 28 days), it was observed that the compression failure in the concrete was mainly caused by the failure in the bond between the cement paste and the OPS aggregate, where the crack path goes around the aggregate (Figure 7a). At later ages (56 to 180 days), the mortar-aggregate bond is stronger and hence, crack travels through the aggregate as illustrated in Figure 7b.

The bond strength development of OPS concrete is illustrated in Figure 8. From the pullout test conducted, the bond strength of OPS concrete was found to be about 2.4 to 3.9 times higher compared to the design bond strength as recommended by BS 8110. All specimens failed by splitting of the concrete cover. The failure was very sudden and was accompanied by the formation of longitudinal cracks. It was observed that cracks progressed over the entire length of the sample before failure occurred. Splitting failure occurs when radial cracks form due to the bearing pressure developed by the projections of the steel bars on the surrounding concrete. When cracks start to form, the bond forces are directed outward from the bar surface and these forces cause anchorage failure by cracking of the confining concrete cover. The bond strength of OPS concrete was approximately 26% to 33% of the compressive strength and is comparable to the bond strength of other lightweight concretes such as sintered pulverised fuel ash concrete (Orangun, 1967) and Aerocrete (Chitharanjan et al., 1988).

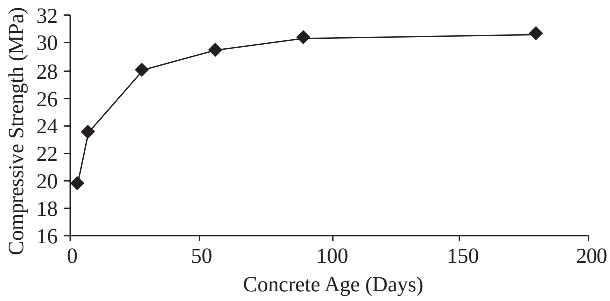

Figure 6. Compressive strength development of OPS concrete.

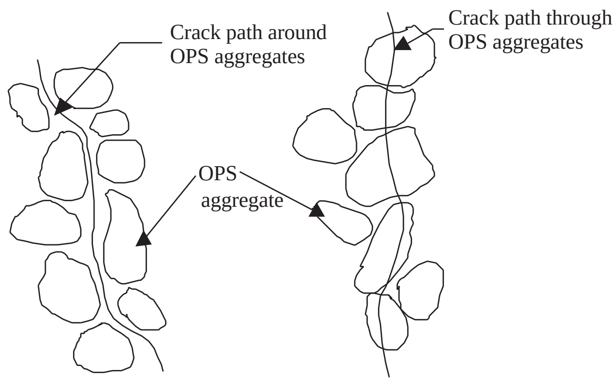

Figure 7. Crack paths (a) at earlier ages (b) at later ages.

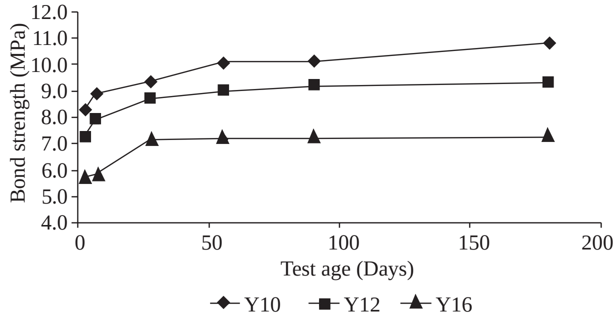

Figure 8. Bond strength development of OPS concrete.

The modulus of elasticity is one of the most important parameters for structural concrete as it is required when assessing deflections and cracking of a structure. Figure 9 shows a typical stress-strain curve for OPS concrete. The strain corresponding to maximum stress is approximately 0.005. One particular concern for OPS concrete is the low value of elastic modulus and this was further investigated with the prototype beam testing.

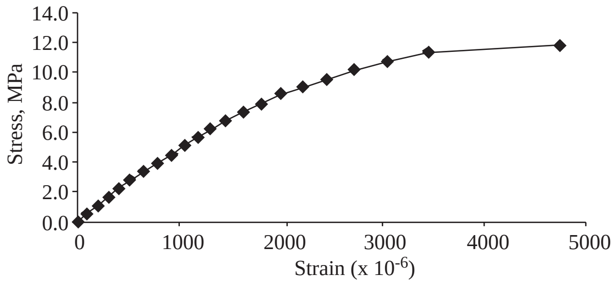

Figure 9. Stress-strain curve for OPS concrete.

All tested beams showed typical failure in flexure. Failure occurred gradually and since all beams were under-reinforced yielding of the tensile reinforcement occurred before crushing of the concrete cover in the pure bending zone. The ultimate moments of the beams were predicted using rectangular stress block analysis as recommended by BS 8110. It was observed that the experimental ultimate moments for the beams were about 19% to 35% greater compared to the predicted moments. This shows that BS 8110 can be used to give a conservative estimate of the ultimate moment capacity for singly reinforced OPS concrete beams. The deflection is one of the main criteria for the serviceability requirements of a structural member. Under the design service loads (dead load + live load), the midspan deflection obtained was 11.40, 11.70, and 11.90 mm for beams S1, S2, and S3, respectively. Although OPS concrete has a low modulus of elasticity, the deflection under the design service loads is acceptable as the span-deflection ratios ranged between 252 and 263, which are within the allowable limit provided by BS 8110. Figure 10 presents the typical moment-deflection curve for beams S1, S2, and S3.

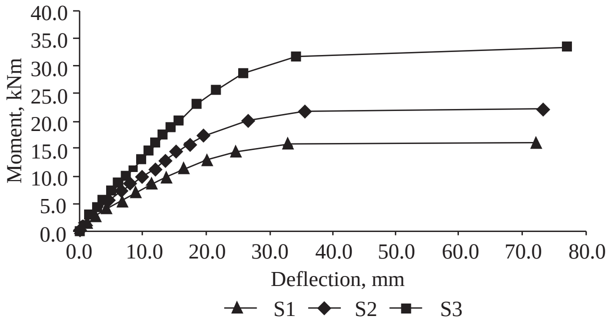

Figure 10. Moment-deflection curves.

Conclusions

In general, OPS has good potential as a coarse aggregate in structural concrete production and can even be used for low to moderate strength applications such as structural members for low-cost houses. Based on this investigation, the following conclusions can be drawn:

(i) The compressive strength of OPS concrete was 28.1 MPa at an age of 28 days, which satisfies the requirement for structural lightweight concrete.

(ii) The bond property of OPS concrete is comparable to other types of lightweight concretes.

(iii) Although OPS concrete has a low modulus of elasticity, beam tests revealed that the deflection under the design service loads is acceptable as the span-deflection ratios ranged between 252 and 263, which are within the allowable limit provided by BS 8110.

(iv) Based on the beam test results, it was observed that the experimental ultimate moment for the singly reinforced beams were about 19% to 35% greater compared to the predicted moments from BS 8110.

Acknowledgement

This project is sponsored by The Ministry of Science, Technology, and Innovation Malaysia, under IRPA research grant no. 03-02-10-0033-EA0031.

References

ACI 213R-87, Guide for Structural Lightweight Aggregate Concrete, American Concrete Institute.

ASTM C330, Standard Specification for Lightweight Aggregates for Structural Concrete, Annual Book of ASTM Standards.

ASTM C 469-87a, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, Annual Book of ASTM Standards.

BS 1881, Part 116, Method for Determination of Compressive Strength of Concrete Cubes, British Standards Institution, London.

BS 1881, Part 125, Methods for Mixing and Sampling Fresh Concrete Samples in the Laboratory, British Standards Institution, London.

BS 8110, Structural use of Concrete Part 1, Code of Practice for Design and Construction, British Standards Institution, London, 1985.

Chitharanjan N., Sundararajan R. and Manoharan P.D., "Development of Aerocrete: A New Lightweight High Strength Material", The International Journal of Cement Composites and Lightweight Concrete, 10, 27-38, 1988.

Mannan M.A. and Ganapathy C., "Behaviour of Lightweight Concrete in Marine Environments", Proceedings of the International Conference on Ocean Engineering, Chennai, India, 409-413, 2001.

Mannan M.A. and Ganapathy C., "Concrete from an Agricultural Waste-Oil Palm Shell (OPS)", Building and Environment, 39, 441-448, 2004.

Mindess S., Young J.F. and Darwin D., Concrete, 2^{nd} Edition, Prentice Hall, USA, 2003.

Orangun C.O., "The Bond Resistance between Steel and Lightweight-Aggregate (Lytag) Concrete", Building Science, 2, 21-28, 1967.

Owens P.L., Lightweight Aggregates for Structural Concrete, Structural Lightweight Aggregate Concrete, edited by J.L. Clarke, Blackie Academic & Professional, London, 1993.

Teo D.C.L., Mannan M.A. and Kurian V.J., "Utilisation of Solid Waste Oil Palm Shell (OPS) in Concrete Production", Proceedings of the International Conference on Natural Resources and Environmental Management, Kuching, Sarawak, Malaysia, 135-140, 2005.