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Durability properties of sustainable concrete containing high volume palm oil waste materials

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ABSTRACT

Huge amount of palm oil wastes were produced annually in Malaysia, among these are oil palm shell (OPS) waste and palm oil fuel ash (POFA). OPS is a waste obtained after the palm oil extraction process while POFA is a resulting waste from the incineration process of OPS along with other palm oil wastes such as palm oil fibre and empty fruit bunch. Considering that the combined amount of OPS and POFA waste amounts to about 15 mil t a year, introduction of these materials into concrete could greatly alleviate this issue while at the same time reduces dependency on conventional concrete-making materials. In this paper, the durability properties of a sustainable concrete incorporating high volume palm oil waste materials, namely OPS and POFA were investigated. The concrete comprised of OPS as complete coarse aggregate substitute and POFA as cement replacement material by up to 70%. Although early age strength of the OPS concrete containing POFA was low, the compressive strength of the concrete containing up to 30% POFA was found to be comparable as the control at later stages. Results revealed that although the sorption properties of OPS concrete were increased in the presence of POFA, other durability properties of the concrete such as sulfate resistance, chloride ion permeability and drying shrinkage were improved at various replacement levels of POFA. For instance, the increase of POFA by up to 50% gave improved sulfate resistance of the OPS concrete and the best performance was found at 30% POFA. In the case of chloride ion permeability and drying shrinkage properties, while the use of up to 50% POFA did not improve the performance of the OPS concrete with water-to-binder ratio of 0.3, the incorporation of 70% POFA in the OPS concrete with water-to-binder ratio of 0.4 exhibited improved behavior compared to the corresponding control concrete.

1. Introduction

Malaysia is one of the foremost trading countries of palm oil in the world. It was reported that 5 mil ha area of land was utilized for oil palm plantation in 2011 (MPOB, 2014). This leads to massive production of by-products such as fibres, nutshells, empty fruit branches throughout the palm oil processing process (Kanadasan and Razak, 2015). One of the most prominent solid waste materials left-over from the palm oil extraction process is oil palm shell (OPS). In Malaysia, about 5.3 mil t of OPS waste was generated annually from the palm oil industries (Sabil et al., 2013). The OPS are disposed as waste with limited utilization in landfills and this could lead to health-related issues, environmental problems and also financial loss (Mo et al., 2015d). Besides that, the wastages from palm oil industries are also usually burnt at temperature 800–1000 °C as fuels to generate electricity in palm oil mills. One of the by-products from the burning process is ash which is about 5% by weight of the residues, termed as palm oil fuel ash (POFA). As much as 10 mil t of POFA was produced in Malaysia as reported by Khankhaje et al. (2016).

Considering the huge amount of the wastes generated, there is great potential in terms of environmental conservation from the utilization of these wastes, namely OPS and POFA as conventional granite aggregate and ordinary Portland cement (OPC) replacements, respectively in the production of concrete. Benefits of OPS concrete (OPSC), as reported in previous research works, include improved ductility performance, bonding and thermal insulation properties (Mo et al., 2016). Considering that OPS is essentially an agriculture solid waste material, it is of prime

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Abbreviations

GGBS	Ground granulated blast furnace slag
LOI	Loss on ignition
OPC	Ordinary Portland cement
OPS	Oil palm shell
OPSC	Oil palm shell concrete
POFA	Palm oil fuel ash
RCPT	Rapid chloride penetration test
SCM	Supplementary cementitious material
SP	Superplasticizer

importance to ascertain the durability properties of the resulting OPSC. Despite the significance of durability investigation for such concrete, there are only few studies carried out in the past. Teo et al. (2010) found that generally OPSC had adequate durability and that proper curing is required to achieve OPSC with better quality at later ages. Another method to achieve improved concrete durability is through the use of supplementary cementitious material (SCM) as the fine SCM could impart pore refinement effect which could enhance the microstructure of the cement matrix. While there are a number of research works dealing with utilization of SCM such as ground granulated blast furnace slag (GGBS) (Mo et al., 2015b), fly ash (Shafigh et al., 2013) and rice husk ash (Foong et al., 2015) as partial cement replacement in OPSC, these investigations mainly focused on the strength properties and limited information on the durability properties are available. Only recently, Mo et al. (2016) reported that the inclusion of GGBS in OPSC resulted in improvement in some of the durability properties mainly due to the pore refinement effect of the GGBS.

More recently, there has been effort to introduce ground POFA as SCM to partially replace cement in OPSC. While the results indicated improvement in the compressive strength (Muthusamy et al., 2015) and other mechanical properties (Muthusamy and Zamri, 2015) of OPSC with the inclusion of POFA, similarly there is lack of study carried out to evaluate the durability of the concrete. The study of the durability properties is important considering that both OPS and POFA are waste materials and thus the effect on the long term performance of the concrete is of great attention.

In the case of unground POFA which is essentially unprocessed waste material, the original size of the POFA might not be suitable to be used as SCM. This is because the large particle size of unground POFA could weaken the microstructure (Tangchirapat et al., 2007) and could have negative effect on the concrete durability. Hence, ground POFA had been used as partial cement replacement material instead as it could increase the reactivity of the material due to the finer particle sizes and also acts as filling agent in cement matrix (Jaturapitakkul et al., 2011). Because of this, when ground POFA was used as partial cement replacement material in normal concrete, it was reported that the gas permeability, water permeability (Tangchirapat and Jaturapitakkul, 2010), sulfate (Tangchirapat et al., 2012) and chloride penetration resistance (Chindaprasirt et al., 2008) were improved, indicating superior durability performance of POFA-blended normal weight concretes.

In view of the potential of re-using waste POFA and OPS for waste reduction in the palm oil industry, as well as in continuation to the previous study of the strength properties of concrete prepared with OPS as coarse aggregate and POFA as partial cement replacement (Islam et al., 2016), this investigation explores some durability aspects of this concrete. The scope of this investigation is focused on the effects of high volume POFA as partial cement replacement (up to 70%) on the durability properties such as water absorption, sorptivity, sulfate resistance, chloride ion permeability and drying shrinkage of OPSC.

2. Experimental program

2.1. Materials

2.1.1. Binder

In this investigation, both OPC and ground POFA were used to form the binder of the concrete. Fig. 1 shows the appearance of OPC and POFA. Type I OPC was used whereas the POFA was collected from a local palm oil mill and further processed. The collected POFA was first oven dried at 100 °C for 24 h and then sieved using a 300 μm size sieve to remove coarse particles. After that, the POFA was ground in a rotating drum for 30,000 cycles lasting 16 h. After grinding, the POFA passing through 45 μm size sieve was collected. The chemical and physical properties of OPC and the ground POFA are shown in Tables 1 and 2.

2.1.2. Aggregates

OPS (Fig. 2) of sizes between 2.36 and 9 mm were used as coarse aggregate. The OPS were collected from a local palm oil factory (Fig. 2), then washed with detergent to remove dirt on the OPS surface and dried before being crushed to obtain the desired sizes. Before casting of concrete, the OPS were soaked 24 h prior followed by air-drying to achieve saturated surface dry condition. The physical properties of OPS are shown in Table 3.

In this investigation, normal mining sand between sizes of 0.3–5 mm was used as fine aggregate. The physical properties of the mining sand used are shown in Table 3.

2.1.3. Water

The laboratory pipeline water free from contamination was used for all the mixes.

2.1.4. Superplasticizer

A polycarboxylic-ether based superplasticizer (SP) was used in this study and this was supplied by BASF Sdn Bhd.

2.2. Mix proportions

In this investigation, fixed binder, sand and OPS contents of 565, 960 and 368 kg/m^3, respectively were used. The main variable in the mix design of the study is the amount of cement replacement with POFA. The ground POFA was used as partial cement replacement levels of 0%, 10%, 30% and 50% for mixes with water-to-binder ratio (w/b) of 0.3 as well as 0% and 70% for mixes with w/b of 0.4. The superplasticizer content was varied between 0.6 and 1.1% (by mass of binder) to maintain the slump value within specific range of 25 ± 15 mm. The mix proportions for all mixes are given in Table 4.

2.3. Mixing procedure

Both OPS and mining sand were dry mixed in a drum mixer for 2 min followed by addition of the binder materials (cement and POFA) which was further mixed for 3 min. Then, half of the mixing water was added for mixing of 2 min and followed by the remaining water and superplasticizer. Thereafter, slump test was performed to ensure that the workability of the fresh concrete mix was within the desired range. The concrete specimens were cast in 100 mm cubes, 100 × 100 × 500 mm^3 prisms and 100 mm ϕ × 200 mm height cylinders. The specimens were de-moulded after 24 h and water cured until the age of testing.