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Concrete corrosion performance using palm oil fuel ash (POFA) as a cement replacement material

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Abstract - The development and use of blended cement is growing rapidly in the construction industry mainly due to considerations of cost saving, energy saving, environmental protection and conservation of resources. Demand for the high durability and environmental friendly nowadays developed POFA as an alternative material to replace cement in construction field. In this research, the durability towards chloride penetration in concrete was assessed. The influence of POFA on the corrosion performance of concrete was studied by some accelerated short term technique in sodium chloride solutions. By adopting various activated techniques such as physical and chemical methods, hydration of POFA blended cement was accelerated and thereby improved the corrosion resistance of concrete. Concrete specimen prepared with 10%, 20% and 30% of POFA replacement were evaluated for their impressed voltage test, half-cell potential test and chloride binding capacity test and the testing results were compared with those for OPC concrete without POFA. All the specimens were cured for 28 days before the testing was done. The study confirmed that level of 20% POFA replacement as cement improved the corrosion resistance properties. Therefore, POFA can be used as a cement replacement material to improve the corrosion resistance of concrete. At the same time, the problem of disposal of palm oil industry can be solved and new product can be produced to generate economic resources.

Keywords: corrosion, durability, palm oil fuel ash, pozzolanic material.

1. Introduction

Corrosion of reinforcement in concrete can be delayed by using material which is designed to resist corrosion such as dual-phase steel, stainless-steel, galvanized-steel, epoxy-coated steel and using non-metallic material as reinforcement. Utilization of blended cement in concrete has been considered to improve concrete properties such as permeability and porosity which is can improve the concrete performance toward corrosion resistance[1-4]. Concrete pore structure and chloride binding capacity have been improved when fly ash was used as cement replacement material [1]. Formation of additional C-S-H gel would fill the existing voids in concrete thus creating denser concrete. This finally increases the strength and durability of this hardened material [3].

Palm oil fuel ash (POFA) has been identified as pozzolanic material and can be used as cement replacement material in concrete [4] due to physical and chemical properties which is can improve the concrete properties. POFA was largely produced in Malaysia and Indonesia [5] as they used as fuel to generate steam in the palm oil mills. In 2007, productive oil palm plantations in Malaysia are 4.3 million hectares, a 3.4% increase from year 2006 which stood at 4.2 million hectares [6] and the growth of palm oil production in Malaysia will increase the amount of residues. One hectare of oil palm plantation can produce about 50–70 tonnes of biomass residues approximately. This paper summarizes the findings and results of recently completed studies undertaken at the University Malaysia Pahang to develop concrete with corrosion resistance by using chloride ingress and accelerated test. The study has focused on use of POFA as cement replacement material in normal concrete with normal curing process.

2. Materials and Experimental

Material used

Composite Portland cement (PC) from YTL Cement Berhad fulfill with MS 522-1:2007 and palm oil fuel ash (POFA) taken from Lepar Hilir palm oil mill at Gambang, Pahang Darul Makmur were used in this study. POFA chemical compositions are shown in Table 1and Table 2 depicted the detail mix proportion of concrete. All concrete samples were cured with water at 28 days before tested with accelerated corrosion test.

Table 1: Major composition of POFA

Parameter	Percentage
Silicon Dioxide (SiO_2)	41.7
Potassium Oxide (K_2O)	7.47
Calcium Oxide (CaO)	7.36
Iron Oxide (Fe_2O_3)	5.07
Sulphur Trioxide (SO_3)	0.93
Aluminium Oxide (Al_2O_3)	5.78

Table 2 Mix identification and proportion of concrete

Mix	PC kg/m^3	POFA kg/m^3	Aggregate kg/m^3	Fine Aggregate kg/m^3	w/c
Control	561	0	885	695	0.41
POFA10	505	56	885	695	0.41
POFA20	449	112	885	695	0.41
POFA30	393	168	885	695	0.41

Techniques adopted

Impressed Voltage Test

The impressed voltage technique is an accelerated corrosion testing technique which indirectly gives information about the permeation characteristics of the concrete. Cylindrical concrete specimens were made using mix proportion with a w/c ratio of 0.41. Specimens with PC and various POFA replacement levels were made with embedded rod as an anode and cylindrical stainless steel electrode acts as a cathode and the electrolyte is 3% sodium chloride solution. A constant voltage of 12V was applied from the external DC source between anode and cathode as shown in Figure 1. The time to initiate a first crack on the concrete was observed and the corresponding anodic current was noted.

Figure 1 Accelerated corrosion test arrangement

Half Cell Potential Test

The steel bar specimens were cut to the required size. Steel bar were polished and degreased and embedded in mortar specimens. The steel bar was embedded in the middle of concrete sample. Then, the concrete samples undergo water curing for 28 days. The testing was periodically monitored using half-cell potential instrument. Saturated calomel electrode (SCE) was used as a reference electrode. The positive terminal of the voltmeter was connected to the working electrode i.e., mild steel rods. The common terminal was connected to the reference electrode. The corresponding potentials were recorded. OCP for all the specimens were monitored over an exposure period of 56 days.

Chloride Binding Capacity

Chloride Binding Capacity is a test method that providing the procedure for sampling and analysis of hydraulic-cement mortar or concrete for chloride as stated in ASTM C 114:2000 [7]. There are two type of analysis chloride binding capacity which is by using acid-soluble chloride and water soluble chloride. The acid soluble chloride indicates the bound chloride while the Water Soluble Chloride indicates the free chloride.

3. Result and discussion

The workability of the POFA studied is presented in Table 3. The concrete slumps were increased due increment of replacement material. Result shows that the concrete become higher workability as the amount of material replacement POFA increase. As the water cement ratio reduces, the concrete mixed become more strength. So, it can conclude that, replacement of POFA increase the workability properties.

Table 3 Workability of the concrete with and without

	Slump (mm)
0%	50
10%	52
20%	53
30%	55

Impressed Voltage technique studies

The graph in figure 1 figure 2 shows control sample of 0% of POFA concrete indicates earlier cracking of concrete with highest value of anodic current which is 1.99 mA. The result followed by 10% POFA and 30% POFA which is 1.93 mA and 1.91 mA respectively. The lowest value is using 20% replacement of POFA which is 1.88 mA. It shows that 20% replacement level has good permeability characteristic of concrete.

Potential-time behaviour studies

The potential-time (in weeks) behaviour of steel in OPC and with various POFA replacement levels are shown in Fig. 3. It was inferred that initially up to 2 cycles of exposure, almost all the sample showed potential values ranging from 0 to -275mV which reflected the passive condition of embedded steel anode. Control sample has shown the highest negativity of potential reading due to 5 cycle exposure in 3% NaCl solution. 20% and 30% of POFA concrete do not cross the threshold limit even after 4 cycles of exposure. From the potential-time behavior studies, it can be observed that up to 20% POFA replacement level, there is no cautious to steel bar under aggressive alternate wetting and drying conditions in 3% NaCl solutions. Rapid hydration occurs in 20% of POFA replacement caused the increasing of durability of concrete.

Chloride Binding Capacity

The graph in figure 4 explained, up to 20% replacement level, the penetration of chloride ion was found to be less when compare to control sample for both bound and free chloride. Control concrete shown the higher percent of chloride present in concrete cement for water soluble and acid soluble which is 0.00251% and 0.0022% respectively. At 30% POFA, the chloride content started to increase but 30% POFA concrete give better result than control sample. As the POFA replacement level increase, the penetration of chloride ions also increase. Beyond 30% replacement level, the chloride binding capacity of concrete increase since the chloride ions get adsorbed to the surface of the pozzolanic material and enter into chemical with aluminates phase.

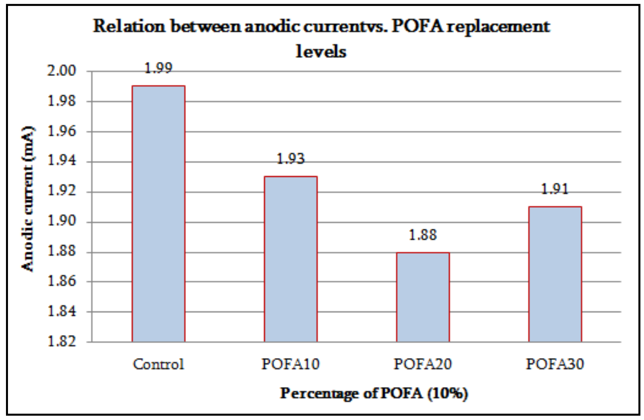

Figure 1. Relationship between anodic current and POFA replacement level.

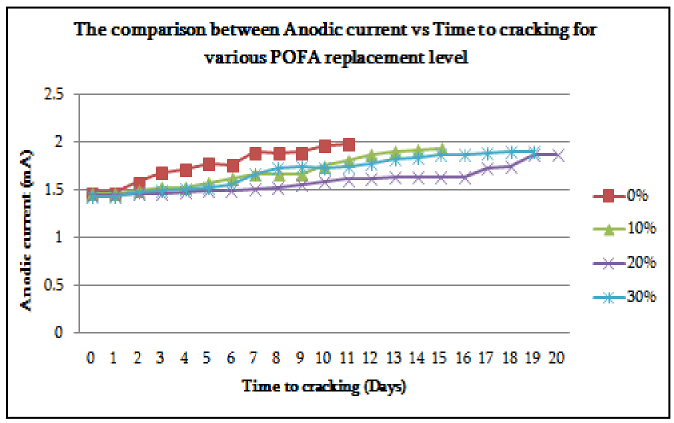

Figure 2. Comparison between anodic current vs. time to cracking for various POFA replacement level

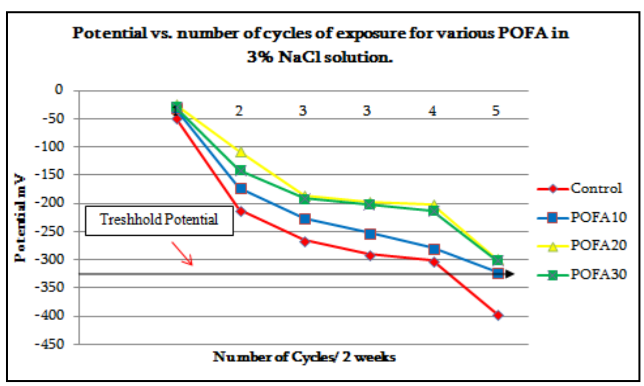

Figure 3. Relationship between Potential vs. number of cycles of exposure for various POFA in 3% NaCl solution.

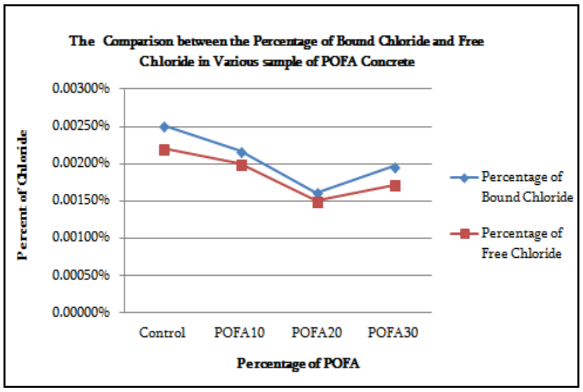

Figure 4. The comparison between the percentage of chloride content for bound chloride and free chloride in concrete sample at 25 mm depth.

4. Conclusion

Based on the findings obtained from the investigation, the following conclusions are drawn:

i. The additional of pozzolan material which is POFA as a cement replacement material increase the corrosion resistance of concrete.
ii. POFA concrete reduced the current density, thus it slower the time to cracking from the analysis that has done from Impressed voltage Test. Concrete mix with 20% of POFA replacement level has shown the optimum replacement material in order to improve the penetration of chloride.
iii. Based on the half cell test conducted, POFA material improved the permeability characteristics of concrete and delayed the initial corrosion time and decreased of corrosion rate.
iv. The resistance of concrete against chloride iron penetration (chloride ingress) from the outside can be improved by reducing the chloride content in concrete.

The overall result for three testing have shown that the concrete with 20% replacement of POFA material gave the best result compare to control, 10% POFA and 30% POFA. It was shows the POFA can be used as cement replacement material and improved the concrete resistance towards corrosion.

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