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Thermal Properties of Oil Palm Shell Lightweight Concrete with Different Mix Designs

Eravan Serri, Md Azree Othuman Mydin*, Mohd Zailan Suleiman

School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia

*Corresponding author: azree@usm.my

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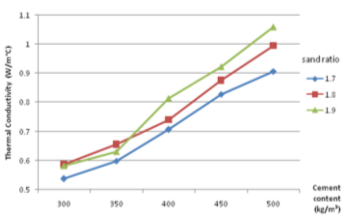
Graphical abstract



Abstract

Nowadays, the utilization of Oil Palm Shell (OPS) as lightweight aggregate in concrete especially in the structure application has become prevalent. As an industrial waste product, Oil Palm Shell (OPS) possibly will be the alternative material to be employed in the construction industry. With its advantage as heat resistant material, this study will focus on the potential of OPS as lightweight aggregate with regard to the optimum content of OPS for thermal insulating material. A total of 15 mixes were prepared and tested with 3 different cement/sand ratios (1.7, 1.8, 1.9) and 5 different cement contents (300, 350, 400, 450, 500 kg/m³). The result of this study show that the highest sand used will produced good workability but increased thermal conductivity of mix value. The test result indicates that the thermal conductivity and insulation criterion is substantially improved with the volume use of OPS and strong relationship between thermal conductivity and unit weight is obtained. The measured thermal conductivity value range from 0.54W/mC to 1.1 W/mC. The ideal value for semi structure insulation material establish by RILEM only achieve for mix that used cement content 400 kg/m³ and below, which thermal conductivity is 0.75 W/mC below.

Keywords: Oil-palm shell; thermal conductivity; concrete; insulation

Abstrak

Pada masa sekarang, penggunaan cenkerang atau kulit buah kepala sawit (OPS) sebagai agregat ringan di dalam struktur konkrit telah menjadi semakin popular. Sebagai bahan buangan industri, OPS berkemungkinan besar untuk dijadikan sebagai alternatif kepada bahan untuk digunakan di dalam industri pembinaan. Dengan kelebihan sebagai bahan tahan panas, kajian ini akan memberi tumpuan kepada potensi OPS sebagai agregat ringan dengan mengambil kira kandungan optimum OPS untuk bahan penebat haba. Sebanyak 15 campuran telah disediakan dan diuji dengan 3 nisbah berbeza untuk simen/pasir (1.7, 1.8, 1.9) dan 5 kandungan simen yang berbeza (300, 350, 400, 450, 500 kg/m³). Hasil kajian ini menunjukkan bahawa pengunaan pasir tertinggi di dalam campuran akan menghasilkan kebolehkerjaan yang baik tetapi pada masa yang sama meningkatkan kaar kekonduksian terma nilai campuran. Keputusan ujian menunjukkan bahawa kekonduksian terma dan kriteria penebat dengan ketara bertambah baik dengan penggunaan isipadu OPS dan mempunyai hubungan yang kukuh di antara kekonduksian terma dan unit berat diperolehi. Nilai kekonduksian haba yang diperoleh adalah daripada 0.54 W/mC kepada 1.1 W / mC. Nilai sesuai untuk bahan penebat struktur separa seperti yang disyorkan oleh RILEM hanya mencapai untuk campuran yang digunakan kandungan simen 400 kg/m³ dan yang lebih rendah, di mana kekonduksian terma adalah 0.75 W/mC dan lebih rendah.

Kata kunci: Kulit buah kepala sawit; kekonduksian terma; konkrit; penebat haba

■1.0 INTRODUCTION

The use of concrete as building material is constantly in high demand [1]. Concrete is an extensively utilized construction material in civil engineering projects throughout the world owing its outstanding resistance to water, structural concrete elements can be produced into a range of shapes and sizes [2] and it is typically the cheapest and most readily obtainable material for the job [3]. Nevertheless, the high density of concrete will result in increase of dead load on building structures because of high usage of steel reinforced [4]. The use of lightweight aggregate in concrete is an option to decrease the dead load on a building, particularly for high-rise buildings [5, 6].

Normally pumice and perlite are used as lightweight aggregate to produce lightweight aggregate concrete and both materials can be found at volcanic area [7]. However, it has not brought much advantage to countries which do not have volcanic environment. The alternative is to use industrial waste material as aggregates for construction. One of the solid waste products that have increasingly gained researchers' interest is oil palm shell produced from the processing of oil palm. Oil palm industry is a fast-growing industry and economically it is able to become the backbone of the economy.

This industry also produces other waste from palm oil processing but, such as fruits, trunks and leaves of palm tree that can be effectively utilized for producing valuable products. For instance approximately 19 million tonnes of crop residues (empty fruit bunch, fiber and shell) were produced per year [8].

Sahu *et al*. [9] reported that the amount of oil palm shell increases every year because there are more than 270 palm oil mills operating in this country to generate the waste. The growing need for sustainable development has motivated researchers to focus their research on the use of waste or recycled materials in potential construction material.

Johnson Alengaram *et al.* [10] conducted a study which focused on the thermal conductivity of foamed OPS concrete of densities in the range of 1100-1600 kg/m3. They also made a comparison with local conventional materials, such as brick and block was also done. They found that the thermal conductivity increases with increasing density. For the low density specimen of foamed concrete, more foam is integrated in the concrete, and, as a result, a high amount of air pores are formed inside. As air is a good insulator, the thermal conductivity of foamed concrete was found to be lower.

There are a number of studies related to OPS lightweight aggregate concrete especially for lightweight structure. However, there was inadequate information regarding the effect of OPS lightweight aggregate on the thermal properties, porosity, unit weight etc. of these concrete in the technical literature. Previous study only mentions that the OPS lightweight concrete has low thermal conductivity compared to normal concrete.

Thermal conductivity of a material is a measure of the ability of a substance or materials a quantity of heat to conduct through a unit thickness in a direction perpendicular to a surface of unit area, due to a unit temperature gradient under given conditions [11]. Previous investigations show that the type of aggregate, porosity and moisture content produce maximum influence on thermal conductivity of concrete [12, 13]. Enclosed pores reduce the conductivity due to low thermal conductivity of air, different from the cement hydrates for which thermal conductivity is not subjected to large variation [14]. By using transient plane source technique the thermal diffusivity of OPS lightweight concrete investigated. Therefore, an experimental investigation related to effect of OPS on thermal conductivity has been carried out and the results are reported in this article.

■2.0 MATERIALS AND METHOD

2.1 Materials

The materials utilized are ordinary Portland cement (OPC) Type I and local river sand. OPS are used as course aggregate and the shells have been left outside the laboratory for 6 months to expose them to natural environment because there might be fibre and oil coating on the surface of fresh OPS. After the exposure, most of the fibres are removed from surface thus reducing the oil coating and other impurities present on the shells. Finally, OPS aggregate were rinsed with potable water to remove the detergent and then dried before being stored in containers. The OPS used has specific gravity, water absorption (24 hour), maximum grain, aggregate impact value and aggregate crushed value of 1.19, 22.1%, 14 mm, 3.3% and 2.62% respectively. The OPS need be absorbed in water for 1 hour and left to saturated dry condition before it can be used and thermal conductivity of OPS are 0.137 W/mC.

2.2 Mixtures

In the experiment, there are 15 mixes with different cement contents (300, 350, 400, 450 and 500 kg/m³) and different sand ratios (1.7, 1.8 and 1.9). For lightweight concrete, the amount of cement content specified is in the range of 285–510 kg/m³ [15].

The mixture proportion is shown in Table 1. Effective water-cement ratio used 0.4 as suggested by previous researchers [16] and it is constant in all mixture. The mix proportioning was based on the absolute volume. The unit weight of the concrete increased as a result of the increase of cement content used. The OPS was kept in water for 1 hour so that the OPS can absorb water and the effective water/cement ratio is not affected.

In order to enhance the workability of the mixture, 1.5% of cement weight was used in all mixture. All mixes were prepared in a laboratory mixer with vertical rotation axis by forced mixing. Precautions were taken to ensure it is homogeneous and fully compacted.

2.3 Thermal Properties Test

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. This method is based on recording the temperature rise of a plane source heating the surrounding materials to be measured. The basic concept of the corresponding sensor is the fact that conducting pattern is used both as a heat source and as a temperature sensor.

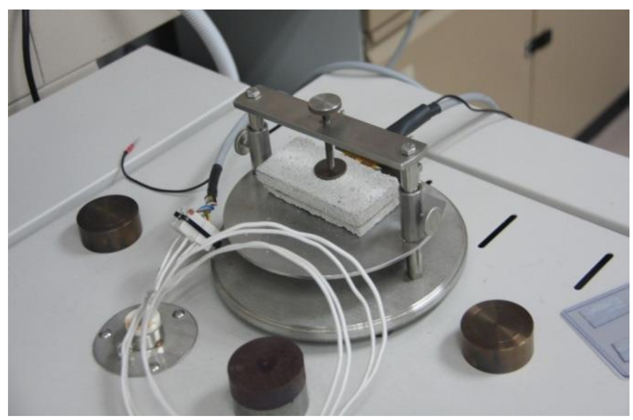


Figure 1 Set-up on Hot disk thermal constant analyzer for thermal test with a Hot-Disk probe TPS2500

All specimens were prepared according to ASTM C332 and the testing met the ISO/DIS 22007-2.2 standard. A sensor chosen with radius 9mm consisting of very fine nikel double spiral covered with two thin layer of electrically insulating materials is placed between two specimens 75ф and 45 mm thickness. The two sample pieces are prepared with a section of flat surface each in order to obtain a contact surface with thinner air layer as possible.

Table 1 Mix proportion of OPS lightweight concrete

Mix Order	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Sand Ratio	1.7	1.8	1.9	1.7	1.8	1.9	1.7	1.8	1.9	1.7	1.8	1.9	1.7	1.8	1.9
Cement (kg/m³)	300	300	300	350	350	350	400	400	400	450	450	450	500	500	500
Sand (kg/m³)	516	539	570	595	630	666	679	721	760	764	811	854	850	899	951
OPS (kg/m³)	699	692	678	623	609	592	544	525	508	463	441	423	375	360	335
Water (kg/m³)	124	124	124	140	140	140	160	160	160	180	180	180	200	200	200
Sp (kg/m³)	4.5	4.5	4.5	5.25	5.25	5.25	6	6	6	6.75	6.75	6.75	7.5	7.5	7.5
Workability (mm)	collapse	5	10	10	15	15	15	20	20	25	25	30	35	40	50
OPS % (kg/m³)	42.59	41.92	40.65	36.48	35.22	33.87	30.49	29.05	27.79	24.76	23.44	22.17	19.69	18.37	16.88

3.0 RESULTS AND DISCUSSION

3.1 Thermal Conductivity

Thermal conductivity of the OPS lightweight concrete is shown in Figure 2. Since moisture content affects thermal diffusivity, all the specimens were tested in oven dry condition. Increasing the volume of OPS aggregate and reducing the cement content will produce porous structure of OPS. The reduction is relatively small for the OPS volume of 20% to 40% from the cube volume. With higher OPS volume ratio, however, more substantial reductions were recorded.

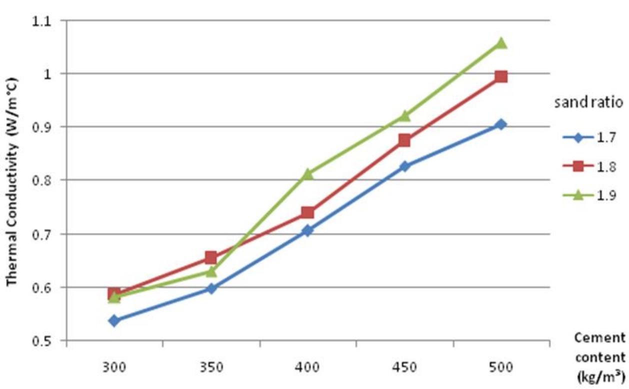


Figure 2 The relationship between thermal conductivity and cement content with different sand ratio

The lowest thermal conductivity recorded is 0.53 W/m°C (mix T1). For semi structured with thermal insulation characteristic, Newman [17] reported RILEM proposed that the thermal conductivity should be below 0.75 W/m°C. Based on that result, mix T1 until T8 fulfilled the requirement. However Okpala [18] reported that with mix proportion of 1:1:2 (cement:sand:shell), the thermal conductivity is 0.45 W/m°C due to higher volume of OPS but with more than 43% of OPS volume kg/m³ and cement:sand ratio below 1.7, it will produce poor workability of concrete.

Porosity is one of the factors affecting the thermal conductivity of concrete and enclosed pores reduced the conductivity due to low thermal conductivity of air. OPS itself are pores aggregate and air entrainment might have also contributed to reduce the thermal diffusivity of all the mixture [10].

Thus thermal conductivity of aggregates primarily determines the insulating quality of the concrete. As it is obvious, aggregate with less thermal conductivity produce less conductive concrete whereas the more conductive aggregates produce more conductive concrete. Aggregate type can cause nearly twice an increase in thermal conductivity of concrete [19].

There is a strong relationship between unit weight and thermal conductivity for the concrete. Low thermal diffusivity and low unit weight, combined with the ability to cast in any desired shape, enables the lightweight concrete to be used as a very suitable material for building blocks or partition walls.

Further, thermal conductivity of 1.89 W/m°C for lightweight concrete with density of 1847 kg/m³ made by composite lightweight aggregate (ground water treatment sludge with water and sawdust) and 0.7 W/m°C with density of 1300 kg/m³ made by expended clay aggregate [19]. Their findings show higher conductivity value compared in this study with same density range. This study shows that the density will influence the thermal conductivity. Moreover, OPS itself have low thermal conductivity value of 0.137 W/m°C which is one of the primary characteristic for the result in this study.

3.2 Specific Heat

Figure 3 shows the specific heat of all mix design. Based on the result, specific heat is not consistent for all different sand ratio and cement content because the specific heat result is obtained base on volume of OPS aggregate at the sample tested. The effect of mineral composition upon specific heat is relatively insignificant, except for the water content and entrained air, because the specific heat of a material is defined as the amount of energy required to raise a unit mass of material by one unit of temperature at constant pressure.

By using transient plane source technique, the measurement of specimen is done by based on recording the temperature rise of plane source heating the surrounding of the sensor [6]. So the reading of specific heat for the specimen depends on unevenly distribution of OPS at the specimen. From Figure 3, it can be concluded that the specific heat of concrete is influenced by the distribution of course aggregate (OPS).

The water content in OPS will increase the amount of specific heat. In general, specific heat varies with variation in temperature. Hydrated cement paste has low specific heat and very define of variation with temperature. Hydrated cement paste has low specific heat. Since water has a specific heat of 1.0, water content is effective in raising the specific heat of concrete.

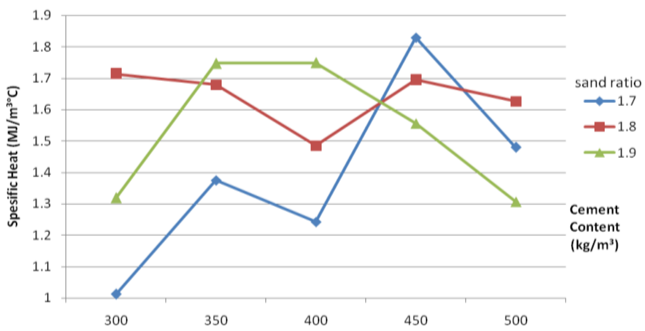


Figure 3 The relationship between specific heat and cement content with different sand ratio

The highest value of specific gravity for OPS lightweight aggregate concrete is 1.829 MJ/m³°C (mix T10) and the lowest value is 1.012 MJ/m³°C (mix T1). Since mix T1 is more porous compared to other mix, the specific heat result showed the lowest value. R Cerny *et al*. (1996) reported another factor that influence the specific heat which is the organic containing of the material. More organic compound will dramatic chance the specific heat the specimen. OPS are natural aggregate, thus the probable reason for this structural change and chemical reactions of the organic substances present in the higher temperature region which can compensate the natural increase in specific heat with temperature. Such latent heat effects are overridden to some extent by the larger contribution of the aggregate fraction to the overall apparent specific heat of concrete.

It is therefore not surprising that data from Harmathy and Allen [20] and other investigators show considerable dispersion in values for the specific heat of concrete. In generally, specific heat appears to be insensitive to the aggregate used. With increasing permeability of the materials are directly proportional. Aggregate normally composed about 70% to 80% by volume of Portland cement concrete. Specific heat of a sample is most influenced by the OPS in concrete. Compared to thermal conductivity, specific heat does not have strong relationship with the density, but it is mostly more influenced by distribution of OPS aggregate in the concrete and area temperature rise of plane source heating the surrounding the sensor.

3.3 Thermal Diffusivity

The result of the experiment on thermal diffusivity rate showed that thermal diffusivity increased with increase of cement content of the mix, except for cement content 350 kg/m with sand ratio 1.7 and 1.8. Heat transfer analysis is influenced by thermal conductivity and volumetric heat capacity. Therefore, high thermal conductivity will increase the thermal diffusivity. Again in case of OPS volume in mix proportion, the diffusivity of the concrete is less when higher OPS volume is used (300 kg/m³ cement content) compared to when less OPS volume (500 kg/m³ cement content) used (Figure 4).

Since it is a function of conductivity, specific heat and density, it will vary according to different influences and both conductivity and specific heat increase with moisture content then one might expect a reduced influence on diffusivity [20]. Hence, thermal diffusivity of concrete is largely influenced by the mineralogical characteristics of the course aggregate.

The capacity of the aggregate to retain moisture and its chemically stable vesicular and glassy (amorphous) competition are also advantageous. Among other, Stephen points out that the compatibility in relative stiffness between the cement paste and lightweight aggregate is also beneficial for low thermal diffusivities [20].

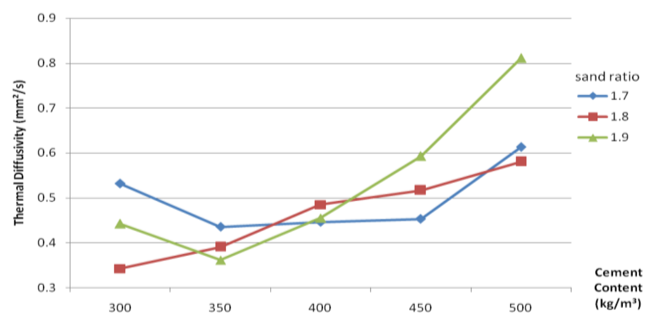


Figure 4 The relationship between thermal diffusivity and cement content with different sand ratio

3.0 CONCLUSIONS

From the experimental works that had been conducted in this research, the following conclusion can be withdrawn:

1. Cement/sand ratio of 1.8 is optimum ratio for load bearing strength with low thermal conductivity value.
3. Thermal conductivity that can be categorized as insulation structure is mix design using cement content of 400 kg/m³ and below. According to RILEM the value of thermal conductivity is less than 0.75 W/mK for load bearing insulation purpose.
4. Specific heat for all mix design showed inconsistencies due to the size, shape, organic substances and distribution of OPS aggregate in concrete. The increase of energy required is due to moisture content of the aggregate.
5. Thermal diffusivity increase when higher cement content is used in mix design and more OPS volume applied.

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