International Journal of Engineering & Technology, 7 (3.18) (2018) 58-61

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Technical paper

Evaluation of Microfine Palm Oil Fuel Ash (POFA) as Cement Partial Replacement Material for Mitigation of Chloride Attack

Raudhah Ahmadi[1], Mohd Syukry Saiful[1], Dzul Fahmi Zawawi[1], Shahrul Zaman Abdul Rahman[1], Idawati Ismail[1], Mohamad Abdul Mannan[1], Ana Sakura Zainal Abidin[2] and Fadzli Mohamed Nazri[3].

[1]Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak
[2]Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Malaysia Sarawak
[3]School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia
**Corresponding author E-mail: araudhah@unimas.my*

Abstract

This paper investigates the effect of microfine palm oil fuel ash (POFA) as cement replacement material for mitigation of chloride attack in concrete. The raw POFA obtained from a local palm oil mill is initially grinded using Los Angeles abrasion machine, and then sieved using 150 µm sieve before it is burned in a furnace at 500°C. The burned POFA is then grinded using electric powder grinder to obtain the targeted microfine size ranging between 1-10 µm. Treated microfine POFA is used in the production of concrete samples for experimental tests; compressive strength test, sorptivity test and chloride penetration test to determine its physical properties and the chloride resistance parameter for the mitigation of chloride attack in concrete. Results showed that 20% of microfine POFA replacement in concrete gives the highest compressive strength at 56th day and reduces the rate of absorption of water and chloride penetration.

Keywords: *Cement replacement; Chloride attack; Microfine POFA.*

1. Introduction

Malaysia has been facing major problem in disposing palm oil fuel ash (POFA) since many years ago. Furthermore, Malaysia has become the second largest palm oil producer since 2010, as the production of palm oil is almost 18.6 million metric tons [1,8]. Hence, to make benefits from it as well as conserving the environment, POFA can be applied as cement replacement material especially in the production of high strength and high durability concrete. A study carried out by [2] discovered that the optimum POFA replacement in concrete is at 30% by weight of the binder, which increases the compressive strength of concrete compared to the usage of purely Ordinary Portland Cement. The outcome of this study also has come to an agreement with [3] that proved the inclusion of 40% microfine POFA could increase the workability and viscosity of the ultra-high strength concrete. A study by [1] also found that concrete made with 10 µm POFA as partial cement replacement material has higher resistance to acid attack than concrete made with 45 µm POFA. It is deduced that the durability of concrete made with finer size of POFA particles as partial cement replacement is much higher than when using larger particle size of POFA. Hence, this research focuses on investigating the effect of microfine sized POFA ranging from 1-10 µm as cement replacement material that could mitigate chloride attack.

2. Materials and Experimental Procedures

This research mainly focused on the utilization of microfine POFA as cement replacement in the concrete mix on the aspects related to compressive strength, rate of absorption (sorptivity) and resistance on chloride attack in concrete using Nordtest (NT Build 492) [4].

2.1. Material

The raw POFA used in this research is collected from a local palm oil mill (Bau, Lundu Palm Oil Mill, Sarawak, Malaysia) and is treated before grinded to produce particle sizes ranging from 1-10 µm [5,6].

2.2. Mix Design

The acceptable particle size of processed POFA, which is ranging between 1-10 µm is then being applied into the production of concrete cubes with the dimension of 100 mm^3 and concrete cylinders (diameter of 100 mm and height of 200 mm). A total number of 18 concrete cubes and 24 concrete cylinders are produced in order to perform the tests to determine its engineering properties. The outcome from the mix design is tabulated in Table 1. Samples are fully submerged in tap water under normal room temperature, 27°C after de-moulding for 7, 28 and 56 days.

Table 1: Mix design

Materials	Quantity (per kg/m^3)		
	0% POFA (control)	10% POFA	20% POFA
Water/Cement Ratio	0.47	0.47	0.47
Cement Content	480	432	384
POFA Content	0	48	96
Water Content	225	225	225
Coarse Aggregate	1185	1185	1185
Fine Aggregate	460	460	460

2.3. Tests for Concrete Sample

Three tests conducted are compressive strength test, sorptivity test and Nordtest for hardened concrete.

2.3.1. Compressive Strength Test

For compressive strength test, 100 mm^3 concrete cubes are tested at 7, 28 and 56 days of curing.

2.3.2. Sorptivity Test (Rate of Absorption)

The initial mass of sample is taken. Sample is then immersed into water where the bottom surface of the sample is fully in contact with water. At intervals of 5 minutes for one hour, sample is removed from water, stopwatch is stopped, excess water is blotted off with a towel and the sample is weighed. It is then replaced in water and the stopwatch started again. The graph of gain in mass per unit area over the density of water is plotted versus the square root of the elapsed time. The slope of the line of the best fit of these points is reported as the sorptivity. Total duration of the experiment is limited to only 10 days. Figure 1 shows the schematic diagram of a lab sorptivity technique used.

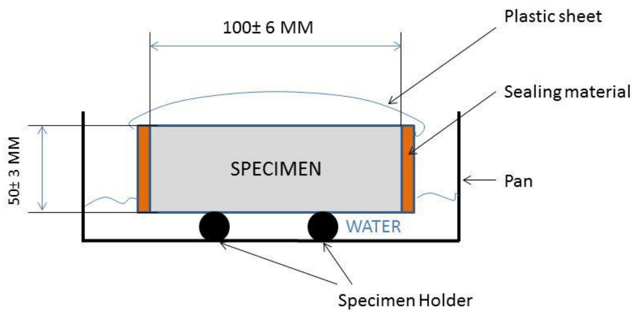

Fig. 1: Schematic diagram of lab sorptivity technique

2.3.3. Nordtest method (NT Build 492)

The Nordtest Method Build 492 is used to determine the resistance of concrete made with microfine POFA as cement replacement material of concrete samples at the age of 28th day. Firstly, the method requires cylindrical specimens with a diameter of 100 mm and a thickness of 50 mm, sliced from the cast cylinders with a minimum length of 100 mm. An external electrical potential is applied axially across the specimen and forces the chloride ions outside to migrate into the specimen as shown in Figures 2 (a) and (b). The anolyte and catholyte used is sodium hydroxide (NaOH) and sodium chloride (NaCl), respectively. After a certain test duration, the specimen is axially split and silver nitrate solution is sprayed onto one of the freshly split sections. The test duration refers to the time period required for the test according to the initial current I30V used as shown in Table 2. Chloride penetration depth can then be measured from the visible white silver chloride precipitation as shown in Figure 3, after which the chloride migration coefficient can be calculated from this penetration depth.

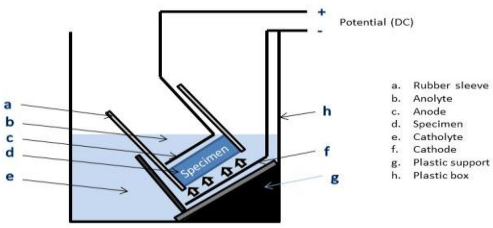

Fig. 2(a): Sketched setup of Nordtest method (NT Build 492)

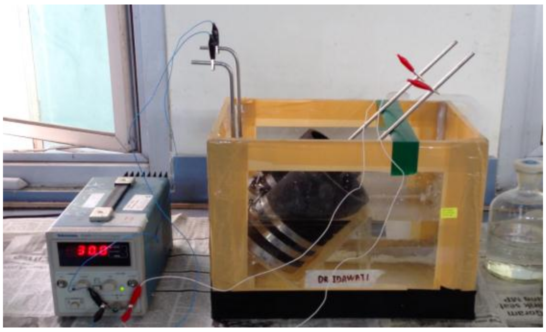

Fig. 2(b): Actual Nordtest setup (NT Build 492)

Table 2: Test voltage and duration for concrete specimen with normal binder content [4]

Initial current, I_{30V} (with 30V) (mA)	Applied voltage, *U* (after adjustment) (V)	Possible new initial current, I_0 (mA)	Test duration, t (hour)
$I_0 < 5$	60	$I_0 < 10$	96
$5 \leq I_0 < 10$	60	$10 \leq I_0 < 20$	48
$10 \leq I_0 < 15$	60	$20 \leq I_0 < 30$	24
$15 \leq I_0 < 20$	50	$25 \leq I_0 < 35$	24
$20 \leq I_0 < 30$	40	$25 \leq I_0 < 40$	24
$30 \leq I_0 < 40$	35	$35 \leq I_0 < 50$	24
$40 \leq I_0 < 60$	30	$40 \leq I_0 < 60$	24
$60 \leq I_0 < 90$	25	$50 \leq I_0 < 75$	24
$90 \leq I_0 < 120$	20	$60 \leq I_0 < 80$	24
$120 \leq I_0 < 180$	15	$60 \leq I_0 < 90$	24
$180 \leq I_0 < 360$	10	$60 \leq I_0 < 120$	24
$I_0 \geq 3600$	10	$I_0 \geq 120$	6

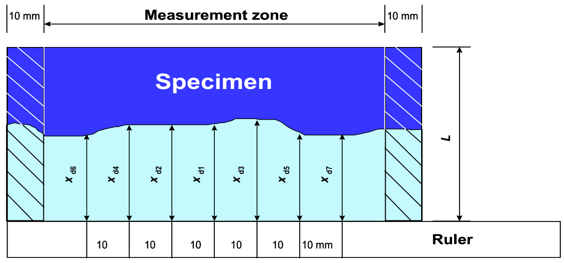

Fig. 3: Illustration of measurement for chloride penetration depths

3. Result and discussion

3.1. Compressive Strength

Figure 4 shows that on the 7th day of water curing; the 10% replacement sample achieved the highest average compressive strength at 43.2 MPa. Meanwhile, the control sample (0% microfine size POFA) and 20% replacement sample obtained the average compressive strength of 33.9 MPa and 38.1 MPa respectively. It is reasonably enough to state that at the early age compressive strength of hardened concrete made with 10% ultrafine POFA replacement is higher than the control sample due to its mineralogy, which contains more pozzolanic materials (silica) that contributes to early strength of concrete.

On the 28th day of water curing, the average compressive strength of the control samples shows a slightly higher result (49.0 MPa) than the concrete samples made with 10% and 20% of ultrafine POFA replacement (45.8 MPa and 44.9 MPa respectively). It is a normal achievement of compressive strength for a hardened concrete made with 100% OPC as the binder, but an impressive achievement for the 10% and 20% microfine POFA replacement to achieve increment of compressive strengths at 28th day of water curing. These results agreed with the findings by [2,3,10] where the highest compressive strengths of concrete made with POFA as replacement at the age of 28 days can be achieved with the replacement percentage of 10-20%. This is due to the results of the

Energy Dispersive Spectroscopy (EDS) which recorded the highest Calcium/Silica ratio (as much as 4.22) in 20% ultrafine POFA replacement [6]. With sufficient amount of calcium and moisture, pozzolanic reaction will take place resulting in formation of C-S-H gel [7]. The reaction will then generate secondary C-S-H gel, which strengthened the bond and consequently the strength of the concrete.

It can be seen from the results that the average compressive strengths of all samples are increasing. This trend is shown in Figure 4 that shows samples made with 20% microfine POFA replacement has the highest average compressive strength among all the samples at the age of 56 days (57.2 MPa), followed by 10% and 0% POFA inclusion (56.5MPa and 55MPa, respectively). The result trend is similar with research by [2] where it can be seen that the results for early days of 10% and 20% POFA inclusion is lower than 0% POFA inclusion. However, the result at 56th day gives the highest compressive strength among all. This is because the pozzolanic reaction takes place and gives extra layer of C-S-H to concrete which causes the strength to increase.

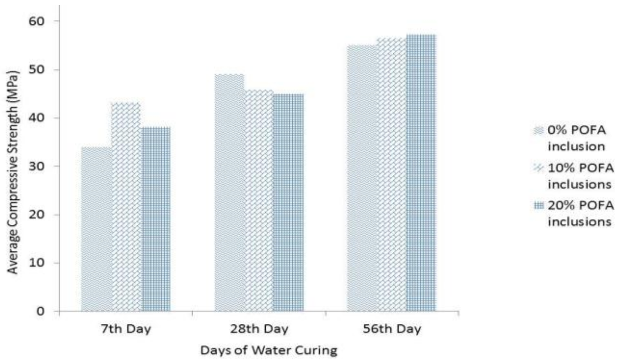

Fig. 4: Average compressive strength of concrete made with microfine size POFA cement replacement at the 7th, 28th and 56th day of water curing.

3.2. Sorptivity

Similarly, with the compressive strength test, the sorptivity of the concrete samples made with partial cement replacement of microfine POFA at 0%, 10% and 20% is tested at the age of 7, 28, and 56 day of water curing. This experiment is to determine the rate of absorption of water (sorptivity) of the concrete samples to estimate the durability of the concrete samples.

From the summary of average absorbed water at 56th day and sorptivity tests results shown in Figures 5 and 6, it can be observed that the sorptivity of concrete samples is lowest in samples with 20% microfine POFA replacement. Hence, it can be deduced that the implementation of microfine POFA in concrete is able to reduce the rate of water absorption, which indicates that the implementation of microfine POFA in concrete can enhance the durability of concrete from deterioration.

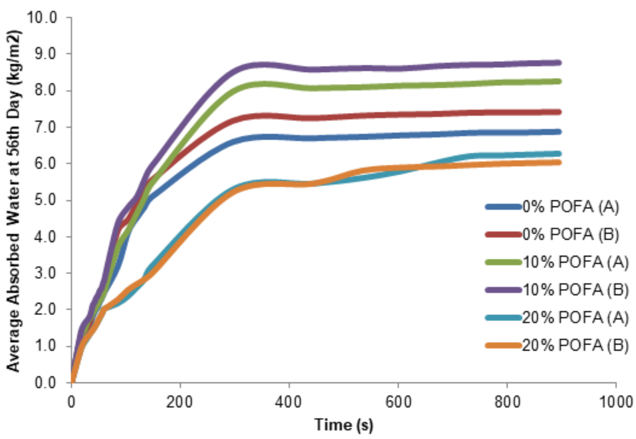

Fig. 5: Summary of average absorbed water at 56th day (kg/m^2)

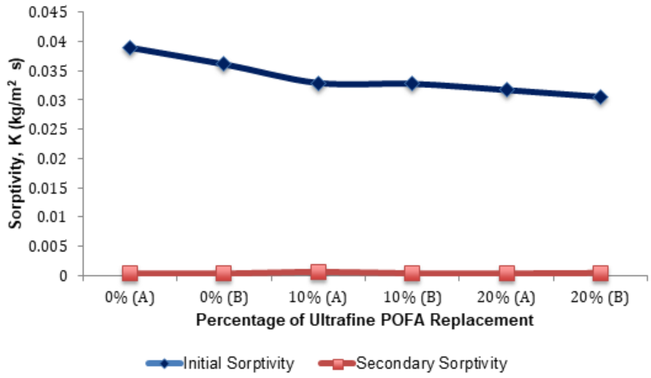

Fig. 6: Summary of sorptivity at 56th day

3.4. Chloride Penetration (Nordtest Method)

The effect of chloride penetration into concrete cylinder samples made with 0% (control), 10%, and 20% microfine POFA as cement replacement is tested using Nordtest Built 492, which is carried out at the age of 28 days of water curing. The determination of chloride penetration parameter is referring to the criteria made by [9] as shown in Table 3. This is to evaluate concrete resistance to chloride penetration by using chloride migration coefficient under non-steady-state (D_{nssm}). Figures 7 (a),(b) and (c) show the axially split samples used for chloride penetration test.

Table 3: Results of the concrete resistance to chloride ion penetration

Chloride Migration Coefficient, D_{nssm} (m^2/s) [9]	Resistance To Chloride Penetration [9]	Samples Category	Results of Average Chloride Migration Coefficient, D_{nssm} (m^2/s)
< 2 x 10^{-12}	Very Good	20% POFA replacement	1.93148 x10^{-12}
2 – 8 x 10^{-12}	Good	10% POFA replacement	7.36519 x10^{-12}
8 – 16 x 10^{-12}	Acceptable	0% POFA replacement	8.71784 x10^{-12}
>16 x 10^{-12}	Unacceptable	-	-

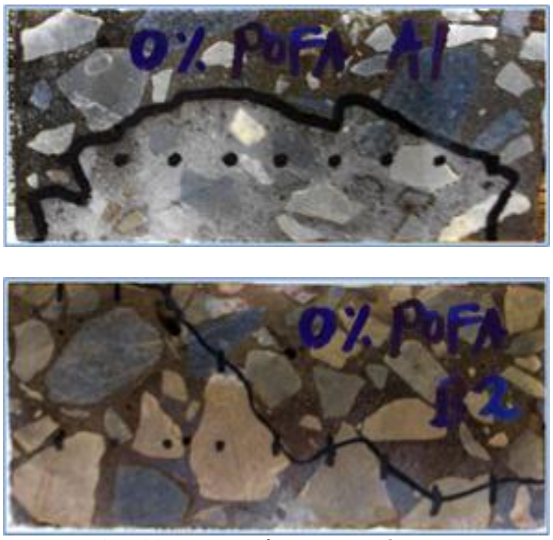

Fig. 7(a): 0% Microfine POFA replacement

Fig. 7(b): 10% Microfine POFA replacement

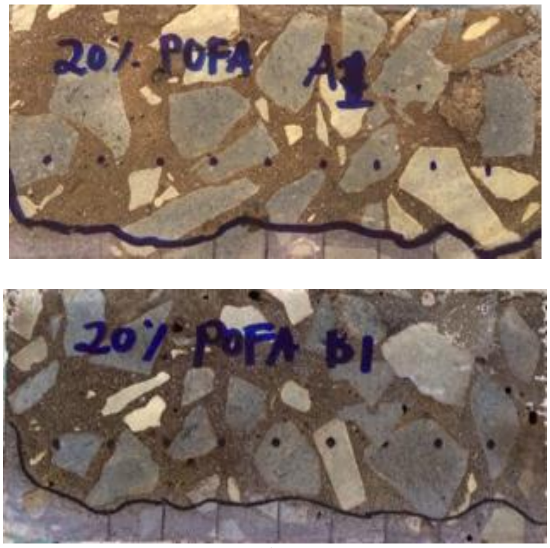

Fig. 7(c): 20% Microfine POFA replacement

From the results showed in Figures 7 (a), (b) and (c) and tabulated in Table 3, it can be seen that concrete with 20% microfine POFA replacement has the higher ability to resist chloride ion penetration. This is because chloride resistance of concrete is depending on the porosity of concrete in terms of pore size, pore distribution and interconnectivity of the pore system. Since the microfine POFA has filled up most of the capillaries and pores in concrete, chloride ion penetration has successfully been reduced. Thus, it can be said that the utilization of the 20% microfine POFA as partial cement replacement in concrete mix is a very good resistance to chloride ion penetration

4. Conclusion

Microfine POFA as cement replacement material performed exceptionally well at 20% cement replacement which gives the highest compressive strength, 57.2MPa at 56th day. The results from the sorptivity tests of concrete samples made with microfine POFA have shown that the sorptivity (rate of absorption) of water is gradually decreasing as the percentage of microfine POFA replacement increased. From the chloride penetration test using Nordtest Method (NT Build 492), the rate of chloride penetration is decreased as the percentage of the microfine POFA replacement is increased. The findings from this research have proved that microfine POFA is suitable to be used as chloride mitigation agent at 20% cement replacement.

Acknowledgement

This research paper is supported by Universiti Malaysia Sarawak via grant F02/SpSTG/1380/16/22.

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