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Sustainable Pervious Concrete Incorporating Palm Oil Fuel Ash as Cement Replacement

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Pervious concrete is one of the best materials used in sustainable drainage system to control the stormwater at source. The use of waste materials in concrete is able to reduce the negative impacts of concrete towards the environment. Therefore, this study presents the development of a sustainable pervious concrete by partially replacing cement with palm oil fuel ash (POFA) from palm oil industry. Properties, including void content, compressive and tensile strength as well as permeability were discussed. The results indicated that it is possible to produce sustainable pervious concrete by incorporating POFA. Furthermore, pervious concrete containing POFA showed higher water permeability and void content but lower compressive and tensile strength than control pervious concrete. However, the obtained compressive and tensile strength were within the acceptable range which is reported for strengths of pervious concrete.

1. Introduction

Pervious concrete is an environmental friendly product, which is recommended by the Environmental Protection Agency (EPA) of United States to control the stormwater at source. The material is advocated to be used as a top layer of permeable pavement systems. Permeable pavement systems are designed to collect stormwater on the pavement surface to prevent flooding during heavy rain, recharge groundwater, reduce the urban heat island effect and remove pollutants from stormwater runoff (Rahman et al., 2015). Moreover, more sustainable and eco-friendly concrete can be produced by using waste materials such as palm oil fuel ash in concrete (Khankhaje et al., 2015). Typical pervious concrete has void content of ranging from 15 to 30 %, high drainage rate from 0.25 to 6.1 mm/s and compressive strength from 2 to 28 MPa.
About ten million tonnes of POFA are produced in Malaysia annually (Yusoff, 2006). Currently, using of POFA is very limited. Landfilling of POFA has in turn caused environmental problems (Khankhaje et al., 2015). Therefore, many researches have been carried out on the possibility of using POFA in blended cement. Tay (1990) revealed that POFA can partially replace cement to be used in concrete due to its pozzolanic reaction. However, it could not be used more than 10 % of cement mass. Awal and Hussin (1996) reported that POFA has a good potential in suppressing expansion due to alkali-silica reaction. Tangchirapat et al. (2009) demonstrated that POFA shows good pozzolanic activity and can replace Ordinary Portland Cement (OPC) up to 30 % (by cement weight) when ground. According to Chindaprasirt et al, (2007) both concrete strength and water permeability increased by partial replacement of cement with POFA. In addition, by using high volume of POFA, the more eco-friendly and sustainable concrete can be produced (Altwair et al., 2012).

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From literature search made, there are no published reports detailing the use of POFA as cement replacement in pervious concrete. Therefore, the main aim of the present study was to produce more sustainable pervious concrete that incorporates POFA as a partial replacement of cement.

2. Methodology

2.1 Materials

The cement used in this study is an OPC type I. In addition, POFA was used as a replacement of cement. In this study, the needed POFA was collected from a local palm oil producing mill located in Johor, the southern state of Malaysia. The chemical and physical properties of POFA and OPC are shown in Table 1.

To achieve a system with interconnection voids in pervious concrete, the selection of single-sized aggregates is vital (Tennis et al. 2004). In this study, limestone with a grain size of 6.30 - 9.5 mm (passed from the 9.5 mm sieve and retained on the 6.30 mm sieve) was used as the natural coarse aggregate. This gravel presented a specific gravity of 2.7 kg/m^3 and water absorption of 1.8 %.

The river sand with a specific gravity of 2.62 kg/m^3, a water absorption of 7.4 % and a fineness modulus of 2.67 was used. The water used in this study was ordinary tap water. To have a fixed water/cement ratio (w/c) of 0.32 in all mixes, 107.54 kg/m^3 water was used for each mix.

Table 1: Chemical and physical properties of the POFA and OPC.

Chemical properties (Wt.%)			Physical properties		
	OPC	POFA		OPC	POFA
CaO	62.4	8.40	Specific gravity	3.15	2.42
SiO_2	20.4	43.60	Specific surface Blain (m^2/kg)	3.99	493
Al_2O_3	5.2	8.50	Initial setting time (min)	125	-
Fe_2O_3	4.2	10.10	Final setting time (min)	210	-
MgO	1.6	4.80			
SO_3	2.1	2.80			
K_2O	0.005	3.50			
Loss on ignition	2.36	18.00			

2.2 Mix Composition and Tests

Control pervious concrete (CPC) and three pervious concrete mixes were produced with a replacement ratio of 10 (PPC1), 20 (PPC2) and 30 % (PPC3) POFA as cement, as listed in Table 2. A small amount of cement (<5 % by mass) were blended in a mixer with gravel for about 1 min. Subsequently, sand and the remaining cement, POFA and water were added into the mixture and mixing was continued for another 3 min. The mixture was then rested for 3 min and finally, was mixed again for another 2 min. Later, the density and void content ratio of fresh pervious concretes were measured. The pervious concrete specimens were cast in steel cylinder moulds (100 × 200 mm) for both compressive and splitting tensile strength, void content ratio and permeability tests. Each test result of mechanical properties is the average of at least three specimens. Specimens were compacted using filling in three layers using 25 drops of a (15.9 mm diameter) steel rod and 10 drops of a standard Proctor hammer (2.5 kg) for each layer was used as the placement method for all mixes. Immediately after casting, all specimens were cured for 24 h in a controlled room maintained at 20 °C ± 2 °C and 95 % ± 5 % relative humidity. After 24 h, the specimens were removed from the moulds and kept at the same conditions for a 7 and 28 d curing periods.

The compressive strength test was conducted at 7 and 28 d in accordance with (ASTM:C39/C39M-15a 2015). The samples for compressive strength tests were dried in room temperature for about 2 h and then capped with sulfur capping compound at both ends in accordance with (ASTM:C617/C617M-15 2015). This was to fill the voids and level both ends of cylinder specimens. The compressive strength was performed at 7 and 28 d intervals using a constant rate loading of 0.06 MPa/s. The splitting tensile strengths were tested in accordance with (ASTM:C496/C496M 2011).

In addition, void content ratio of fresh mixes were tested according to (ASTM:C1688/C1688M-14a 2014) while void content ratio of hardened mixes were tested following (ASTM:C1754/C1754M-12 2012). Besides that, the diameter and length of the sample were measured to obtain the total volume of the cylinder. The sample were weighted in both dry (A) and submerged conditions (B) and the void content was calculated using the following Eq. (1).

Table 2: Mix proportions of different mixes of pervious concrete.

Mix	Rate POFA	Cement (kg/m^3)	POFA (kg/m^3)	Water (Kg/m^3)	Coarse aggregate (Kg/m^3)	Sand (Kg/m^3)
CPC	0	339.5	0	107.54	1313.8	146.0
PPC1	10	305.5	34.0	107.54	1313.8	146.0
PPC2	20	271.6	67.9	107.54	1313.8	146.0
PPC3	30	237.6	101.9	107.54	1313.8	146.0

$$\text{Void content\%} = \left[1 - \left(\frac{A-B}{\rho_w Vol}\right)\right] \times 100\ \% \tag{1}$$

where A is the dry weight (g), B is the weight under water (g), Vol is the volume of sample (cm^3) and ρ_w is the density of water at 21˚C (kg/cm^3).

Several authors have previously used the falling-head test to determine the water permeability coefficient of pervious concrete (Neithalath et al., 2006). Water permeability coefficient was determined by the following Darcy's law equation (2):

$$K = \frac{A_{tube} \times L}{A \times t} \times \ln\left(\frac{h_1}{h_2}\right)$$

(2)

where K (mm/s) is the water permeability coefficient, A and A $_{tube}$ (mm^2) are the areas of the cross-sections of the sample and tube, L (mm) is the length of sample and t (s) is the time required for water to fall from an initial water level h_1 (mm) to a final water level h_2 (mm). Figure 1 shows the test device for the falling-head water permeability test.

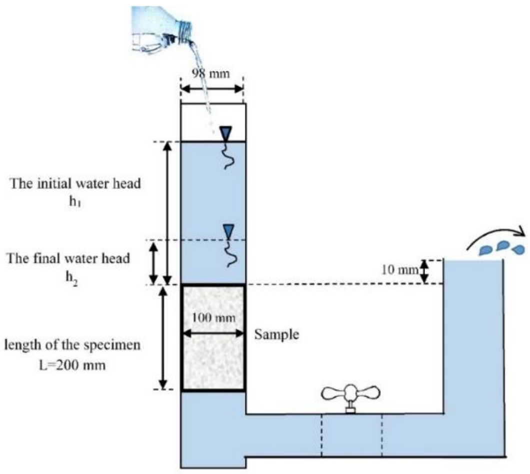

Figure 1. Scheme of permeability test.

3. Results and Discussion

3.1 Effects of POFA on void content ratio of Pervious Concrete

Figure 2 presents void content ratio of all mixtures of pervious concrete that was measured by volumetric method. In addition, one standard deviation for the void content of three specimens, which belonged to the same mixture, was represented by the error bars for the volumetric void content measurements. It can be concluded that by increasing POFA from 10 to 30 %, void content of pervious concrete mixes slightly increased. This might be due to the high porosity of POFA particles, which causes more water absorption and increasing void content of pervious concrete. However, the void content of pervious concrete containing POFA is almost similar to that of control pervious concrete.

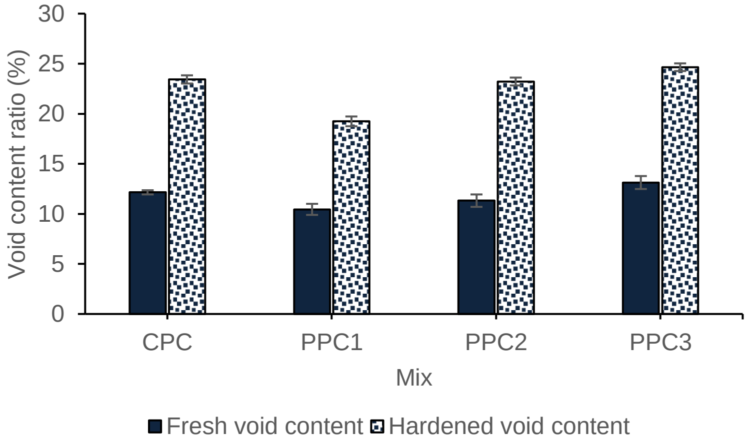

Figure.2. Void content ratio of pervious concrete mixes.

3.2 Effects of POFA on Compressive Strength of Pervious Concrete

Figure 3 shows the variation in compressive strength of the mixtures incorporating POFA. In addition, one standard deviation for the compressive strength of three specimens, which belonged to the same mixture, was represented by the error bars. As the POFA content of mixtures increased, the compressive strength of mixtures decreased. The PPC1, PPC2 and PPC3 pervious concrete mixes had a 9 %, 20 % and 30 % decreased in compressive strength respectively compared to the control mix at the age of 28 d. This could be due to the high porosity of POFA particles, which causes more water absorption, increasing void content and decreasing compressive strength of pervious concrete. However, the obtained compressive strengths were within the acceptable range which was reported for strength of pervious concrete.

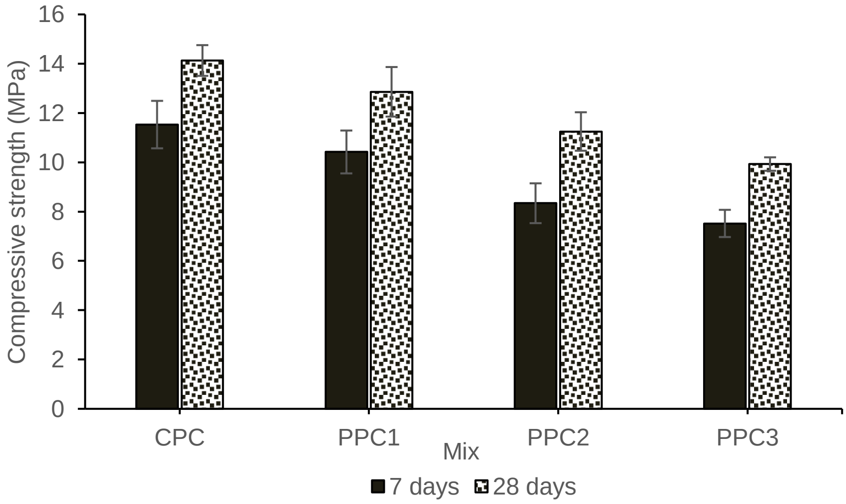

Figure. 3. Compressive strength of pervious concrete specimens at 7 d and 28 d.

3.3 Effects of OPKS on Tensile Strength of Pervious Concrete

The results of splitting tensile strength test of all mixtures are shown in Figure 4. The range of tensile strength of pervious concrete mixtures were from 1.92 MPa to 2.44 MPa. The influence of the POFA on the tensile strength seemed to be similar to that of the compressive strength of the specimens. By increasing POFA, tensile strength decreased, while it was within the typical range which was reported for strength of pervious concrete.

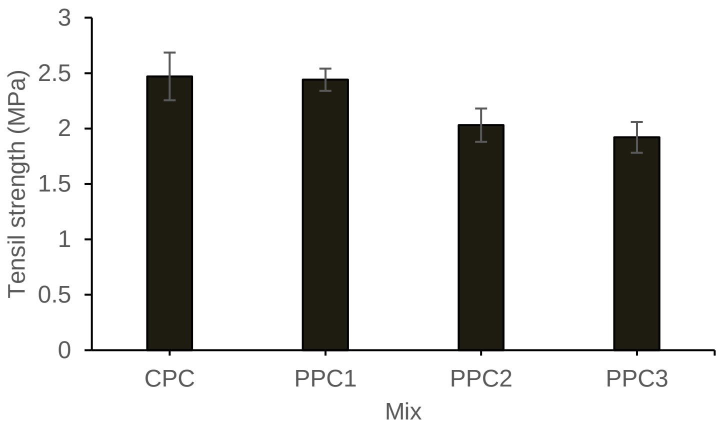

Figure.4. Tensile strength of pervious concrete mixes.

3.4 Effects of OPKS on Water Permeability of Pervious Concrete

Figure 5 shows the permeability coefficient that was measured by the falling head test for all mixes. The water permeability increased with increasing of POFA. The permeability coefficients ranged from 5.80 mm/s to 10.49 mm/s. Other researches showed similar results with typical permeability ranging from 2 mm/s to 12 mm/s (Tennis et al., 2004) .

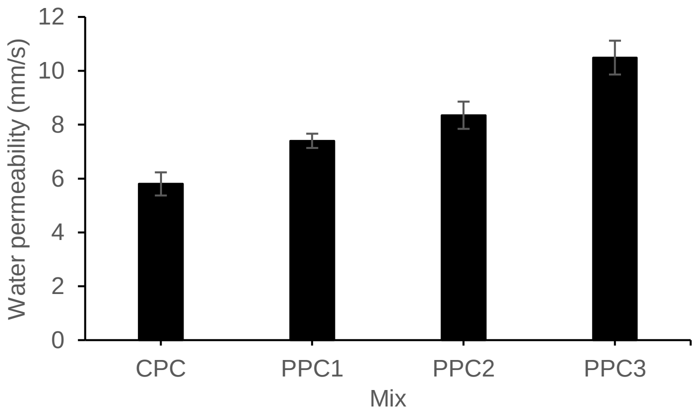

Figure. 5. Water permeability of pervious concrete mixes.

4. Conclusion

It can be concluded that the POFA could be used as partially cement replacement for producing pervious concrete. Pervious concrete containing POFA contributed higher void content, higher permeability, lower compressive and tensile strength than those of control pervious concrete. However, the obtained compressive and tensile strength were within the acceptable range which was reported for strength of pervious concrete.
The pervious concrete containing POFA can be used for light traffic roads and parking lots. In addition, the use of POFA will also reduce waste materials.

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