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Chloride Resistance of Concrete Containing Palm Oil Fuel Ash

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Abstract

Experimental study was conducted to investigate the chloride resistance of concrete containing palm oil fuel ash (POFA). Ground POFA was used to partially replace Portland cement Type I, by 20% by weight of binder in order to prepare POFA concrete. Water cement ratio of 0.28 was used and high water reducing admixture was added to maintain workability. POFA concrete was investigated and tested for compressive strength at ages of 7, 28 and 90 days. Rapid chloride penetration test (ASTM C1202) and salt ponding test (ASTM C1543) were conducted on standard concrete specimens to investigate the chloride resistance of concrete. The results showed that the compressive strength of POFA concrete was improved comparing with plain concrete. The results of chloride penetration tests revealed that significant improvement in terms of chloride resistance could be obtained by using 20 % of ground POFA in concrete mix as cementing replacement material.

Keywords: Palm oil fuel ash; chloride resistance; RCPT test; ponding test; compressive strength.

1. Introduction

Pam oil industry is one of the biggest industries in Malaysia. Currently, Malaysia accounts for 41 % of world palm oil production and 47% of world exports. Several processing operations are used to produce the finished palm oil that meets the users' requirements. The first step in processing is at the mill, where the crude palm oil is extracted from the fruit. Approximately 52 tonnes of nut shells, fibres and empty bunches discharged from the mills for every 100 tonnes of fresh fruit bunches processed [1]**.** discharged materials are used as fuel for the production of steam in the palm oil mills. As a result of burning the discharged materials at temperature of about 800–1000 °C in the palm oil mill boilers, 5 % of ash is produced. This light and small particles size ash is disposed of in landfills resulting in traffic hazard besides a potential health hazard leading to bronchi and lung diseases [2].

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As a solution to these problems, many researchers have been studying the feasibility of using palm oil fuel ash (POFA) as supplementary materials to replace part of cement in mortar and concrete mixes. In 1990, Tay [3] had investigated the feasibility of using shell and fibre palm oil ash as cement replacement materials. Cement was partially replaced by 10, 20, 30, 40 and 50 % of POFA. The results showed that the decrease in compressive strength of concrete is almost proportional to the amount of ash in the blended cement, except when only 10% ash is used, therefore, the researcher concluded that shell and fibre ash can be blended in small amounts (up to 10%) with cement for concrete making. Five years later, Tay, H. and Show, K. [2] had conducted a study on the use of oil-palm bunch ash as a partial replacement material for Portland cement where 10, 20, 30, 40 and 50% of cement were replaced by weight of the ash. They observed that the compressive strength of the concrete decreases with the increasing of ash content in the cement. However, they concluded that the oil-palm bunch ash can be used as cement replacement materials in small amounts (Up to 10 %) without detrimental effects on long-term strength property.

Subsequently, many researchers [4-10] have studied the compressive strength and durability of concrete and mortar. Their studies have revealed that the compressive strength and sulphate resistance are improved when ground palm oil fuel ash is partially replaced cement in concrete or mortar mixes. Chindaprasirt, P. et al. [11] studied the ability of POFA mortar to resist the chloride ions penetration, the results showed that the resistance to chloride penetration of POFA mortar was substantially improved. All researchers attributed the improvements in POFA mortar and concrete behaviour to the pozzolanic reaction where the hydration products react with the silica contained in POFA resulting in highly dense and impermeable matrix. Also, the researchers found that the improvements in strength and sulphate resistance properties are proportional with the fineness of ash.

However, as long as authors knowledge no studies have been conducted to investigate the chloride resistance of concrete containing POFA since today; therefore, this study has been conducted to investigate the POFA concrete's ability to resist chloride ion penetration using short term test named rapid chloride penetration in accordance with ASTM C1202 [12] and long term test named salt ponding test ASTM C1543 [13]. For more understanding of the behaviour of POFA when blended with cement, Sodium sulphate resistance of mortar containing POFA was investigated.

Both the RCPT and salt ponding test are widely used to predict the ability of concrete to resist chloride penetration. According to ASTM C1543, three percent (3%) by mass of sodium chloride solution is ponded and maintained in depth of 15 mm to 20 mm on the surface of at least 0.003 m2 concrete specimens for three months. Subsequently, samples from specified depths were extracted and chemically analysed to determine the chloride content of the concrete at those depths. According to RCPT test, a potential difference of 60 V dc is maintained for six hours across the ends of 2 inches thick and 4 inches diameter cylinder or core slice. One of the ends is immersed in a sodium chloride solution while the other in a sodium hydroxide solution. The total charge passed, in coulombs, are recorded and then interpreted according to the standard (ASTM C1202). For sulphate resistance test, laboratory tests in accordance with the ASTM C1012 [14] were conducted on mortar bars.

2. Experimental program

2.1. Materials

Ordinary Portland cement (OPC) complies with the requirements specified by ASTM C154 Type I. Palm oil fuel ash from private palm oil mill located in the middle part of peninsular Malaysia was collected, dried and sieved through 300 μm sieve in order to obtain the desired ash. The ash was ground by modified Loss Angles abrasion machine to reduce the particle size to 45 μm. The chemical composition of OPC and POFA is summarized in Table 1.

The combination of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) was more than 70 %, loss on ignition is 7.34 % and sulphur trioxide is 0.96 % for POFA. Therefore, the POFA could be classified as class N pozzloana according to the standard [15]. The particle shapes of POFA are illustrated in Fig. 1. It could be observed that POFA had an angular and irregular particle shape with some porous particles.

TABLE 1: CHEMICAL COMPOSITION OF OPC AND POFA

	OPC	POFA
Sio_2	43.1	58.30
Al_2O_3	5.0	6.69
Fe_2O_3	2.6	9.77
CaO	46	6.72
MgO	1.1	3.69
SO_3	-	0.96
K_2O	0.5	8.40
LOI	1.3	7.34

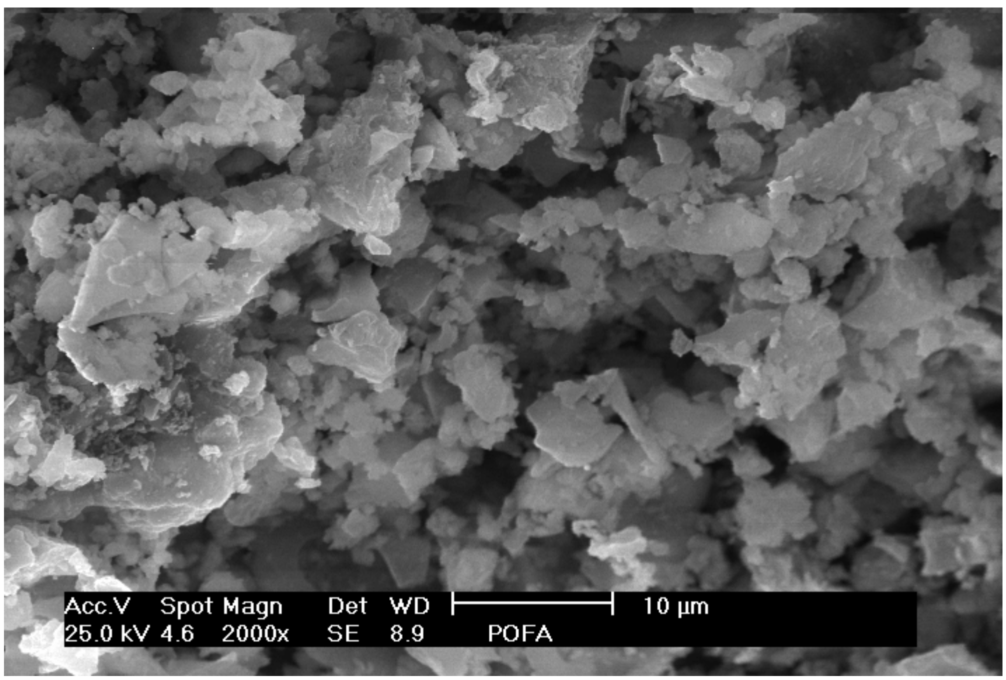

Figure 1: Scanning electron microscopy (SEM) of POFA

Sand with specific gravity of 2.585, absorption of 2.04% and fineness modulus of 3.21 and crushed granite of 10 mm size and specific gravity of 2.595, absorption of 0.5% were used as fine and coarse aggregates respectively.

2.2. Mix proportion and testing procedures

2.2.1. Mix *proportion*

2.2.1.1. Concrete

For the sake of comparison, this investigation was conducted on plain and blended concrete mixes. Plain concrete mix was prepared using high amount of cement (500 kg/m^3). To control the negative effects of mixing water, the ratio of water to cement was kept constant with 0.28, high water reducing admixture was added to maintain the workability, the ratio of coarse to fine aggregate was 3:2 by weight. Ordinary Portland cement in plain concrete mix was replaced by 20 % by weight by ground POFA in order to produce blended concrete mix (Table 2).

TABLE 2: MIX PROPORTION OF CONCRETEMIXES

Mixes	Mix proportion [kg/m3]						W/B
	Cement	POFA	Fine agg.	Coarse agg.	water	SP[liter]	
OPC	500	-	711.25	1066.87	145.84	11.5	0.28
POFA	400	100	711.25	1066.87	145.84	11.5	0.28

2.2.1.2. Mortar

Two mixes were prepared according to ASTM C1012 [14] as shown in Table 3. The control mortar was made using plain Portland cement. The mixes consist of 1 part binder [cement + POFA] and 2.75 parts of sand proportioned by mass. For control mix, water binder ratio of 0.485 was used, and then the flow in 25 drops of the flow table was recorded. Water binder ratio that is sufficient to develop a flow within ± 5 of the reference mix flow was used for mix containing POFA.

TABLE 3: MIX PROPORTION OF MORTARS

Type	Cement [kg]	Sand [kg]	W/C	Water	Flow %
OPC	2	5.5	0.485	1.082	100
POFA	2	5.5	0.498	1.108	95.63

2.2.2. Testing procedures

2.2.2.1. Compressive strength

Compressive strength of concretes was tested at ages of 7, 28 and 90 days using concrete cubes of 100 mm size. Specimens were left covered by plastic sheeting for 24 hrs. after casting then demolded and cured in water tank until testing ages.

2.2.2.2. RCPT test

Concrete cylinders with 100 mm diameter and 200 mm height were used to determine the ability of concrete to resist the penetration of chloride ions using rapid chloride penetration test [12].

The specimen was prepared before carrying out the test, where 50 mm slice was taken from the top of the cylinder to be the test specimen, then the side surface of specimen was coated with rapid setting, electrically nonconductive product. The specimen was subjected to saturation vacuum in sealed dissector for 3 hours and for one additional hour after covering the specimen with de-aerated water. Subsequently, the specimen was immersed in de-aerated water for 18 hours then transferred to sealable container which maintain specimen in 95% or higher relative humidity.

A potential difference of 60 V dc is maintained across the ends of the specimen for 6 hrs, one of which (top surface of specimen) is immersed in 3% by mass a sodium chloride solution, the other in 0.3N sodium hydroxide solution. Along the period of test the current was recorded every 30 minutes and each half of the test cell was remained filled with the appropriate solution for the entire period of the test.

2.2.2.3. Salt ponding test

To correlate the results of rapid chloride penetration test, 200 x 200 mm slabs were cured after 24 hrs from casting in conditions of 95% relative humidity and 23±2°C for 14 days. Then, the slabs were cured in moisture room (50±5 % relative humidity and 23±2 °C) until they reached the age of 28 days where a sodium-chloride solution was ponded on the surface of concrete slabs according to test method prescribed in [13]. At age of 21 days, the specimens were coated by rapid setting epoxy onto side surfaces to prevent the lateral moisture migration.

After three months ponding, samples from specified depths were extracted by coring and chemically analyzed to determine the chloride content of the concrete at those depths.

Considering the background chloride content which was determined in specified depths of 100 x 200 mm cylinder cast from same batch, the penetrated chloride value is the chloride content of the sample from each depth of the ponded specimens after subtracted the background chloride content of same depth.

2.2.2.4. Expansion test

Three mortar bars of 25 x 25 x 285 mm from each mix were prepared and cured according to the standard [14]. Then, the specimens were immersed in 5% of sodium sulfate Na_2SO_4 solution and the change in length of bars was recorded using a mechanical strain gauge having 0.001 mm sensitivity at intervals of 1, 2, 3, 4, 8, 13 and 15 weeks.

3. Results and discussion

3.1.compressive strength

Compressive strength of OPC concrete and OPC concrete containing POFA are illustrated in Figure 2. At 7 days, the compressive strength of OPC concrete containing POFA is 39.31 MPa which is lower than OPC concrete that retains compressive strength of 43.11 MPa at the same age. The reason is that OPC concrete contains 100 % of ordinary Portland cement type I, which induces higher hydration reaction than OPC concrete containing POFA [16]. At 28 and 90 days, the compressive strength of OPC concrete containing POFA was developed to become 48.72 and 53.02 MPa against 48.03 and 49.05 MPa for OPC concrete. This is due to the high SiO_2 content of POFA that react with calcium hydroxide at later ages to produce impermeable concrete by producing addition calcium silicate hydrate [8, 9, 16, 17]. Considering the results of compressive strength, it can be stated that ground POFA could be used as cement replacement material to replace 20 % of Portland cement type I in concrete mixes without any degradation in later age compressive strength.

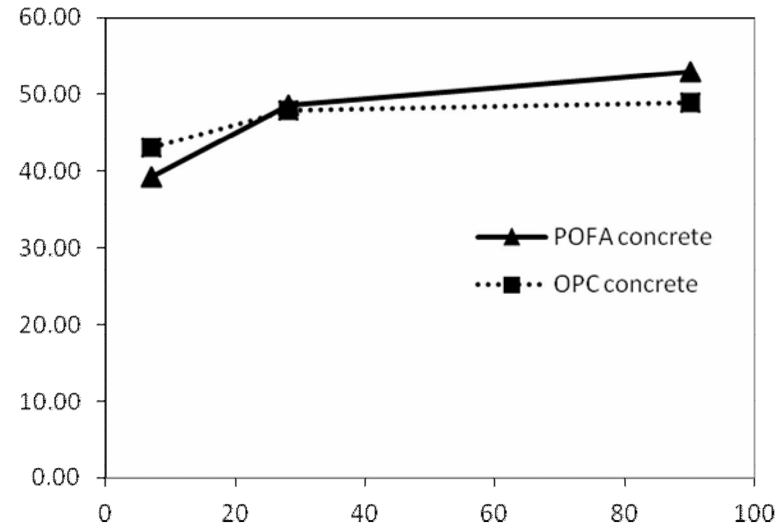

Figure 2: Relationship between compressive strength and age of concrete.

3.2. Chloride resistance

3.2.1. RCPT test

The results of the RCPT test for OPC and OPC concrete containing POFA are shown in Figure 3. After applying a potential difference of 60 V dc for 6 hrs across the ends of OPC and OPC concrete containing POFA specimens, the average of charge passed were 731.7 and 276.3 (in coulombs) respectively. The charge passed was significantly reduced with replacing 20% of cement by POFA as compared to pure OPC concrete where reduction in charge passed of 63% was achieved. Reduction in charge passed of 60 % was recorded by Sharfuddin M., et al., [18] when RCPT test was conducted on concrete specimens containing 10 % of silica fume.

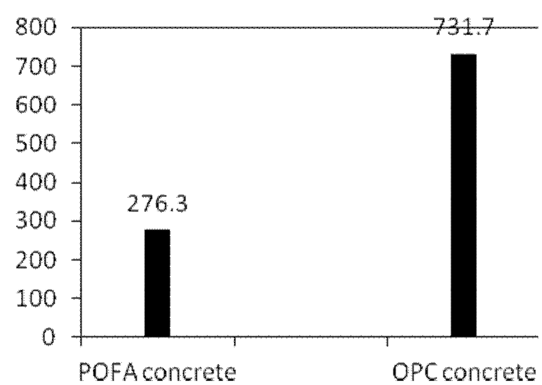

Figure 3: RCPT test results

Also, essential improvements in chloride resistance have been observed when specimens of mortar containing 20% of POFA were tested using RCPT test [11]. This improvement in concrete resistivity is due to the pozzolanic reaction that improves the interfacial bonding between the aggregates and pastes resulting in impermeable and dense concrete [9, 19, 20].

3.2.2. *Salt ponding test*

The profiles of OPC and OPC concrete containing POFA, obtained from the test, are provided in Figure 4. The chloride content is expressed as a percentage of the mass of sample and the depth is the mid-point of each slice from the exposed to chloride surface. It is clearly observed that OPC concrete containing POFA showed better resistance against chloride ions ingress than OPC concrete by about 70%. This result confirms the result obtained from RCPT test. Also, it can be observed that the migration of chloride ions through OPC concrete containing POFA was much lower than OPC concrete, this is due to the pozzolanic reaction that produce more calcium silicate hydrate resulting in a highly impermeable matrix that prevents or slow down the chloride transport.

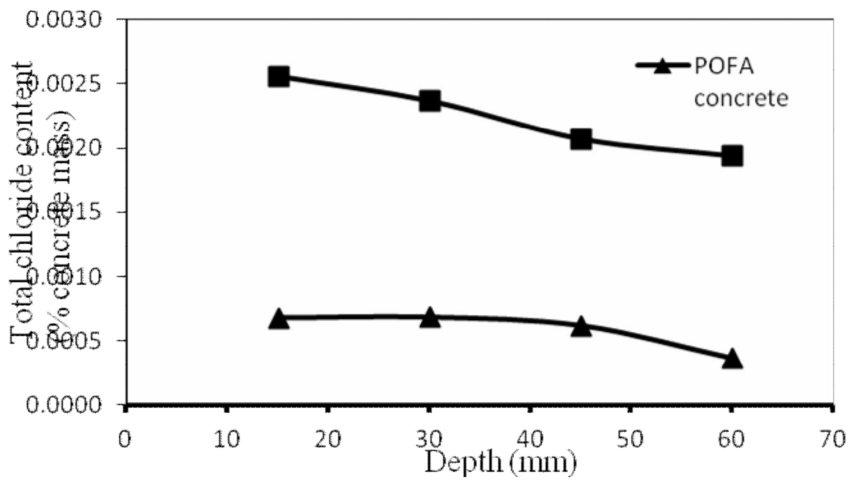

Figure 4: The chloride content profile obtained from 90-days ponding test

3.3. *Sulfate resistance*

The expansion values of mortar bars immersed in sodium sulfate solutions are demonstrated in Figures 5. For mortar bars immersed in sodium sulfate, the expansion value of OPC mortar bars is 0.075% after 15 weeks, while that of the POFA mortar is 0.047%, which is substantially lower than OPC mortar.

Calcium silicate hydrate gel (C-S H) that produced as a result of the reaction of silica contained in POFA with calcium hydroxide product is the reason beyond the improvements in the behavior of POFA mortar against sulfate attack. In addition, a reduction in $Ca(OH)_2$ lead to reductions in the formation of gypsum and ettringite [21].

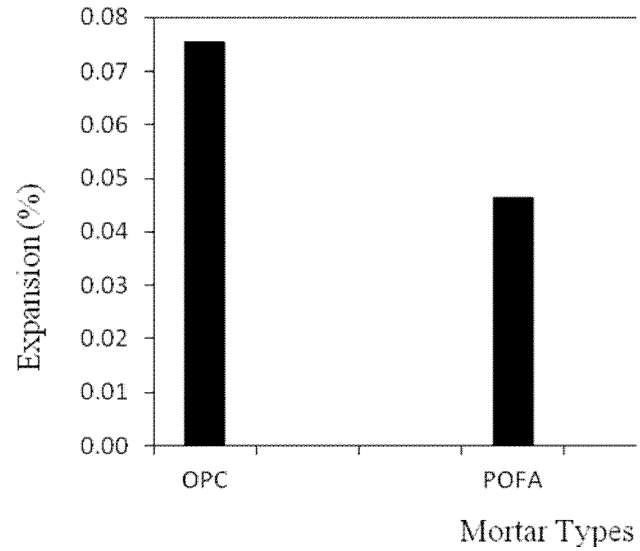

Figure 5: Expansion of mortar immersed in 5 % Na2SO4 for 15 weeks.

4. Conclusion

From the result of this study, the following conclusions can be stated:

1. POFA has high content of SiO_2 and could be used to replace 20 % of Portland cement in concrete mix without any degradation in compressive strength.
2. The ultimate compressive strength of concrete could be improved by using 20 % of POFA to replace Portland cement in concrete mix.
3. POFA works as filler materials at early ages. However, at later ages, POFA starts to react with hydration products to produce impermeable concrete.
4. Resistance to chloride ions penetration of concrete containing 20 % of POFA is substantially improved.
5. Resistance to sodium sulfate attack of mortar containing 20 % of POFA is significantly improved.
6. POFA could be used as cheap pozzolana to produce High performance concrete.
7. Consuming POFA as cementing materials in construction industry will reduce the environmental problems associated with disposing of it in landfill.

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