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Thermal conductivity, compressive and residual strength evaluation of polymer fibre-reinforced high volume palm oil fuel ash blended mortar

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HIGHLIGHTS

- POFA and polymer fibre addition of more than 0.3% reduced thermal conductivity.
- POFA and fibre addition exceeding 0.3% reduced strength loss at elevated temperature.
- Compressive strength reduced and water absorption increased with POFA and fibres.
- High volume POFA and addition of more than 0.3% polymer fibres recommended.

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ABSTRACT

This paper presents the investigation of the properties of polymer fibre-reinforced high volume palm oil fuel ash (POFA) blended mortar. Considering the targeted application for non-structural building material, the thermal conductivity, compressive and residual strengths as well as the water absorption of the mortars were evaluated. The incorporation of POFA and polymer fibres (polypropylene and acrylic) exceeding 0.3 vol.% fraction generally reduced the thermal conductivity and compressive strength as well as increased the water absorption of the mortars. Although the inclusion of POFA did not reduce the strength loss upon exposure to elevated temperature, the addition of fibres above 0.3% had slight effect in reducing the compressive strength loss. Thus, based on the optimization in terms of the thermal conductivity, compressive and residual strengths, it is recommended to incorporate high volume POFA and addition of polymer fibres exceeding 0.3 vol.% fraction for non-structural application in building materials.

1. Introduction

Palm oil fuel ash (POFA) is an increasingly popular waste material used in cement-based materials, particularly in the South East Asia region. This is because in this region, huge amount of POFA are obtained as wastes from palm oil factories. In these factories, POFA is obtained from the burning of wastage such as empty fruit bunches, oil palm shell and palm oil fibres at temperature between 800 and 1000 °C [1] for electricity generation. It was reported that as much as 10 mil t of POFA is produced in Malaysia [2]. Commonly, the POFA is dumped in the surrounding of factories or used in landfill without any commercial return.

In recent years, the advancement in concrete technology has brought upon the possibility of utilization of supplementary cementitious material (SCM) as high volume cement replacement for the benefit of environment. Utilization of SCM such as fly ash and ground granulated blast furnace slag as high volume cement replacement in normal and high strength concrete had already been developed in the past. In more recent times, POFA has also found its usage as SCM to partially replace cement, even at high replacement levels of up to 70% [3,4]. It was reported that inclusion of high volume POFA could enhance the mechanical and durability properties of normal concrete [4]. Beneficial effects in terms of the concrete properties could also be observed in non-conventional concrete such as recycled aggregate concrete [5], lightweight aggregate concrete [6] and self-compacting concrete [7] when POFA was used as high volume cement replacement. The introduction of POFA as high volume cement replacement not only reduces the manufacture of ordinary Portland cement (OPC), solid wastes from the palm oil factories can be reduced as well.

Researchers have also actively carried out trials to incorporate POFA into non-structural building materials such as bricks [8]

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and non-load bearing wall [9], achieving satisfactory strength performance. Nevertheless, as with conventional bricks and concrete blocks used for building construction, the thermal properties and the fire performance of these building materials are also of paramount importance apart from the strength properties. The thermal conductivity of a building material is an essential criteria to ensure thermal comfort of occupants in the building as a building material with low thermal conductivity would have slower heat transfer, preventing a quick build-up of indoor temperature within the building. In addition, building material needs to exhibit certain resistance towards elevated temperature, which could occur in the event of fire. This could be potentially life-saving as the resistance towards elevated temperature would delay the collapse of structure due to fire which allows occupants to have sufficient time for escape.

The addition of fibres in cementitious materials is widespread due to the benefits of enhancing properties of the resulting composite material. There are mainly two types of fibres commercially available, namely steel and polymer fibres. Example of polymer fibres include polypropylene (PP), nylon and acrylic, amongst others. As polymer fibres costs significantly less than conventional steel fibres, the use of polymer fibres would present a more appealing alternative in non-structural building materials, whereby production costs involved are given great emphasis. One of the major benefits of the incorporation of fibres is the enhancement of strength. Addition of polymer fibres is known to improve the strength of the resulting fibre-reinforced composite due to the ability of the fibres to reinforce the matrix of the cementitious composite. Besides that, polymer fibres are advantageous in lowering strength loss of cementitious material exposed to elevated temperature. This is mainly due to the melting of fibres when exposed to temperature above its melting point, which subsequently induce voids and act as a channel in releasing the pressure within the composite [10]. On the other hand, the thermal performance is one of the least known properties for polymer fibre-reinforced composite properties. In limited literature available, Fraternali et al. [11] suggested that inclusion of polyethylene terephthalate (PET) fibres could reduce the thermal conductivity of concrete while it is not known the effects of adding other polymer fibres on the thermal conductivity of the resulting composite.

Based on the above, in the present study, an experimental programme is carried out to evaluate the properties of high volume POFA blended mortar reinforced with polymer fibres. The variables investigated in this study include different contents of POFA as cement replacement (0%, 50% and 70%) and the different volumes (0%, 0.1%, 0.3% and 0.5%) of polymer fibres (PP and acrylic fibres). As part of the initial research study to utilize such mortar for non-structural application, the concrete properties investigated include compressive strength, residual strength upon elevated temperature and thermal conductivity. In addition, water absorption of mortar was studied as it is an important factor for quantifying the durability of the mortar produced. The workability and consistency of the mortar were also determined based on the determination of the flow diameter from flow table test.

2. Experimental programme

2.1. Materials

The binder of cement mortar consist of both Type I OPC and ground POFA (Fig. 1). The ground POFA was prepared in accordance to the previous research work carried out by Islam et al. [1] by the processes of drying, sieving, grinding and further sieving. The main chemical compositions of POFA is shown in Table 1. The specific gravity of the OPC and POFA was 3.14 and 2.15, respectively while the median particle size was 23.6 and 19.0 µm, respectively. The particle size distributions of OPC and POFA are shown in Fig. 2.

Fine aggregate used to produce mortar in this study was normal mining sand of sizes between 300 µm and 5 mm. The mining sand had specific gravity, water absorption and fineness modulus of 2.60, 0.52% and 2.83, respectively. Pipe water in the laboratory was used in casting of the mortar specimens.

Two types of polymer fibres were selected in this study, namely PP and acrylic fibres (Fig. 3). Both fibrillated PP fibres and monofilament acrylic fibres of 12 mm length were used. The diameter of the PP and acrylic fibres was 30 and 9 µm, respectively. Comparison of the physical properties of the fibres is shown in Table 2.

2.2. Mix proportion

The mix proportions prepared in this study are listed in Table 3. There were three main sets of mortar, which consisted of mortars with binder compositions of 100% OPC, 50% OPC + 50% POFA and 30% OPC + 70% POFA. The mix designations for these three main sets of mortar were denoted by ‘A’, ‘B’ and ‘C’, respectively. For PP and acrylic fibres, the mixes were denoted by ‘PPF’ and ‘AF’, respectively while the volume fractions of the fibres of 0%, 0.1%, 0.3% and 0.5% were denoted at the end of the mix designation as ‘0’, ‘0.1’, ‘0.3’ and ‘0.5’, respectively.

2.3. Testing

The flow table test was conducted according to ASTM C1437-15 to determine the workability of the fresh mortar. After filling up the mould and tamping of fresh mortar, the mould was lifted away from the mortar and the table was dropped 25 times in 15 s. The diameter of the flow spread of the fresh mortar was subsequently recorded.

Compressive strength test was carried out on 50 mm^3 mortar specimens according to BS EN 12390-3: 2009. The cubic specimens were tested after water curing of 7-, 28- and 90-d. Fig. 4 shows the testing of the cubic specimens using ELE compression machine of 2000 kN.

Water absorption test was also carried out on the 50 mm^3 cube specimens at the age of 90-d. The specimens were dried in oven for 48 h prior to the test. The water absorption of the specimen was determined after full immersion in water for 30 min and 72 h to attain the initial and final water absorption values of the specimen.

For the determination of the residual compressive strength, mortar specimens after 90-d of curing were used. The mortar specimens were first subjected to exposure of temperatures of 300 °C and 600 °C in a muffle furnace for a period of 1 h after attainment of the desired temperature. The heating curve of the muffle furnace is shown in Fig. 5. After that, the specimens were allowed to cool to room temperature before subjected to compressive strength test to obtain the residual strength.

The thermal conductivity of the mortar specimens were determined using Transient Hot Bridge (THB) thermal conductivity machine. 100 mm^3 specimens were used for this test. Prior to testing, the surface of the cube specimens were polished to ensure smooth contact surface (Fig. 6). The THB sensor was placed between two cubic specimens and the resulting thermal conductivity measured was obtained from PC connected to the THB machine (Fig. 6).

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