Jurnal
Teknologi

Full Paper

DURABILITY PERFORMANCE OF OIL PALM SHELL LIGHTWEIGHT CONCRETE FOR INSULATION BUILDING MATERIAL

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Article history
Received
7 July 2015
Received in revised form
3 November 2015
Accepted
3 March 2016

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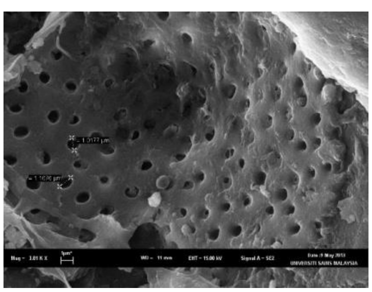
Graphical abstract



Abstract

The advantage of oil palm shell (OPS) as coarse aggregate in concrete can be extended to insulation concrete capacity. Thus, this paper will explain the durability of oil palm shell lightweight concrete (OPSLC) for insulation concrete capacity in building. Nine mix designs were developed containing high volume of OPS, which is 30, 32 and 34% from total volume of concrete with three different OPS shapes (raw, crushed and partly crushed). The water absorption and drying shrinkage were examined; besides, thermal conductivity testing that was conducted for confirmation as insulation concrete category. The observation of all the specimens lasted one year for durability performance test and 28 days for thermal conductivity value. The highest water absorption value is 43% from previous study that was designed for structural concrete. Higher OPS volume fraction produced higher air void content and caused water loss and increase of the hydration effects on OPSLC shrinkage. It also affected the microstructure conditions, especially specimens that used 34% of OPS volume fraction which show weak interface bond in cement matrix.

Keywords: Water absorption, drying shrinkage, thermal conductivity, insulation concrete

Abstrak

Kelebihan tempurung kelapa sawit (OPS) sebagai aggregat kasar dalam konkrit dapat dimanfaatkan juga untuk konkrit penebatan. Artikel ini akan menjelaskan tentang ketahanan konkrit ringan tempurung kelapa sawit (OPSLC) dalam konkrit penebatan di bangunan. Sembilan jenis campuran yang mengandungi kandungan OPS yang tinggi iaitu sebanyak 30%, 32% dan 34% daripada jumlah isipadu konkrit dan bentuk OPS yang berbeza (asal, hancur, separa hancur) telah dihasilkan. Penyerapan air dan pengecutan kering juga dikaji, selain pengujian kekonduksian haba yang dilakukan untuk mengesahkan konkrit sebagai kategori konkrit penebatan. Pemerhatian semua spesimen dijalankan selama setahun untuk ujian prestasi ketahanan dan 28 hari untuk mendapatkan nilai kekonduksian haba. Daripada kajian ini, nilai penyerapan air tertinggi yang diperoleh adalah 43% lebih tinggi daripada nilai dalam kajian terdahulu yang dijalankan terhadap konkrit struktur. Pecahan isipadu OPS yang lebih tinggi menghasilkan kandungan rongga udara yang lebih banyak dan menyebabkan kehilangan air serta meningkatkan kesan hidrasi terhadap pengecutan OPSLC. Ia juga menjejaskan keadaan mikrosturktur terutamanya bagi spesimen yang menggunakan 34% pecahan isipadu OPS yang menunjukkan ikatan antara muka yang lemah dalam matriks simen.

Kata kunci: Penyerapan air, penyecutan kering, termal konduktiviti, konkrit penebat

1.0 INTRODUCTION

The increase of energy usage in building now a days, encouraged the researcher to explore new materials for insulation purposes. One of the alternative is, by using insulation concrete as part of the structure. Not only can it carry the load, but it is also capable of improving comfort and reducing heat loss in the building. The thermal insulation of the building envelope in one of the alternative available for conserving energy. There in an increasing demand for insulation building materials like lightweight aggregate concrete due to the need to cut down on energy wastage. To produce insulation concrete with load bearing strength, lightweight aggregate concrete (LAC) is one of the options. There are some lightweight aggregates that are already established as coarse aggregate in LAC such as pumice, perlite, expanded clay and expanded polystyrene. Another potential lightweight aggregate that caught the interest of the researcher is oil palm shell (OPS). The natural characteristics of OPS, which is light and hard are suitable as coarse aggregate in LAC, and it is already established as structural lightweight concrete by previous researchers. The highest strength obtained by Shafigh *et al*. [1] which is 42Mpa was by using crushed OPS. Most of previous studyies only used 25% and below of OPS volume fraction from the total concrete volume for structural lightweight aggregate. However, for insulation concrete, the volume fraction of lightweight aggregate is normally higher than structural lightweight concrete. Thermal conductivity is an essential parameter to classify lightweight concrete in insulation concrete category (RILEM) and it is an important parameter to measure heat flow in cement concrete pavement [2]. Low temperature is obtained for conduction of high-temperature thermal energy within an object or between two objects in contact.

The energy performance of a building greatly depends on the thermal conductivity of the building materials which depicts the capability of heat to flow across the material in the presence of a differential temperature [3]. Thermal conductivity is influenced by density of concrete, porosity content, chemical composition and moisture content. Ramazan & Rusnem [4] reported that for expanded perlite aggregate, they used 31% volume fraction to achieve 0.17 W/mK. However for expanded polystyrene aggregate, Demirboga [5] reported that only 12% is needed to achieve the insulation range, due to it having low thermal conductivity which is 0.03 W/mK and low specific gravity. And for OPS lightweight aggregate Okpala [6] already investigated the thermal conductivity of OPS that is 0.19 W/mk. Thus the possibility of OPS as coarse aggregate on insulation concrete is high. To investigate this potential, Serri *et al*. [7] already conducted the study and reported, that starting from OPS volume fraction of 30% and above, the OPSLC achieved the insulation concrete, according to RILEM requirement. However no literature was found on the discussion about the durability of OPSLC insulation concrete that focus specifically on water absorption, shrinkage and thermal conductivity. The previous researchers only covered the structural lightweight concrete performance. The high volume fraction of OPS in insulation concrete design is definitely different with structural OPSLC performance. LAC for insulation purpose has considerably higher water absorption value than do normal weight concrete, however, it does not necessarily indicate that the concrete has poor durability or high permeability.

The individual aggregate particle the amount of water absorbed and the rate of absorption depend primarily on the pores, for example whether connected or disconnected. For lightweight aggregate particles, which have a relatively large pore volume, the rate of water absorption is likely to be much higher than for natural dense aggregates. However, the characteristic of the surface zone of aggregate particle has a large influence on absorption such that the disparity between natural and lightweight aggregate may not be as large as expected from the differences in diminishes with time [8]. Demirboga and Kan [9] reported, that the shrinkage of modified expanded polysrine (MEP) LAC increased with increasing volume fraction of MEP: usage of 100% of MEP caused drying shrinkage to be 2.36 times higher compared to when only 25% of MEP used for 210 days exposure in ambient temperature. For volcanic umice aggregate LAC, for 12 weeks of exposure caused 34% higher drying shrinkage compared to normal concrete, according to Hossain *et al.* [10]. The focus of the study, are to investigate the effect of the volume fraction of OPS and OPS shape on water absorption and drying shrinkage of OPSLC insulation concrete.

2.0 METHODOLOGY

2.1 Materials

Ordinary Portland cement ASTM type I with specific gravity of 3.10 and Blaice specific surface area of 3510 cm²/g; local sand with specific gravity, fines modulus, water absorption and maximum grain size of 2.67,2.66, 0.95% and 2.36 mm., respectively. Superplasticizer (SP) in the range 1% of cement volume was used and potable water.

Old OPS was used as coarse aggregate, which is OPS that has been left outside for approximately half a year at the palm oil mill yard. Old OPS does not have fibre and less oil coating, which result in better bond within the OPS surface and mortar. OPS in different shapes and sizes were used and for crushed OPS, stone crushing machine was used to crush the OPS. The physical properties of OPS that are used in this study are shown in Table 1. Due to high water absorption of OPS, it was washed and kept in a saturated dry (SSD) condition before mixing.

Table 1 Physical properties of OPS aggregate

OPS Shape	Raw (R)	Crushed (C)	Partly Crushed (P)
Specific Gravity	1.19	1.22	1.21
Water absorptions (%) 24 hour	21.1	18.73	20.8
Bulk Density	568	626.4	618
Fines Modulus	6.25	5.82	6.01

2.2 Testing

Water absorption test according to BS 1881-122:1993. The specimens used are cylinders with dimension of 75mmф x 100mm were cored from prism. The drying shrinkage test procedure is compiled by ASTM C 157 and the specimens dimension are comply with ATSM C490 which is 75 mm x 75 mm x 280 mm prism. The thermal properties of specimen at room temperature are measured with a Hot-Disk probe TPS2500 (Figure 1). The system is based on the Transient Plane Source technology. All specimens were prepared according to ASTM C332 and the testing met the ISO/DIS 22007-2.2 standard. A chosen sensor with a radius of 9mm consisting of very fine nikel double spiral covered with two thin layer of electrically insulating materials is placed between two specimens with 75ф and 45 mm thick. The two sample pieces are prepared with a section of flat surface each in order to obtain a contact surface with the thinnest air layer possible. The mix proportion for all the specimens are presented at Table 2.

Figure 1 Set-up of Hot disk thermal constant analyzer for thermal test with a Hot-Disk probe TPS2500

Table 2 Mix proportion for all OPSLC specimens

Mix	OPS				C	W	S	SP (%)
	Raw	Crushed	Partly crushed	Vf (%)				
R- 30	524	-	-	30	400	160	720	4
R -32	566	-	-	32	375	150	675	3.8
R -34	606	-	-	34	350	140	631	3.5
C -30	-	537	-	30	400	160	721	4
C -32	-	581	-	32	375	149	674	3.8
C -34	-	617	-	34	350	143	631	3.5
P -30	-	-	531	30	400	159	719	4
P -32	-	-	574	32	375	150	676	3.8
P -34	-	-	617	34	350	140	631	3.5

Note* C: cement; W: water; S: sand; Vf; Volume fraction

3.0 RESULTS AND DISCUSSION

3.1 Water Absorption

One of the methods to determine the durability of concrete is through water absorption test that measures the volume of pore space in concrete. Absorption is generally measured by drying of the specimens to a constant weight followed by immersion in water for a stipulated time and eventual measurement of increase in weight of specimens as a percentage of dry weight. Good quality concrete should have below 10% of water absorption by dry weight [2]. The water absorption increased in the range of 26% to 67% from 28 days to 360 days. This situation shows that although the OPS has high porosity, however, its water absorption was already optimum during pre-water absorption in material preparation stages. Thus, the development of cement matrix will influence the water absorption of OPSLC. Specimen P-34 has the highest water absorption value than other specimens. From 28 days to 360 days this specimen showed higher water absorption compared to other specimens. Specimen C-30 obtained the lowest water absorption at 28 days. However, after a long term exposure, specimen P-30 shows the highest reduction of water absorption content. The group of specimens that used OPS Vf of 30% produced the lowest water absorption compared to other Vf, especially at 360 days. In terms of the effect of OPS shape, R shape OPS show better performance in water absorption. Previous studies that used Vf of around 14% to 22%, have water absorption of around 4% to 6%. [11]. For insulation concrete at least 30% or and more of OPS Vf is needed to achieve the requirement [7], and this will affected the water absorption.

To analyse OPSLC water absorption, Shafigh *et al.* [16] conducted a test for structural lightweight concrete design at 28 days (Table 4). The OPS Vf is in the range of 14%–22%, while the water absorption result lies between 4.2%-5.9%, which is 43% lower than water absorption mean in this study. The increasing of

OPS Vf will increase the water absorption value of OPSLC. This comparison analysis proved that increasing Vf of OPS in concrete will increase water absorption of OPSLC. Table 3 shows the water absorption for all the specimens,

Table 3 Water absorption for all the specimens (%)

Specimens	Days 7	28	90	180	270	360
R-30	10.09	9.76	7.95	7.06	6.49	5.84
R-32	10.86	10.56	9.52	8.11	7.26	6.32
R-34	11.5	10.76	9.58	8.63	8.23	7.05
C-30	9.59	9.29	8.34	8.09	6.81	5.31
C-32	11.08	10.41	9.89	8.47	7.82	6.02
C-34	11.47	11.24	10.05	9.52	8.13	7.59
P-30	10.72	10.49	9.29	7.83	6.51	5.23
P-32	11.45	10.72	9.22	8.58	7.59	6.38
P-34	11.79	11.53	10.98	10.84	10.23	9.12

Table 4 Water absorption of previous studies on OPSLC [16]

Reference	OPC	W	S	OPS (kg/m³)	OPS Vf (%)	OPS Shape	W A (%)
	(kg/m³)						
[16]	550	234	950	273	14	raw	5.9
	480	182	1050	295	15	raw	3
	520	177	852	364	19	raw	3.5
	520	177	746	420	22	raw	4.2

Note* W: water; OPC: ordinary Portland cement; S: sand; WA: Water absorption

3.2 Drying Shrinkage

Drying shrinkage is another parameter in durability properties that needs to be considered in OPSLC. Due to high water absorption, OPSLC is very sensitive to curing environment and drying shrinkage. Compared to other lightweight aggregate such as expanded clay, OPS has greater drying shrinkage for long term exposure [12]. Clearly, the time of drying is a factor in shrinkage as it takes place over a long period of the time with a high initial rate of shrinkage that decreases rapidly.

The lower the relative humidity, the greater the shrinkage because the higher relative humidity gradient between the concrete and environment promotes greater loss of water. Thus, the particles have the tendency to move to each other when they were evaporated to the atmosphere and hence the shrinkage is occurred.

The result for drying shrinkage as presented in Figure 2, shows the result of all specimens for up until one year. The figure clearly shows that the drying shrinkage for all OPSLC specimens is dramatically high in early age until 28 days, and slowly increases until one year exposure. Based on a previous study conducted by Clarke [8]. Concrete shrinkage is found to have a correlation with the modulus of elasticity of concrete. This correlation also happens to OPSLC due to high modulus elasticity obtained by specimens as in specimen C-30, which produced lower drying shrinkage compared to specimens P-34, with lower modulus of elasticity value and greater drying shrinkage.

Another indicator that can be used to see the differences of OPSLC drying shrinkage is Vf of OPS. Higher V_f of OPS will cause greater drying shrinkage. Specimens that used 30% of OPS V_f have low drying shrinkage than specimens that used 34% of OPS V_f. At 360 days, Vf of 30% has contributed to reduction of shrinkage by around 8%, whereas for Vf of 32% and 34%, drying shrinkage is around 13% and 16%, respectively.

Drying shrinkage in cement paste is an early indication for shrinkage performance. The loss of water from the pores in OPS significantly affects the volume change of OPSLC. This is in agreement with findings of Mannan and Ganapathy [13], who reported that by using 6% Vf of OPS in mix design, the drying shrinkage is around 6% compared to normal concrete and when continuously exposed until 90 days, the dying shrinkage increase up to 14%. Generally the drying shrinkage for lightweight concrete is approximately 50% greater than normal concrete [7].

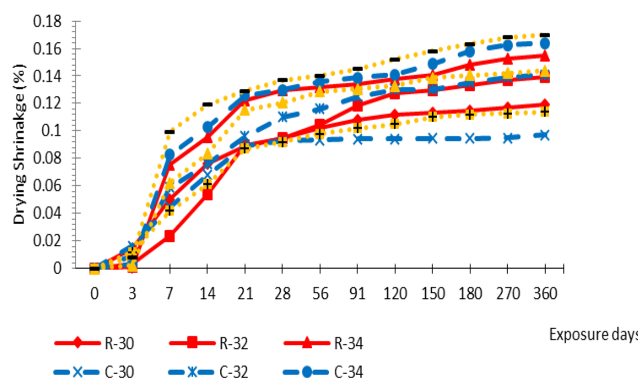


Figure 2 Drying shrinkage of OPSLC subject to drying exposure

And generally, the major factor for the shrinkage behaviour of a concrete is cement paste. After exposure to dry environment, the water inside the Calcium silicate hydrate (C-S-H) is removed, and the loss of water from the small capillary pores significantly affect the volume of OPS [12]. Hence, it can be concluded that higher Vf of OPS will cause water loss and increase the hydration effects of OPSLC shrinkage, due to presence of more pores.

The increasing of OPS Vf directly reduce the cement content in concrete and will contribute to un-hydrated cement, due to high water absorption by the OPS itself. Thus, un-hydrated cement in cement mixture may be considered as fine aggregate [14]. Therefore, this finding is in line with the study by Hooton *et al*. [15] which found that the main cause of drying shrinkage in concrete is the total aggregate volume. The empirical equation developed by Mehta & Monteiro [14] shows the significance (Equation 1):

$$Sc = (1 - g)^n \ Sp \quad (1)$$

Where, *Sc* is the shrinkage of concrete, *Sp* is the shrinkage of the cement paste, *g* is the Vf of aggregate and *n* is a constant that varies between 1.2 and 1.7 depending on the elastic modulus of aggregate.

On the different shape of OPS, it does not have significant effect to drying shrinkage. Even though specimens that used crushed OPS produced the lowest drying shrinkage, however when Vf of OPS is increased to 34%, it contributes to the second greater shrinkage from all the specimens.

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3.3 Thermal Conductivity

The OPS physical properties as lightweight aggregate achieved the requirement as a material with low thermal conductivity and insulation characteristic. And for insulation concrete, thermal conductivity must be below 0.75W/mK according to RILEM requirement.

As can be seen in Table 4, the thermal conductivity of specimens decreased with the increasing Vf of OPS. All specimens achieved the insulation concrete range, except specimens C-30. Based on the 28 days of age result, thermal conductivity is found to be dependent on Vf of OPS; higher Vf of OPS produced lower thermal conductivity. The microstructure in Figure 3 clearly shows the porosity of OPS that is essentially the element that influences the heat transfer of OPSLC. The porosity on OPS, will reduce the heat transfer, thus reducing the thermal conductivity value of OPSLC.

Raw OPS produced lower thermal conductivity compared to crushed and partly crushed OPS, and it is related to high air void content. Bigger OPS will increase the porosity of OPS as coarse aggregate and subsequently reduce the thermal transport on OPSLC. Furthermore, thermal conductivity in lightweight aggregates with a more porous outlet layer encouraged the migration of mobile ions towards it.

Table 4 Thermal conductivity for all specimens

Specimens	Thermal Conductivity (W/mK)
R-30	0.73
R-32	0.67
R-34	0.61
C-30	0.78
C-32	0.73
C-34	0.65
P-30	0.74
P-32	0.71
P-34	0.62

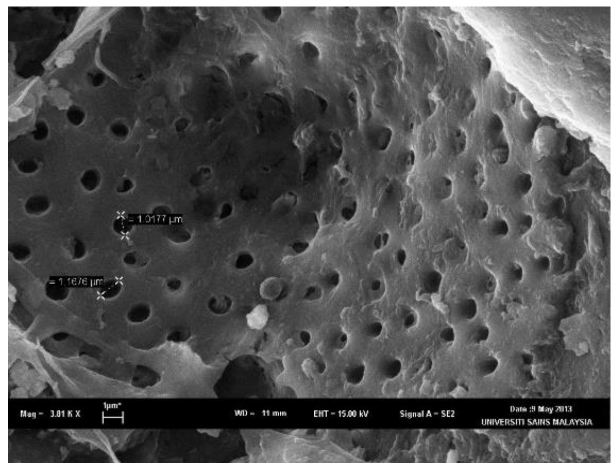

Figure 3 Microstructure of OPS

4.0 CONCLUSION

The conclusions of this paper a presented below:

1. The durability properties of OPSLC are the same as normal weight concrete which is primarily a function of the cement paste quality and amount of well distributed, discrete air bubble entrained in the cement paste.
2. The specimen produced the highest reduction of water absorption at long term exposure, which is 61% at 28 days rate. The water significantly improved the hydration of the cement, thus, allowing the cement matrix of OPSLC to take place.
3. At a given specific volume, OPS with smaller size (crushed) has more influence in reducing drying shrinkage. The highest reduction in drying shrinkage was obtained by specimens P-34. Drastic drying shrinkage started from age 7 days to 28 days.
4. The thermal conductivity increased with addition of OPS Vf. All mix are in the range for insulation structure according to RILEM, except for mix C-30 with thermal conductivity of more than 0.75 W/mK.

Acknowledgements

This research work is founded by Universiti Sains Malaysia under research university grant (RUI) No.1001/PPBGN/814213

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