Materials and Design 51 (2013) 522–529

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

A comparison of the thermal conductivity of oil palm shell foamed concrete with conventional materials

U. Johnson Alengaram *, Baig Abdullah Al Muhit, Mohd Zamin bin Jumaat, Michael Liu Yong Jing

Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 5 January 2013
Accepted 20 April 2013
Available online 30 April 2013

Keywords:
Oil palm shell foam concrete
Thermal conductivity
Conventional materials
Temperature variation
Structural and insulating concrete

ABSTRACT

Foamed concrete (FC) is characterized by its low self-weight and insulation properties. This paper reports on the thermal conductivity of structural and non-structural grade foamed concretes developed using locally available waste materials – oil palm shell (OPS) – as lightweight coarse aggregate. Six mixes of oil palm shell foamed concrete (OPSFC) of oven-dry density ranging from 1100 to 1600 kg/m^3 were prepared and tested for thermal insulation and compared with the non-foamed oil palm shell concrete (OPSC) as the control concrete and conventional materials, such as brick and block. Non-structural grade OPSFC with a density of 1100 kg/m^3 showed the lowest thermal conductivity of 0.40 W/m K, which is 33% and 56% lower than the conventional materials – block and brick – respectively. OPSFC with 1500 and 1600 kg/m^3 can be considered as structural and insulating concrete as per the RILEM classification. The tiny air pores created in the concrete act as an insulator and it was found that the thermal conductivity of OPSFC with densities of 1100 and 1300 kg/m^3 are similar to those of pumice concrete and expanded perlite aggregate concrete (EPAC), respectively.

1. Introduction

Foamed concrete (FC) falls under the broader category of cellular concrete. In the cellular concrete, air-voids are introduced artificially either by the use of aluminum powder or a foaming agent in the concrete [1,2]. FC is prepared by adding foam, produced by a foaming agent solution, into the cement paste or concrete [3]. The presence of air voids in foamed concrete makes the concrete light. Furthermore, it has the following characteristics such as high flowability, low controlled strength and excellent thermal insulation [2,4,5]. So far, researchers have been successful in producing foamed concrete in the density range of 300–1800 kg/m^3 [2,5]. Jones and McCarthy [4] produced foamed concrete in the density range of 600–1200 kg/m^3 using a cement content of 300–600 kg/m^3. Nambiar and Ramamurthy [3] used fly ash (FA) produced to develop foamed concrete with densities of 1000, 1250 and 1500 kg/m^3. Utilization of waste materials, such as FA, slag, sludge, etc. to produce foamed concrete adds to the sustainability of the material. Kearsley and Wainwright [6,7] concluded that the long-term properties of FC can be enhanced by replacing 75% cement with fly ash. They [7] also investigated the relationship between the porosity and the compressive strength of foamed concrete. Kim et al. [8] investigated the thermal conductivity of aerated concrete using expanded shale and reported that the pore size became smaller and the distribution of pores was enhanced with the inclusion of 0.5% of air entraining agent. Yun et al. [9] used hollow glass bubble to enhance the thermal insulating capacity of lightweight concrete (LWC). Thermal conductivity depends on the pores and the density of FC [5]. Jitchaiyaphum et al. [10] reported that the replacement of fly ash by 30% of cement weight decreases the pore sizes and hence increase the compressive strength of LWC. In addition, microstructural investigations have been carried out by Narayanan and Ramamurthy [1] using X-ray diffraction (XRD) analysis on FC. Because of the presence of a volume of air inside, FC is an excellent choice for thermal insulation [2,5]. Recently trends have changed to use FC for structural purposes besides being used as thermal insulation and a void filling material. Due to its low density, and controlled low strength, FC can be very useful for structural utilities, floor topping and the foundations of a building. FC has also been used as a void filling material due to its high flowability, which is, however, dependent upon the air volume [3].

Oil palm shell (OPS) is the waste product at the time of extracting palm oil, which originates from the oil palm tree [11]. The oil palm tree, being in the same genera as the coconut palm tree, shares many features with it. Its scientific name is *Elaeis guineensis* and it happens to be found mainly in East Africa [12]. According to Ramli [13], Malaysia alone produces 4 million tons of OPS annually and it is predicted that Malaysia will have nearly 5 million hectares (ha) of palm oil trees by the year 2020. Being the second largest palm oil producing country in the world, Malaysia is also responsible for producing a large amount of palm oil waste. The use of OPS as lightweight aggregate (LWA) has been exploited by

* Corresponding author. Tel.: +60 379677632; fax: +60 379675318.
E-mail address: johnson@um.edu.my (U. Johnson Alengaram).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.04.078

researchers and it has been shown that structural grade OPS concrete (OPSC) could be produced with the 28-day cube compressive strength in the range of 24–35 MPa and a density reduction of about 20% compared to normal weight concrete (NWC) [14]. Further investigation found that the 90-day drying shrinkage of OPSC was 14% higher than the NWC [15].

Alengaram et al. [16] investigated the influence of diverse size of OPS on the mechanical properties of OPSC and reported that the use of 70% of OPS of particle size more than 10 mm produced higher modulus of elasticity compared to OPSC with all particles. The recent investigations on the OPSC include shear behavior, bond properties and the development of high strength concrete using OPS [17–19]. Alengaram et al. [17,18] reported that reinforced OPSC beam of grade 30 produced 24% higher shear strength than the corresponding NWC; in addition, the bond between the reinforcement and OPSC was strong with no slip failure. The latest development in the OPSC is the enhancement of the compressive strength of about 53 MPa using crushed OPS aggregate [19]. Jumaat et al. [20] reported the density of OPS foamed concrete (OPSFC) in the range 1600–1700 kg/m^3 similar to the density of FC of 300–1800 kg/m^3 reported by other researchers [1,2,5]. The cube compressive strength of OPSFC was reported to be in the range of 16–24 MPa, which satisfies the requirement for structural lightweight concrete (SLWC) stipulated by ASTM C330-09 and ACI 318M-08 [21]. However, a higher compressive strength of FC in the range of 1–43 MPa was reported; the compressive strength depends on the density and use of cementitious materials as a cement replacement [2]. Cementitious materials, such as fly ash and silica fume, help to ensure a uniform distribution of air-voids created by foam. In the FC of higher density, the compressive strength decreases with an increase in void diameter. If the pore diameter increases the air bubbles merge with each other resulting in lesser paste volume, and, consequently, results in lower compressive strength [3]. Kearsley and Wainwright [6] found that with the use of fly ash, the later strength of FC could be increased up to 67%. Small changes in the w/c ratio do not affect the strength of FC [4].

Most of the above mentioned researches on OPSC focused on the mechanical, structural and durability characteristics. However, there is no research work has been carried out on the thermal insulating characteristics of OPSC. The convex surface of OPS has lot of tiny pores of size in the range of 16–24 μm [5] and hence the thermal insulating characteristic of OPS through the air trapped inside the OPS could be exploited. In addition, the use of foam to introduce further air bubbles in the OPSC might enhance the thermal insulating property of OPSC.

Although the effect on foam in enhancing the thermal insulation properties of OPSC has not yet received much attention from the researchers, the issue of thermal insulation of buildings has recently received immense consideration worldwide due to the energy crisis [22]. The use of foam in OPSC is a relatively new area of research. From the economic and environmental point of view, it is more effective to design buildings with high thermal insulation characteristics. In hot weather areas, buildings are being built with solid or hollow concrete blocks termed as single skin walls [23]. It is well known that the thermal conductivity of air is lower than that of concrete; thus, by incorporating air bubbles inside concrete, a thermally insulating material can be produced. It has been reported by Uysal et al. [24] that thermal conductivity of concrete increases with an increase in the cement content.

In this investigation, artificially generated foam is introduced to produce both structural and non-structural grade LWC in which OPS was used as the coarse aggregate. Since air is a good insulator, air voids were induced through foaming. Cementitious materials, such as Class-F fly ash (FA) and silica fume were used as cement replacement and additional cementitious materials, respectively. The oven dry densities (ODDs) along with the compressive strengths up to the age of 28-day were reported. The main objective of this research is to determine the thermal conductivity of foamed OPS concrete and make a comparison with non-foamed OPSC and materials, such as brick and blocks, which are conventionally used for walls in buildings in Malaysia. The ODD of FC was in the range of 1100–1600 kg/m^3.

2. Experimental study

2.1. Materials

2.1.1. Cement

Ordinary Portland cement (OPC) conforming to MS 522:1 [25] from Tasek Corporation Berhad, was used in the concrete as the primary binding material.

2.1.2. Fine and coarse aggregates

For the FC, mining sand passing through 2.36 mm and retained on 300 μm was used as fine aggregate in dry condition. However, for the NFC, mining sand passing through 5 mm and retained on 300 μm was used in a similar dried condition. OPS was used as the coarse aggregate. It was obtained from a local palm oil factory and washed with detergents to remove oil; then it was dried and sieved to remove fiber and particles smaller than 2.36 mm. BS EN 933-1 [26], BS EN 1097-3 [27] and BS EN 1097-6 [28] were used for the particle size analysis, bulk density and water absorption of aggregates, respectively. Table 1 shows the comparison of the physical properties of the aggregates. The OPS of diverse sizes used in this investigation is shown in Fig. 1.

2.1.3. Mineral admixtures

Class-F (low calcium) FA and silica fume (SF) were used as cement replacement (5%) and additional cementitious materials (10%) by weight of cement, respectively. These two admixtures conforming to ASTM C618-12a and ASTM C1240-12, respectively, were supplied by Lafarge Cement and Sika, respectively. The chemical compositions of cement, FA and SF are shown in Table 2.

2.1.4. Chemical admixture

Rheobuild 1000 naphthalene based high range water reducing admixture, alternatively known as superplasticizer (SP), was used as a chemical admixture in concrete with a dosage of 0.5% and 1% by weight of cement for foamed and NFC, respectively. The SP used in the concrete, which has the commercial name Rheobuild 1000, is chloride free, chemically stable and non-hazardous with a specific gravity of 1.20 g/cm^3.

2.1.5. Water

Potable water was used for the mixing of concrete.

2.1.6. Foaming agent and foam

A synthetic foaming agent (Naphthalene Sulfonated – Finefoam 707) with a specific gravity of 1.02 was used in this investigation. The ratio of foaming agent to water was 1:20; the foaming agent was then poured into the foaming generator to produce foam

Table 1
Physical properties of OPS aggregate.

Property	Value
Specific gravity	1.27
Bulk density (Loose) (kg/m^3)	589
Bulk density (Compacted) (kg/m^3)	620
Fineness modulus	6.37
Moisture content (%)	8–15
Water absorption (1 h) (%)	13
Water absorption (24 h) (%)	23.8