Fresh and Hardened Properties of palm oil fuel ash (POFA) based lightweight concrete from palm oil industrial wastes

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Abstract

The efficacy of two palm oil industrial waste materials, namely palm oil fuel ash (POFA) and oil palm shell (OPS), as partial and whole replacement materials, respectively, for ordinary Portland cement (OPC) and conventional crushed granite aggregate on fresh and hardened concrete properties has been investigated and reported. OPC was partially replaced with POFA by weight proportion of 0%, 10%, 30%, and 50% cementitious material. The fresh concrete and hardened concrete properties of the sustainable concrete developed through this research were investigated through slump test, saturated surface dry density, ultrasonic pulse velocity, and cube compressive strength test. In addition, the efficiency factor was also calculated and reported. The slump test results of different concrete mixes show low slump values between 25 and 40 mm, and this is attributed to high loss on ignition of POFA. The saturated surface dry density was found in the range of 1941 to 2001 kg/m^3 for 0-50% replacement of ordinary Portland cement (OPC) by Palm oil fuel ash (POFA) and hence could be categorized as lightweight concrete. Thus, the usefulness of POFA as partial cement replacement material in lightweight concrete with OPS as a whole replacement for conventional aggregate is feasible.

Keywords: *sustainable concrete materials; palm oil fuel ash (POFA); oil palm shell (OPS); fresh concrete properties; hardened concrete properties.*

1. Introduction

Concrete is one the most versatile construction materials used in every part of the globe after water. The demand for concrete is increasing enormously over time. It is predicted that concrete demand will be 18 billion tons by the year 2050 (Mehta (Mehta & Monteiro, 2014). Conversely, the consumption of natural aggregate for concrete production is reported to be about 8-12 billion tons per year since 2010 (Loh & Wackernagel, 2004). Moreover, the use of a conventional binder, namely ordinary Portland cement (OPC) releases a massive amount of CO_2 during the manufacturing process and results in the emission of a large amount of greenhouse gases. It was reported that in the near future, the production of OPC would cause 10% of total anthropogenic CO2 emissions throughout the world (Taylor, 1997), and the level of CO_2 may increase in the range of 380 ppm to 800 ppm by the end of the century (Bažant et al., 1996). Therefore, there has been a lot of research work carried out by researchers as explained below to investigate the possibility of utilizing alternate binders for cement and other industrial waste materials as coarse and fine aggregates to replace the conventional aggregates.

One of the research emphases is the utilization of industrial and agricultural waste materials as alternative concrete materials. Many researchers in developed and underdeveloped countries such as North America, Indonesia, Nigeria, and Malaysia are involved in research works to utilize locally available industrial and agricultural waste materials in an effective way. One of the significant research contributions from researchers in Malaysia, Indonesia, and Nigeria has been the utilization of palm oil industrial wastes as construction material (Alengaram et al., 2013). Also, some of these countries have been engrained with profitable plants, such as coconut, tea, sugar can, rubber, paddy, cocoa, and oil palm, and the wastes generated could be utilized in the development of construction materials (Kanadasan & Razak, 2014). Presently, Malaysia is one of the leading exporting countries of palm oil. In 2011, it was reported 5 million hectares area of land was used for oil palm plantation (Alengaram et al., 2013). This resulted in enormous production of by-products such as empty fruit branches, fibers, and oil palm shells (OPS), palm oil fuel ash (POFA) throughout the palm oil processing periods (Kanadasan & Razak, 2014). As such, a new window of prospect has opened up to utilize waste materials from the palm oil industry, namely POFA and OPS, and as replacement materials for conventional OPC and crushed granite aggregate in the production of concrete.

As detailed above, there had been researched works on the POFA as pozzolanic material in NWC; however, the use of POFA as cement replacement material in the development of lightweight concrete with another palm oil industrial waste, OPS as a lightweight aggregate for whole replacement of conventional crushed granite or normal weight aggregate hasn't been explored. This is crucial in view of vastly available local waste materials from the palm oil industry, which could be re-used in the production of lightweight concrete for environmental and financial advantages. Therefore, this study underlines the investigation of the effects of POFA as partial cement replacement from 0 to 50% and its impact on some engineering properties of OPSC. The variable investigated in this assessment is the POFA content. The fresh and hardened concrete properties through slump tests and density have been studied and reported.

2. Experimental Programs

2.1 Materials

2.1.1 Cement

Type 1 Ordinary Portland cement, which meets the ASTM: C150/C150 M-12 specifications, was used in all mix proportions. The Blaine surface area and specific gravity of the cement were 346 m^2/kg, 3.14, respectively. Table 1 shows the chemical properties of OPC.

2.1.2 Palm Oil Fuel Ash (POFA)

POFA was used as partial cement replacement in this investigation. The un-processed POFA was collected from a local palm oil mill. The collected POFA was oven-dried at 100˚C for 24 hours 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 hours to achieve the targeted fineness (>66%). After grinding, the POFA passing through a 45 μm size sieve was collected. The total amount of POFA passing through the 45 μm was 87%. The POFA had specific gravity and surface area of 2.15 and 171 m^2/kg, respectively. Table 1 and Table 2 show the chemical and physical properties of POFA, respectively. Figure 1 shows the physical appearance of OPC and POFA.

2.1.3 Oil Palm Shell (OPS)

Crushed OPS of sizes between 2.36 and 9 mm were used as coarse aggregate. The OPS were soaked 24 hours before casting and then air-dried to achieve saturated surface dry condition before used for casting. Table 3 and Figure 2 show the physical properties and appearance of OPS, respectively.

Table 1. Chemical properties of POFA and OPC by using X-ray Fluorescence (XRF) analysis.

Chemical composition	Materials	
	POFA (%)	OPC (%)
CaO	4.32	64.1
Al_2O_3	5.49	4.4
MgO	3.71	3.5
SiO_2	63.2	22.8
Na_2O	0.14	0.1
SO_3	0.92	2.6
P_2O_5	3.74	0.2
K_2O	6.37	0.8
MnO	0.17	0.8
Fe_2O_3	4.19	1.3
LOI	6.15	1.0

Table 2. Physical properties of POFA

Physical Properties	POFA
Specific surface area	171 m^2/kg
% Passing 45- μm sieve	87
Specific gravity	2.15
Color	dark

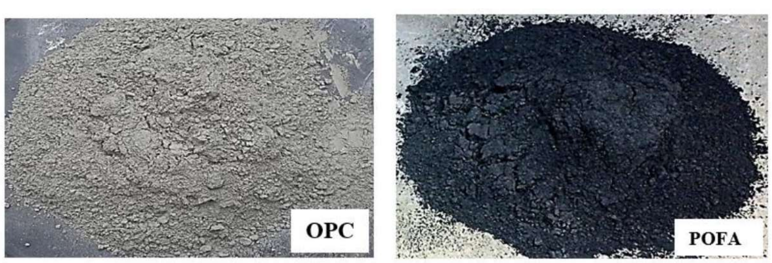

Figure 1. The contrast in color between ordinary Portland cement (OPC) and palm oil fuel ash (POFA).

Figure 2. The physical appearance of crushed oil palm shell (OPS).

Table 3: Physical properties of OPS

Physical Properties	Crushed OPS
Bulk density (compacted) (kg/m^3)	684
Fineness modulus	5.94
Specific gravity	1.25
Water absorption (30 min) (%)	9.65
Water absorption (24 h) (%)	18.7

2.1.4 Superplasticizer

A polycarboxylic-ether based superplasticizer with a specific gravity of 1.20 was used in this study, and this was supplied by BASF Sdn Bhd. with a commercial name Glenium Ace 388.

2.1.5 Normal Sand

Normal mining sand was used as fine aggregate with maximum grain size, water absorption, specific gravity, and fineness modulus of 4.75 mm, 0.81 %, 2.79, and 2.88, respectively.

2.1.6 Water

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

2.2 Mix Proportion

The 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 at 0%, 10%, 30%, and 50% by mass of binder, and their mix designations are christened as M0, M10, M30, and M50, respectively. In this investigation, a fixed binder, sand, OPS, and water contents of 565, 960, 368, and 170 kg/m3, respectively, were used. The superplasticizer was used to 0.6 to 1.1% to maintain the slump value within a specific range. The mix proportions (kg/m^3) are given in Table 4.

2.3 Mixing procedure

Both OPS and sand were mixed in a drum mixer for 2 min followed by binder materials (cement and POFA) which were further mixed for 3 minutes. Then, half of the mixing water was added for mixing 2 minutes, followed by adding the remaining mixing water and superplasticizer. The mixing procedure continued for a further 2 minutes before the slump test was performed to check the workability of the fresh concrete mix. The concrete specimens were cast in 100-mm cubes for the determination of the density, ultrasonic pulse velocity, and compressive strength. The specimen was de-moulded after 24 hours and water cured for 28-days, and then removed from the water curing tank and exposed to the laboratory condition with a temperature of 30˚± 2C and relative humidity of 85 ± 3% for the determination of concrete properties at ages of 90- and 120-day.

Table 4. Mixture Proportions of concrete (kg/m^3)

Mix No.	Cement	POFA	Water	Super-plasticizer	Sand	Coarse aggregate (OPS)
M0	565	0	170	3.4	960	368
M10	508	57	170	3.4	960	368
M30	395	170	170	4.9	960	368
M50	283	282	170	6.2	960	368

2.4 Test method

The initial slump was measured according to ASTM C 143. The UPV test was done on 100 mm cube specimens. A portable ultrasonic non-destructive digital indicating tester with adjoining transducers was used to measure the traveling time for pulse between the ends of specimens. The UPV is calculated by dividing the length of pulse travel by the time measured. The compressive strength test was done in accordance with BS EN 12390-3: 2002.

3. Result and Discussion

3.1 Workability

Slump is one of the methods to identify the workability of freshly mixed concrete (Figure 3). Figure 4 shows the view of concrete mixes M30 and M50 in a concrete mixer just prior to mixing the superplasticizer. The slump values of OPSC mixes of all the mixes are shown in Figure 5. As observed, the M0 mix had a slump of 25 mm while the use of POFA at 10% to 50% cement replacement levels increased the slump to between 25-40 mm. Mehta and Monteiro recommended the slump value for structural lightweight concrete of about 50-75 mm, which is comparable to the slump value of about 100-125 mm for conventional concrete (Mehta et al., 2006). However, the lower slump value of this study could be attributed to the high loss of ignition (LOI) content in POFA. It causes the increase of water demand for POFA based OPSC to get the same slump associating with the normal weight concrete (NWC). To maintain the slump, super plasticizer were added 0.6-1.1%.

Figure 3. Slump test.

Figure 4. Mixes M30 and M50 in a concrete mixer machine at lower superplasticizer content.

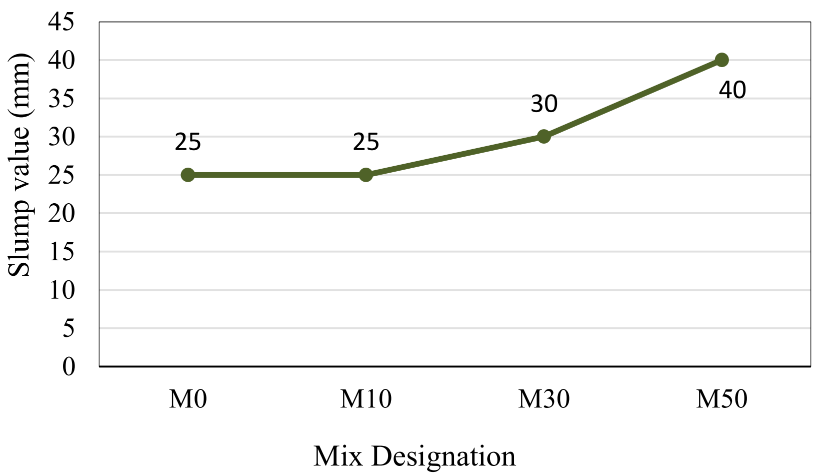

Figure 5. Effect of POFA on slump values.

Superplasticizer was used to reduce the water demand as in this study, the water-cement ratio was kept constant at 0.3, and POFA content was increased to 50% as cement replacement. The 10% replacement of cement by POFA didn't affect the slump, but later with a higher percentage of replacement, the slump got increased. This is because high POFA volume in concrete could act as a filler material to fill up the voids in the fresh concrete and improve the mix's fluidity. This is commonly associated with other kinds of pozzolanic materials such as rice husk ash and metakaolin (Hassan et al., 2012; Modarres & Hosseini, 2014).

3.2 Density

The saturated surface dry density of the control OPSC mix-without POFA was found about 1986 kg/m^3 and 1941-2001 kg/m^3 for POFA based OPSC. Okafor (Okafor, 1988) mentioned that the density of OPSC might vary 1753-1763 kg/m^3 depending on the w/c ratio and mix proportion. The effect of superplasticizer on the saturated surface dry density of the OPSC was also reported by Okafor, and it was found in the range of about 1845-1915 kg/m^{3,} which depends on the doses of superplasticizer and w/c ratio (Okafor, 1988). In this research work, lower w/c was kept constant, and high cement quantity was used for OPSC, which increased the density of OPSC. Conversely, the density increased slightly by about 1% to replace OPC with 10% POFA (mix M10). Figure 6 shows, with the higher POFA replacement for 30% and 50%, the density reduced about 2.1% and 2.3%, respectively, compared to the control mix-M0. It was reported by previous researchers (Kılıç et al., 2003; Mannan & Ganapathy, 2004) that the replacement of cement by cementitious materials reduces the density of structural lightweight concrete. This is attributed to the lower density of the supplementary cementing materials; in this work, as shown in Table 2**,** the specific gravity of POFA was found 2.15, which is much lower than that of OPC, and hence the overall density of the mixes-M30 and M50 was reduced due to high POFA contents. In this paper, the replacement of cement by high volume POFA in OPSC with a lower w/c ratio reduced the density of concrete more significantly than the low volume of POFA. Mannan and Ganapathy (Mannan & Ganapathy, 2004) showed that by replacing cement with another pozzolanic material like 10% and 15% fly ash on OPSC, the density reduced up to 2% and 3%, respectively. They also evaluated for NWC that the density reduced up to 1% and 2% for the same mix proportion.

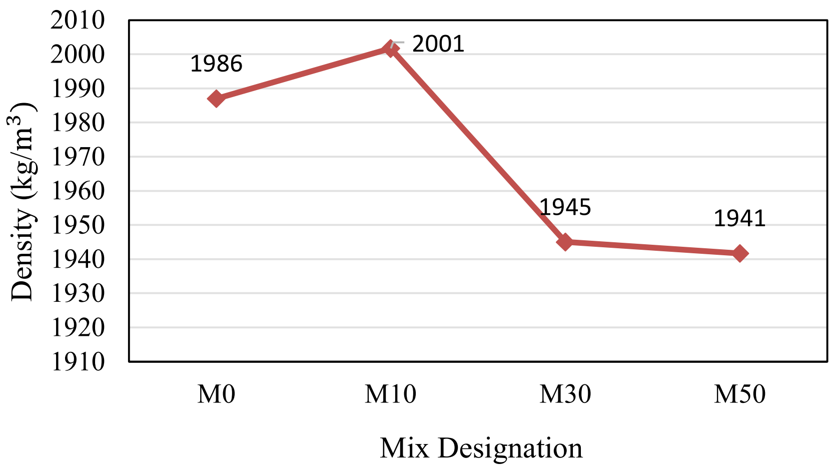

Figure 6. Density of different concrete mixes.

4. Conclusions

The slump value 25-40 mm for POFA based OPSC was lower than the slump value 50-75 mm of structural lightweight concrete because of the lower w/c ratio. The density of all mixes below 2000 kg/m^3 for POFA based OPSC could be categorized as structural lightweight concrete based on EN206-1. However, a slight increase of density was found for 10% replacement of OPC by POFA. This study recommends the 10% replacement of binding materials with POFA for achieving higher strength of structural lightweight concrete i.e., OPSC.

5. Acknowledgements

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