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Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler

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HIGHLIGHTS

- Study on lightweight foamed concrete (LFC) with vary percentage of POFA filler.
- Engineering properties and thermal conductivity of LFC were investigated.
- 10–20% POFA enhanced LFC's strengths, ductility and compressive toughness.
- Thermal conductivity of POFA based LFC were slightly increased.

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ABSTRACT

Incorporation of pozzolans can give useful enhancements to the concrete properties. This paper aims to study the effects of palm oil fuel ash (POFA) on engineering properties of lightweight foamed concrete (LFC) with 1300 ± 50 kg/m^3 of density in terms of compressive, splitting tensile and flexural strengths, compressive toughness, and thermal conductivity. Three types of LFC were prepared, namely (i) LFC with 100% sand filler as control mix (LFC-CM), (ii) LFC with 10% POFA replacement as a part of filler (LFC-PF10) and (iii) LFC with 20% POFA replacement as a part of filler (LFC-PF20). All specimens were under water curing condition. It was observed that the incorporation POFA into foamed concrete as a part of filler for LFC-PF10 and LFC-PF20 has enhanced their compressive strength, flexural and splitting tensile strengths, ductility as well as compressive toughness. Besides, the thermal conductivity of POFA based LFC specimens were slightly increased compared to that of control LFC specimens. It is demonstrated that lightweight foamed concretes with certain percentage of POFA replacement filler (LFC-PF10 and LFC-PF20) obtained better strengths performance compared to the controlled specimens (LFC-CM) with solely sand filler.

1. Introduction

Nowadays with the advancement of technology, lightweight foamed concrete (LFC) becomes an innovation product for the construction sector which offers advantages such as light densities ranging from 1000 to 1600 kg/m^3, better fire protection, thermal and sound insulations etc. compared to those of normal weight concrete. Foamed concrete is lighter than normal weight concrete due to there are artificial air bubbles trapped in its cement mortar by using suitable foaming agent [1]. Consistency and stability of fresh mixed foamed concrete are needed to prevent a separation of artificial air bubbles and cement mortar as well as broken of the bubbles, and eventually affect its hardened properties. Flow cone spread test is one of the methods adopted to assess the consistency of fresh foamed concrete. This measurement is also related to the fresh mix rheological property [2–4]. Previous study reported that a replacement of sand with coarse fly ash as filler in foamed concrete exhibited 2.5 times higher spread value compared to cement–sand mix. This enhanced consistency and workability is attributed to different particle shape and size of fine aggregate [1,2]. Jones and McCarthy [2] also reported that the finer low lime fly ash as compared with sand increased the water to solid ratio, thus satisfy the consistency requirement.

According to Awal and Hussin [5], incorporation of pozzolans, either naturally occurring or artificially made into concrete has been in practise since the early civilization. Besides its economic advantages, the main reason for their use is that they can give useful modification or enhancements to concrete properties. Many researchers have studied the use of agricultural wastes as constituents in normal weight concrete and cement mortar, namely

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rice-husk ash [6], sawdust ash [7] and palm oil fuel ash (POFA) [5,8]. Their study have revealed that the agricultural waste ashes contained high amount of silica in amorphous form and could be used as a pozzolanic material [5–8]. Although there are few studies on the use of these agricultural ashes in normal weight concrete, the use of them especially POFA in lightweight foamed concrete is still limited. In fact, the production and application of the lightweight concrete in Malaysian construction sector is still at the early stage. It is of necessity to promote the use of lightweight concrete in local construction projects. The POFA is suggested to be used in the production of lightweight foamed concrete (LFC) due to the fact that Malaysia as one of the major palm oil exporter has been facing challenges to efficiently manage the waste which cause environmental pollution. As framed in Tenth Malaysian Plan (TMP-10), palm oil is listed as one of the main commodities in Malaysia to be exported internationally due to high demand of crude palm oil in the world. In 2011, the Malaysian Palm Oil Board (MPOB) reported that the total oil palm planted area in Malaysia was 5 million hectares [9]. Crude Palm Oil (CPO) production in 2011 reached a record high of 18.91 million tonnes. The total amount of fresh fruit bunches processed by over four hundred palm oil mills were approximately 87.5 million tonnes. Approximated 61.1 million tonnes of solid waste by-products in the form of fibers, kernels and empty fruit bunches were produced annually, which was about 70% of fresh fruit bunches processed [9]. According to Tangchiparat et al. [8], the combustion of palm oil husk and palm kernel shell in the steam boiler produces approximately 5% of POFA. MPOB [9] reported that there were over 3 million tonnes POFA had been produced in 2011. Hussin et al. [10] used finely ground POFA (100% passing 45 μm sieve opening size) as partial cement replacement material in aerated concrete and found that the compressive strength performance and drying shrinkage control of POFA cement-based aerated concrete were superior than those of pure OPC aerated concrete.

The chemical constituents and physical properties of POFA in Malaysia are reviewed [10–30] and summarized in Table 1. All reviewed works are carried out in the Peninsular of Malaysia, and the sources of POFA are classified into northern region [11–13], central region [14–20] southern region [10,21–29] and in general [30]. The scopes of study for these researches cover wide range of effect of POFA in concrete, e.g. workability of concrete [13,15,16,22], mechanical properties (compressive and flexural strength), durability in terms of chloride and acid resistance [12,27], shrinkage [20] and elevated temperatures [11], heat of hydration behavior [17,21,23] and influence of POFA for aerated concrete [10,24,25]. From the review, it is noted that the content of reactive silica in POFA is vary from different sources of mill. The variation of the chemical constituent is due to several factors e.g. the parts of the palm oil tree burned, particle fineness and the burning temperature. Higher reactive silica content comes from the kernel of palm oil tree. If the brunches are included in the burning process, the fiber of the palm oil tree brunches would produce more carbon content, which does not bring effect on strength and just remain as a filler in concrete. The reactivity of POFA particles is majorly depends on its fineness. Finer POFA particles increase the content of more reactive silica (SiO_2), and this would help in developing higher strengths and durability [14,15]. Studies have shown that unground POFA decreases the workability, due to its irregular shape and porous structure which absorbed more water [16,22]. A detailed and comprehensive study is suggested in order to summarize the characteristic of POFA from various sources in Malaysia. Works have been done on the behavior of POFA in aerated concrete [10,24,25], but no researches have been noticed for the use of POFA in lightweight foamed concrete. Thus, this paper focuses on the investigation of the effects of palm oil fuel ash (POFA) as a part of filler in producing lightweight foamed concrete (LFC) on its fresh and hardened properties.

2. Experimental program

2.1. Materials

Lightweight foamed concrete in this study were produced by using raw materials namely ordinary Portland cement (OPC), river sand, POFA, water and synthetic foaming agent. The localize OPC used as binder which was manufactured by YTL Cement complied with the Type I Portland cement as per in ASTM C150 [31]. Different batches of sand and POFA samples were subjected to varying degrees of tropical natural weathering exposures. As a result, the samples may contain different initial moisture content. To standardize the preparation procedures of the specimens, it was necessary to oven dry the both sand and POFA samples at 105 °C for 24 h to remove the total moisture content. It is easier to control the w/c ratios used in this study by using the oven-dried sand and POFA samples rather than the natural sand and POFA samples with inconsistent moisture content. Both river sand and POFA were then

Table 1
Chemical compositions and physical properties of palm oil fuel ash (POFA) in Malaysia.

Region Source of references	Central	Central Refs. [11–13]	North Refs. [14–20]	South Refs. [10], [21–29]	General Refs. [30]
A. Chemical constituents					
Silicon dioxide (SiO_2) (%)	53.8	43.60–62.27	51.18–67.09	21.45–62.60	44.0–66.0
Aluminium oxide (Al_2O_3) (%)	5.7	3.18–11.4	4.61–6.44	1.90–11.40	1.5–11.5
Ferric oxide (Fe_2O_3) (%)	4.5	4.70–13.57	3.42–5.92	1.10–8.12	1.5–5.5
Calcium oxide (CaO) (%)	4.2	4.89–8.40	5.09–8.19	4.24–60.98	4.0–8.5
Magnesium oxide (MgO) (%)	3.2	3.67–4.80	2.79–4.58	0.59–4.80	2.0–6.5
Sulphur oxide (SO_3) (%)	2.3	0.36–2.80	0.28–0.36	1.16–2.80	0.2–3.0
Sodium oxide (Na_2O) (%)	0.1	0.39	0.06–0.19	0.10–1.30	0.1–3.5
Potassium oxide (K_2O) (%)	4.5	3.50–8.40	5.09–6.48	0.51–9.05	2.0–8.5
Phosphorous oxide (P_2O_2) (%)	3.0	3.64	3.32–4.69	2.40–3.58	N.A.
B. Physical properties					
Loss on ignition (LOI)	10.5	7.34–9.17	2.20–9.88	1.37–18.00	0.1–21.5
Specific gravity (S.G.)	2.2	2.48	2.42–2.56	2.22–2.42	1.78–2.78
% Passing through 45 μm sieve (%)	9.0	95.0	N.A.	90.00–95.02	5.6–99.0

Central – central part of Peninsular Malaysia, i.e. the states of Selangor, Negeri Sembilan and Kuala.Lumpur Federal Territory.
North – northern part of Peninsular Malaysia, i.e. the states of Perlis, Kedah, Penang and Perak.
South – southern part of Peninsular Malaysia, i.e. the states of Melacca and Johore.
General – review on POFA in Malaysia made by the authors of reference [30].
N.A. – information not available from the source of references.