Asian Journal of Civil Engineering (2018) 19:673–678
https://doi.org/10.1007/s42107-018-0057-9

ORIGINAL PAPER

Properties of structural lightweight concrete containing treated oil palm shell as coarse aggregate

V. Swamynadh[1] · K. Muthumani[1]

Received: 23 January 2018 / Accepted: 5 June 2018 / Published online: 11 June 2018

Abstract

One way of attaining sustainable and environment friendly structures is to use industrial waste as construction material. Oil palm boiler clinker obtained from palm oil extraction process in palm oil industry is a promising material which can be used for replacement of coarse aggregate in concrete. In this study, development of water absorption rate in oil palm shell is modified with water-repellent admixture to maintain the mechanical properties as same as normal weight concrete (NWC). These oil palm shells are lightweight and can be used as coarse aggregate for structural application in construction structures. The physical and chemical properties of such aggregate are evaluated and improved for those parameters which are deficient to produce good quality concrete. Internal curing of concrete takes place when treated oil palm shell is used as lightweight aggregate which is an added advantage for durable concrete. Properties like sorptivity, density, compressive strength were measured and discussed. Results show that replacement of normal aggregate with industrial waste product is structurally good and environmental friendly, compression strength ranging from 25 to 30 MPa which is same in case of NWC.

Keywords Water absorption · Water repellent · Density · Oil palm shell (OPS) · Oil palm shell structural lightweight concrete (OPS Concrete)

Introduction

Construction industry is growing at a greater speed and they use natural resources extensively. The current focus of policy planners is to increase the use of environmentally renewable concrete and makes it lighter, stronger and durable. The new development in material is directed towards using industrial waste. Oil palm shell, a by-product from palm oil industry, is widely available in the southern part of India. These shells are lightweight and have similar mechanical properties of aggregates used in concrete. Basic physical and chemical properties of OPS are not good enough to be used directly in making structural concrete and hence need improvement in certain properties of material. Structural lightweight concrete (SLC) has normal air dry density in the range of 1440–1840 kg/m^{3}as per the ASTM 567-A Standard Test Method for determining the Density of SLC. Concrete with low density can be achieved by natural and industrial wastes like pumice, scoria, oil palm shells, etc. Density of concrete made with these waste products and natural materials are in the range of 1200–1900 kg/m^3 (Teo et al. 2007). Density of SLC is lighter than normal weight concrete (NWC) by about 25–35%.

Processing of palm oil from palm oil fruit is made in four stages, i.e. sterilization, separation, pressing, depericarping, separation of kernel and shell, and clarification. In the processing stage, shells are the waste product and they are dumped as waste. Normally, the colour of shell is dark grey to black. The concrete made with this oil palm shell looks black after crushing of concrete. These shells are left under environment without any care or protection. Usage of this industrial waste in the concrete had to be investigated. These shells which can be replaced as the aggregate in concrete show huge improvement on mechanical and physical properties.

✉ V. Swamynadh
swamynadh.2016@vitstudent.ac.in

1 School of Mechanical and Building Sciences, Vellore Institute of Technology, Chennai, India

Although the LWC aggregate properties will affect the compressive strength and durability properties, the nature of constituent material matrix plays a greater influence. Fine aggregates used in matrix should have fine enough particles to maintain the cohesiveness of the concrete mixture. Mix designs for SLC have been under development for many decades to get the optimum strength and to make the concrete durable. SLC has been in use in Malaysia to build sustainable environmentally structures among developing countries (Uemura et al. 2012). They use some of the agricultural wastes and industrial by-products to make the concrete lightweight and to make the construction environmental friendly. In tropical regions, OPS is widely used and are widely available. OPS is agriculture waste from the oil palm industries throughout the world. Their by-products are oil palm shell (OPS) and palm kernel shell (PKS). Research on OPS for SLC was started in the year 1985 by Salam and Abdullah in Malaysia (Teo et al. 2006). Malaysia, Nigeria, Indonesia and many other countries have established oil palm industries. 57.8% of the total supply of palm oil in the world is produced and exported to different countries by Malaysia (Teo et al. 2006). In Malaysia and Nigeria, it was estimated that over 4 and 1.5 million tons, respectively, of OPS solid waste are produced annually.

OPS can be used as an aggregate for making lightweight structural concrete as can be seen from various investigations by the researchers. OPS for SLC shows good mechanical and physical properties and good thermal performance for low cost housing (Mannan and Ganapathy 2002). Using solid agricultural wastes as aggregates can reduce the cost of construction materials and OPS is the best replacement of granite gravel which is used commonly for making concrete. Using such industrial wastes in making concrete resolves the problem concerning the disposal of waste products generated at different industries.

Treatment of oil palm shell has to be done before casting. Water absorption or sorptivity value is 8 times higher than normal aggregate. The shells after separation from the fruit are crushed. The shape of the shell is angular and polygon, etc. The face of the shells is smooth and these have thickness of about 2.3–10 mm. Due to high porosity in OPS, the density is around 350–600 kg/m^3 (Basri et al. 1999), which has specific gravity in the range of 1.13–1.38. OPS is 60% lower density than normal weight aggregate (gravel). OPS is hard and does not deteriorate easily.

Materials

Binder

Cement used for making of structural lightweight aggregate concrete is Ordinary Portland cement (OPC), Specific gravity of cement is 3.14, the Blaine-specific surface area is 3510 cm^2/g, silica fume used has a specific gravity of 2.05 and the specific surface area is 15,000 m^2/kg. GGBS has the specific gravity of 2.85, and specific surface area of 4000 cm^2/g. The chemical composition of OPC is given in Table 1.

Aggregates

Normal river sand of size of 300 μm to 5 mm is used as fine aggregate while for the coarse aggregate, oil palm shells are used which have a specific gravity of 1.3. These are obtained from Andhra Pradesh and India, having the size of 2.36–10 mm as shown in Fig. 1. Table 2 shows the physical properties of OPS which has compacted the bulk density of 510 kg/m^3 and loose bulk density of 380 kg/m^3 (Shafigh et al. 2010). The 24 h water absorption of oil palm shell (OPS) is 22% as against 4% for gravel. The partial distribution grading is given in the granular grading analysis for the OPS aggregate. Sieve analysis is carried out and is in the range of 2–10 mm in size which is crucial in

Table 1 Chemical composition of OPC

SiO_2	Fe_2O_3	CaO	MgO	Al_2O_3	SO_3	LOI
Chemical composition (%)						
21.22	3.39	64.6	2.07	5.8	2.16	0.65

Fig. 1 Oil palm shell

Table 2 Physical properties of OPS aggregate and crushed granite

Compacted bulk density (kg/m^3)		Water Absorption (%)		Aggregate Impact value (%)	
OPS	Crushed granite	OPS	Crushed aggregate	OPS	Crushed aggregate
Physical properties					
350–550	1470	23–30	2–5	21.1	17.85

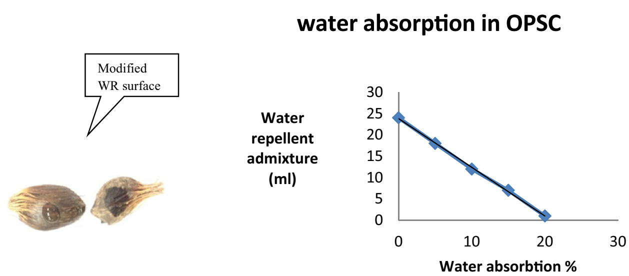

Fig. 2 Water repellent for pumice and water absorption in OPS aggregate

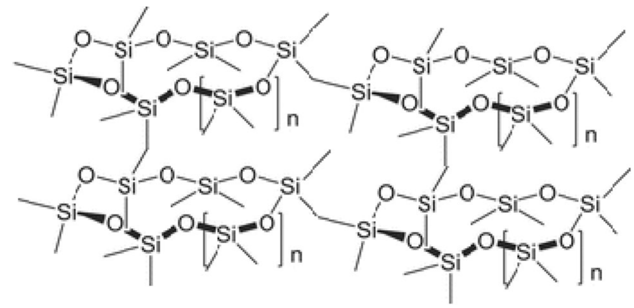

Fig. 3 Silicon and oxygen forming series to form hydrophobic nature

the mix design of concrete. Grading curve shows the impact on mechanical properties of OPS concrete. SLC mix design is done for a 28-day compressive strength around 25–30 MPa and cement is partially replaced by silica fume and GGBS to improve strength and durability properties (Shafigh et al. 2011).

Water

Normal water is used to mix the concrete constituents. Water/cement ratio taken is 0.35 which is about 170–220 kg/m^3.

Water repellents

Acrylic bonding agent and penetrative waterproofing are the admixtures which form a water-resistant cementitious bonding coat and reduce porosity of the aggregate. It acts as an excellent bonding agent for improving adhesion of concrete. Water absorption of OPS is about 23–30% which is 60–70% high when compared to NWC (Ardakani and Yazdani 2014). Use of water repellent admixture can make the OPS aggregate to absorb less water as shown in Fig. 2. Graph shows decrease in water absorption rate with an increase of water repellent admixture (Zycocyl). This nano-sealer becomes integral part of the aggregate which should be done before 24 h for making OPS concrete (Akhnoukh 2017). This gives good slump value and workability. Making of concrete with untreated OPS gives low slump value and less bonding to cement paste which is not acceptable for good bond strength of concrete. Chemical action of penetrative waterproofing creates molecular level hydrophobic zone as in Fig. 3, which is the high level water-resistant zone.

Mix proportion and procedure

Two types of concretes are investigated with different mix proportions to know the mechanical properties. All the ingredients were blended in a pan mix. Concrete is prepared to conduct slump test for all the blended mix and then prepared concrete is poured in moulds and allow them

Table 3 Quantity of constituent materials as per mix design

Mix	Cement (kg)		Water (l)	*w/c* (ratio)	Sand (kg)	Coarse aggregate		Slump (mm)	Density (kg/m^3)
						OPS (kg)	Gravel (kg)		
NWC	400		160	0.4	751.8	–	1080.6	60	2390
LWC	450		180	0.4	715	382	–	95	1727
LWC SF 15	Cement 383	SF 67	180	0.4	715	394	–	90	1739
LWC GGBS 15	Cement 383	GGBS 67	180	0.4	715	394	–	90	1739

in the room temperature for 24 h. Standard cubes and cylinders were prepared and are cured for 28 days till the test is conducted. Two mix designs were prepared for LWC and NWC. Three types of mix proportions are prepared in case of LWC concrete to observe the difference in mechanical properties. Mix proportions of all the type of concretes are listed in Table 3. Replacement of cement with 15% silica fume and 15% GGBS in LWC is designed to improve the strength and to maintain the strength same as NWC as reported by Mehta and Monteiro (2006). As listed in Table 3, lightweight concrete (LWC), lightweight concrete with 15% silica fume (LWC SF 15), lightweight concrete with 15% GGBS (LWC GGBS 15), and normal weight concrete (NWC) were prepared to test for mechanical properties. All the LWA are pre-soaked in water for 24 h and treated with water-repellent admixture before the mixing is done.

Tests and results

Sieve analysis for OPS

OPS is collected from the dumping yard of palm oil industry. These are mixed with debris and cannot be used directly. Sieve analysis for the sample of 50 kg is carried out with different sieve sizes as shown in Table 4 and represented in the percentages of each stage. Sieve analysis is carried out to collect the aggregate of size range from 8 to 10 mm for making the lightweight concrete.

Compressive strength

The compressive strength test is conducted on cubes of standard size of 150 mm at the age of 3, 7, 14, 28, 35 days using UTM of 2000T capacity in accordance with compressive strength test of concrete (IS:516) (Parhizkar and Najimi 2012). Compressive testing is conducted for all the mix samples and is listed in Table 5. Compressive strength of LWC is 18% less when compared to NWC due to lack of interlocking between the lightweight aggregate and cement paste. LWC SF 15 shows similar strength as NWC due to the micro-pores in the lightweight aggregates which are filled with percentage of silica and bonding between the paste and aggregate is much higher than that of LWC.

Table 4 Results of sieve analysis show size distribution of OPS

S.No	Sieve size	Pass percentage
1	16	100
2	14	94.4
3	12	82.6
4	10	57
5	8	16.8
6	6	0

Table 5 Compressive strength of concrete (MPa)

Age (days)	7	14	28	35
LWC	22	26	30	32
LWC SF 15	24	27	31	33
LWC GGBS 15	18	24	27	29
NWC	25	28	34	36

Figure 4 shows the compressive strength and age of concrete for all the mix designs. NWC has compressive strength of 36 MPa which is 85% of that of SF15. Remaining mix designs show decrease in mechanical properties compared to NWC due to their respective ingredients in concrete. GGBS 15 shows gradual decrease in compressive strength than NWC and SF 15 for the 7, 14, 28 days but nearly equal compressive strength at 35 days of SF 15. This is due to the delay in heat of hydration in the LWC GGBS 15. Gel formation at this level of mix does not show good binding nature with the OPS and there is a decrease in compressive strength. Such comparative studies reported by Aslam et al. (2016a) show less compressive strengths of LWC when compared to NWC of all the sample mixes.

Replacement of cement with 15% silica fume shows the higher compressive strength than GGBS 15 for 28 days. The 28 days compressive strength of these concrete mixes is in structural range. The decrease in compressive strength is mainly due to the weak bond between the cement paste and the type of aggregate used in the concrete. Density of the aggregate also influences the strength of concrete (Aslam et al. 2016a, b; Okpala 1990).

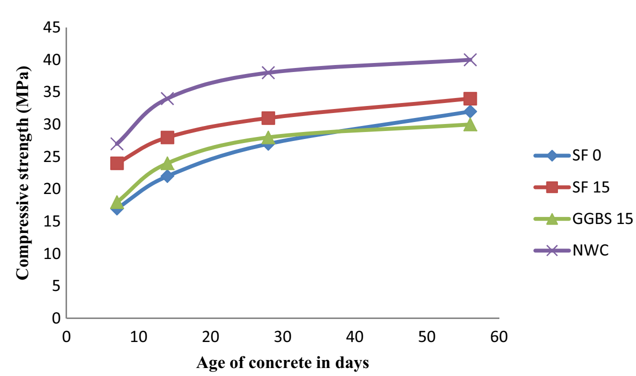

Fig. 4 Compressive strength of concrete

Tensile strength of SLC

Reinforced concrete structures ignore the tensile strength of concrete and provide steel reinforcement in the RCC structures. It is not practical to use reinforcement in the huge constructions like dams, airfield slabs and dams under seismic loading (Mehta and Monteiro 2006; Neville 2008). Splitting tensile strength of LWC and NWC is plotted in Fig. 5. As expected, NWC has higher splitting tensile strength than LWC. Results show 3.4 MPa for LWC for 28 days and 3.98 MPa for NWC. The variation in NWC and LWC splitting tensile strength is due to the toughness of the aggregate in LWC which falls in less tensile strength than NWC. Kockal and Ozturan reported that the minimum splitting tensile strength of 2 MPa is required for making SLC (Kockal and Ozturan 2011). The ratio of splitting tensile strength to compressive strength for LWC falls under 15.7–17.2% whereas for NWC it falls under 11.7–12.6%. This shows that for similar grade of concrete there are contrasting results for both compressive strength and splitting tensile strength of concretes. This also shows that there is a possibility of increase in splitting tensile strength if the toughness of the aggregate in LWC is more. Shafigh et al. reported that the ratios of LWC have 8–10% tensile to compressive strength which comes close to the NWC (Shafigh et al. 2012).

Aggregate impact value

Aggregate impact value (AIV) gives toughness or impact value of aggregate. It is the percentage of fine produced from the aggregate sample after subjecting to a standard amount of impact. Aggregate size of 8–10 mm is considered and then sieving of aggregate is carried out with 8–10 mm sieves. The aggregate that passed through this and retained on 10 mm sieve is taken to conduct the test. Both the NWA and LWA are sieved and weighed in balance machine and are prepared for testing. The apparatus required to conduct the test is impact testing machine. The

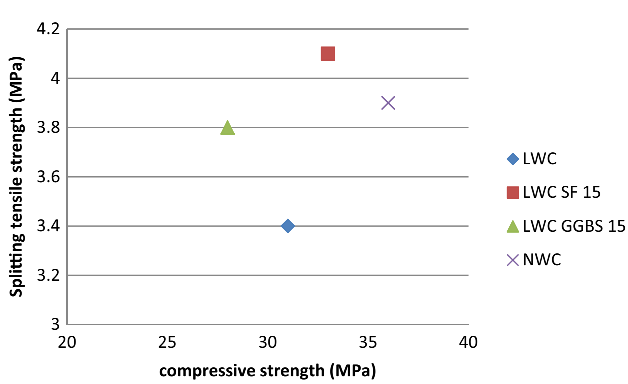

Fig. 5 Comparison of split tensile strength and compressive strength

Fig. 6 Test setup for impact strength of lightweight aggregate and conventional aggregate

measuring cup should be filled with these samples one by one and should be fixed firmly at the bottom of the testing machine as shown in Fig. 6. The falling weight is 135 kg and the falling distance of 300 mm height. The sample is taken out from the measuring cup and passed through 2.36 mm sieve and is weighed. The aggregate impact value is computed. The samples of NWA and LWA are considered for the test and AIV is found as reported in Table 6. Test results shows the percentage impact values are in the range of strong values as recommended by (IS: 2386 part IV 2002) Methods of test for aggregates for concrete.

Conclusions

1. OPS needs pre-processing to improve the water absorption property. The strength needed for structural performance of concrete can be obtained using OPS and other ingredients. 15% replacement of cement with silica fume shows good compressive strength comparable to NWC. This is due to the aspect ratio of silica fume to cement. When 15% cement is replaced with GGBS, the compressive strength decreases initially but gains in longer duration. This is because the C–S–H gel formation is delayed in case of LWC with GGBS.
2. Water repellents are used to process the OPS aggregate for making of LWC. Use of hydrophobic water repellent for OPS shows decrease in water absorption rate to 2% from 24%.
3. Aggregate impact value for LWA is 21.1% which is in the range of strong impact value classification, which

Table 6 Aggregate impact value

NWA	LWA
Total weight of sample = 420 g	Total weight of sample = 118 g
Weight of sample passing 2.36 mm sieve = 75 g	Weight of sample passing 2.36 mm sieve = 25 g
Aggregate impact value = 17.85%	Aggregate impact value = 21.1%

can be absolutely fine to use for the construction of the structures.

4. As the OPS aggregates are collected from industrial waste, grading is needed to make sure that all the aggregates are of same size.
5. OPS concrete shows similar properties as that of NWC and these can be used as structural concrete. This shows that OPS concrete falls in structural property range. These property values can be increased by redesigning the mix suitably.

References

Akhnoukh, A. K. (2017). Internal curing of concrete using lightweight aggregates. *Journal of Particulate Science and Technology, Taylor & Francis., 3,* 1–6.

Ardakani, A., & Yazdani, M. (2014). The relation between particle density and static elastic moduli of lightweight expanded clay aggregates. *Applied Clay Science, 93–94,* 28–34.

Aslam, M., Sha, P., Zamin, M., & Lachemi, M. (2016a). Benefits of using blended waste coarse lightweight aggregates in structural lightweight aggregate concrete. *Journal of Cleaner Production, 119,* 108–117.

Aslam, M., Shafigh, P., & Jumaat, M. Z. (2016b). Drying shrinkage behaviour of structural lightweight aggregate concrete containing blended oil palm bio-products. *Journal of Cleaner Production, 127,* 183–194.

Aslam, M., Shafigh, P., Jumaat, M. Z., & Lachemi, M. (2016c). Benefits of using blended waste coarse lightweight aggregates in structural lightweight aggregate concrete. *Journal of Cleaner Production, 119,* 108–117.

Basri, H. B., Mannan, M. A., & Zain, M. F. M. (1999). Concrete using waste oil palm shells as aggregate. *Cement and Concrete Research, 29,* 619–622.

IS: 2389 part IV. (2002). Methods of test for aggregates for concrete. Mechanical properties.

Kockal, N. U., & Ozturan, T. (2011). Strength and elastic properties of structural lightweight concretes. *Materials Design, 32*(4), 2396–2403.

Mannan, M. A., & Ganapathy, C. U. (2002). Engineering properties of concrete with oil palm shell as coarse aggregate. *Construction and Building Materials, 16,* 29–34.

Mehta, P. K., & Monteiro, P. J. M. (2006). *Concrete: Microstructure, properties, and materials*. New York: McGraw-Hill.

Neville, A. M. (2008). *Properties of concrete, fourteenth*. Malaysia: CTP-VVP.

Okpala, D. (1990). Palm kernel shell as a lightweight aggregate in concrete. *Construction and Building Materials, 25,* 291–296.

Parhizkar, T., & Najimi, M. (2012). Application of pumice aggregate in structural lightweight concrete. *Asian Journal of Civil Engineering, 13*(1), 43–54.

Shafigh, P., Jumaat, M. Z., Bin, M. H., & Alengaram, U. J. (2011). A new method of producing high strength oil palm shell lightweight concrete. *Material Design, 32*(10), 4839–4843.

Shafigh, P., Jumaat, M. Z., & Mahmud, H. (2010). Mix design and mechanical properties of oil palm shell lightweight aggregate concrete. A review. *International journal of the physical science, 5*(14), 2127–2134.

Shafigh, P., Jumaat, M. Z., Mahmud, H. B., & Hamid, N. A. A. (2012). Lightweight concrete made from crushed oil palm shell: Tensile strength and effect of initial curing on compressive strength. *Construction and Building Materials, 27*(1), 252–258.

Teo, D. C. L., Mannan, M. A., & Kurian, J. V. (2006a). Flexural behaviour of reinforced lightweight concrete beams made with oil palm shell (OPS). *Jouranl Advanced Concrete Technology, 4,* 459–468.

Teo, D. C. L., Mannan, M. A Ã., Kurian, V. J., & Ganapathy, C. (2007). Lightweight concrete made from oil palm shell (OPS). *Structural Bond and Durability Properties, 42,* 2614–2621.

Teo, D. C. L., Mannan, M. A., Kurian, V. J., & Program, C. E. (2006b). Structural concrete using oil palm shell (OPS) as lightweight. *Structural bond and durability propertie, 30,* 251–257.

Uemura, Y., Omar, W. N., Tsutsui, T., Yusup, S. B., Basiron, Y., & Friends of the Earth. (2012). Oil palm biomass as a sustainable energy source, a Malaysian case study. *Biomass and Bioenergy, 3*(1), 97–103.