



LONG TERM INVESTIGATION ON SULPHATE RESISTANCE OF AERATED CONCRETE CONTAINING PALM OIL FUEL ASH

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ABSTRACT

The increasing demand for natural sand supply by concrete industry and rising quantity of palm oil fuel ash, an environmentally polluting solid waste disposed by Malaysian palm oil industry has led to the innovation of aerated concrete containing palm oil fuel ash as partial sand replacement material. This lightweight concrete exhibits improvement in the compressive strength with the incorporation of 30% palm oil fuel ash. However, the long term experimental result of the strength and durability performance of this modified concrete is unavailable. This paper reports the one year result on strength performance of aerated concrete containing palm oil fuel ash when subjected to different curing method and behavior of this material upon exposure to long term sulphate attack. Comparisons are made between behavior of plain aerated concrete mix as control specimen and another mix, aerated concrete with 30% palm oil fuel ash as partial sand replacement. Compressive strength performance of the specimens were observed by placing it in two types of curing regime, water curing and air curing. Durability of the mixes were assessed by exposing the specimens in Sodium sulphate environment. Findings indicate that water curing promotes better pozzolanic reaction in aerated concrete containing palm oil fuel ash, that leads to formation of larger amount of C-S-H gel resulting it to be stronger than control specimen. Integration of palm oil fuel ash consumes calcium hydroxide which is vulnerable to sulphate attack and produces secondary C-S-H gel making the concrete more compact thus enhancing its durability against sulphate attack.

Keywords: aerated concrete, palm oil fuel ash, different curing method, compressive strength, sulphate attack.

INTRODUCTION

As the various industries continue to increase their production to cater the expanding need of world population, consumption of resources also rise and larger amount of industrial by-product is generated. Construction industry is one of the growing trade which uses concrete as the main construction material owing to its superior strength. The blooming constructing industry directly pushes concrete manufacturing sector to increase their production. This causes more raw materials namely plain water, limestone, granite aggregate, natural sand and other materials harvested from environment to be used for production of concrete material. In relation to this issue, rising in sand dredging at the river to meet the escalating demand of concrete manufacturing industry has posed negative impact to the environment.

The mining of river sand disturbs aquatic habitats and also lowers the water quality creating ecological imbalance finally affecting the healthy lifestyle of present and future generation. The issue of natural sand mining and its negatives impact to environment has been well elaborated by Manap and Voulvoulis (2015). In Malaysia, sand mining activity in certain local rivers which cause harm to the environment has also been reported by researchers, Asyraf *et al.* (2011) and Tan and Roshaliney (2013). As a solution, monitoring system and guidelines have been established to ensure the sand mining is carried out at the rate which ensure sustainable environment. Other than that, another possible alternative is to reduce the demand for natural river sand through the use of waste material as partial sand replacement in concrete production. Integrating the waste materials in

concrete production would lower the dependency of the industry on natural sand supply and also promotes towards cleaner environment by decreasing amount of industrial by-products ending at landfill. These ideas have inspired many researchers, Yang *et al.* (2005); Ismail and Al-Hashmi (2008), Sales and Lima (2010), Singh and Siddique, (2013); Muthusamy *et al.* (2013) and Prabhu *et al.* (2013) to look into possibility of exploiting the available locally produced industries solid waste as partial sand replacement in concrete.

In Malaysia, palm oil fuel ash (POFA) which is a by-product of palm oil industry is dumped as waste in the vicinity of palm oil mill. Palm oil fuel ash is end of product from the combustion process of pressed oil palm fiber and oil palm shell to generate power supply for operation of the mill. Annually 4 million tonnes of POFA were produced (Mohamed *et al.*, 2005). Being light, this ash which appear in form of black to greyish colour is easy to be carried by wind causing environmental pollution. Prolonged exposure of the community surrounding to the polluted air may cause health problem. The problems created by the disposal of POFA has been highlighted by researchers, Tay and Show, (1995), Sumadi *et al.* (1996) and Aprianti *et al.* (2015) throughout the years. Previous researcher Hussin *et al.*, (2010) highlighted that larger amount of POFA is expected to be generated and then disposed as environmental polluting waste in future, unless this material is processed for other application. Issues on pollution caused by this solid waste and initiative to find alternative material to reduce use of natural sand has motivated a local researcher Mat Yahaya (2003) to add this material as partial sand replacement in



aerated concrete production. Short term investigation results shows that inclusion of 30% POFA as partial sand replacement contributes towards strength increment of aerated concrete. However, the most suitable curing method for long term strength performance and sulphate resistance of this lightweight concrete yet to be investigated.

Thus, the current research investigates the most suitable curing method for better long strength development of aerated concrete with POFA and also resistance of concrete upon sulphate attack. Experiments have been conducted to examine the long term durability performance of aerated concrete containing palm oil fuel placed in Sodium sulphate environment.

EXPERIMENTAL PROGRAMME

Constituent Materials

Among the materials used in preparation of the specimens are palm oil fuel ash, cement, water, sand, gas producing agent and palm oil fuel ash. Ordinary Portland cement (OPC) conforming to Malaysian Standard MS 522: Part 1(2003) was used. Supplied tap water used for concrete mixing and curing purpose. The sand used was natural river sand which subjected to oven drying process before ground to be fine and sieved passing sieve 300 μ m. Aluminium, type Y-250N was integrated to produce air voids in the mix. Palm oil fuel ash (POFA) was supplied by a local palm oil mill located in the state of Johor, West Malaysia. After the palm oil fruit undergoes oil extraction process, products known as pressed oil palm fiber and oil palm shell are produced. Both material are burned in incinerator which finally produces palm oil fuel ash. Figure-1 illustrates simplified process of palm oil fuel ash production. The ash dumped behind the mill as illustrated in Figure-2 was collected and brought to the laboratory. Then, it was sieved passing 300 μ m before ground to be fine. Based on the chemical composition of palm oil fuel ash tabulated in Table-1, this pozzolanic ash is categorised as Class F in accordance to ASTM C618-12a (2012).



Figure-1. Process of palm oil fuel ash production.



Figure-2. POFA collected from behind the mill.

Table-1. Chemical constituent of POFA.

Chemical Constituent	%
Silicon dioxide (SiO ₂)	82.07
Aluminium oxide (Al ₂ O ₃)	6.04
Ferric oxide (Fe ₂ O ₃)	2.70
Calcium oxide (CaO)	5.11
Magnesium oxide (MgO)	2.28
Sodium oxide (Na ₂ O)	1.34
Potassium oxide (K ₂ O)	2.90
Sulphur oxide (SO ₃)	2.20
Loss of ignition (LOI)	5.30

Mix Proportion

In this experimental work, two types of mixes were used. Plain aerated concrete with 100% natural river sand (P-0) acting as reference specimen. Another one mix is aerated concrete containing 30% palm oil fuel ash (P-30) as partial sand replacement by weight of sand. The inclusion of POFA as partial sand replacement in aerated concrete was based on a simple approach of direct replacement. Mix proportion for aerated concrete with 30% POFA is tabulated in Table-2.

Table-2. POFA aerated concrete (P-30) mix proportion.

Binder sand ratio	30 : 70
Ordinary Portland cement, %	100
River sand, %	70
Palm oil fuel ash, %	30
Water dry mix ratio	0.45
Aluminium powder, %	0.20

Testing Method

In order to determine the effect of curing method on long term compressive strength of aerated concrete with POFA, two types of curing method namely continuous water curing and air curing were employed up to one year of curing age. All specimens were cast in form of cubes (70.6mm x 70.6mm x 70.6mm) and left overnight. After 24 hours, it was demoulded and placed in determined curing regime. Specimens were tested for its compressive strength at 28, 180 and 365 days. The compressive strength test were carried out following the



procedures in BS EN 12390 – 3 (2009). Figure-3 illustrates the cubes produced using aerated concrete containing palm oil fuel ash (left) and plain aerated concrete (right).



Figure-3. Aerated concrete containing palm oil fuel ash, P-30 (left) and plain aerated concrete, P-0 (right)

The sulphate resistance of concrete were evaluated by measuring the length changes of specimens which prepared in form of mortar bars (25mm x 25 mm x 250mm) in accordance with ASTM C1012 – 13 (2013). Both mixes were prepared in form of mortar bars and then subjected to water curing for 28 days. Initial length measurement were made before placing the specimen in 10% Sodium Sulphate Solution. Periodical length measurement was carried out up to a period of 51 weeks. Along with the length measurement, the durability of the concrete mix were also investigated by determining the mass change of the specimens. Both plain concrete and POFA concrete mix were prepared in form of cubes and water cured for 28 days before placed in 10% Sodium sulphate solution. The mass changes was recorded for time to time until the end of testing period.

RESULT AND DISCUSSIONS

Compressive Strength Performance

The compressive strength of both mixes, P-0 and P-30 after subjected to different curing regimes is illustrated in Figure-4. Evidently, curing method influences the compressive strength development of the concretes. Both, P-0 and P-30 that have been subjected to water curing exhibit better compressive strength as compared to the one placed in air curing. Application of air curing provides a very limited water supply that interrupts the hydration process. Disturbance in the occurrence of hydration process leads to generation of lesser amount of C-S-H gel causing lower concrete strength development. In the case of air cured P-30, the insufficient supply of water that disrupts hydration process affect the role of palm oil fuel ash as pozzolanic ash. In addition, interruption in hydration process also results in lower amount of calcium hydroxide that is essential for pozzolanic reaction to take place. As a result, air cured P-

30 exhibit lower strength in comparison to water cured P-30. The importance of moisture availability for occurrence of pozzolanic reaction has been clearly stated in ASTM C618-12a (2012).

Comparing the performance of all mixes, water cured P-30 exhibit the highest compressive strength. This presumably owing to the continuous supply of water that promotes occurrence of better pozzolanic reaction. This undisturbed pozzolanic reaction that takes place produces larger amount of secondary C-S-H gel that fills in the voids of concrete internal structure. As a result, internal structure of P-30 consist larger amount of C-S-H gel that makes the concrete denser and possess higher compressive strength as compared to plain aerated concrete. The suitability of water curing for excellent strength performance of concrete containing palm oil fuel ash has been reported by researcher elsewhere, Abdul Awal, (1998) and Abdullah *et al.* (2009).

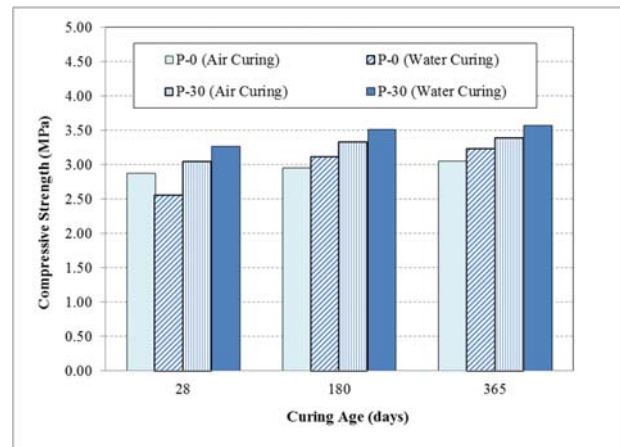


Figure-4. Compressive strength of concrete mixes.

Expansion in Sulphate Environment

Expansion value for P-0 and P-30 concrete bars are shown in Figure-5. Throughout the immersion period, plain aerated concrete bar, P-0 exhibit higher expansion value as compared to P-30. It can be observed after one week of exposure, the expansion of P-0 become steep until it breaks it two at 9th week of immersion. At 9th week, the expansion of P-0 was 11 times higher than P-30. Whilst, P-30 demonstrate slow and gradual expansion until the end of immersion period. In P-0, the abundantly available calcium hydroxide from hydration process which remain unused due to absence of pozzolanic material causes larger amount of ettringite to be formed leading higher expansion value and faster deterioration process. The role of ettringite in causing expansion of cement concrete that was placed in sulphate solution has been highlighted by Bonen and Cohen (1992).

On the other hand, inclusion of palm oil fuel ash in P-30 consumes calcium hydroxide that can readily react with sulphate ion resulting in production of gypsum and ettringite that capable of destroying the concrete. The occurrence of pozzolanic reaction due to the presence of



finely ground palm oil fuel ash benefits the concrete in terms of microstructure densification and most importantly consumption of the vulnerable calcium hydroxide. In P-30, sulphate ion could not react much because the availability of calcium hydroxide content is lesser and that results in lower expansion value as compared to P-0. Generally, integration of fine palm oil fuel ash as partial sand replacement enhances the concrete durability against sulphate attack. Similar trend, has also been reported by Jaturapitakkul *et al.* (2007) and Hussin *et al.* (2008).

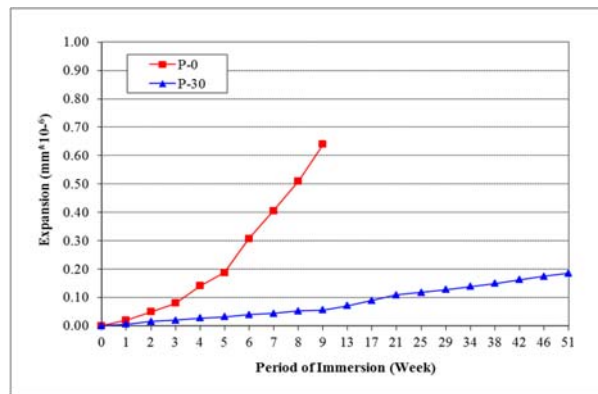


Figure-5. Expansion of concrete mortar bars in 10% Sodium sulphate solution.

Mass Change in Sulphate Environment

The mass changes of concrete cubes throughout the exposure period in Sodium Sulphate solution is illustrated in Figure-6. At the early stage of investigation, mass of both concrete increases. P-0 experience increment of its mass for a longer period as compared to P-30. This probably due to the internal structure of P-0 that is less dense because of the lower amount of total C-S-H gel that is produced solely through hydration process in comparison to P-30. The gypsum and ettringite produced from the reaction between sulphate ion and the abundantly available calcium hydroxide fills in the existing voids resulting in the increment of P-0 mass. On contrary, P-30 is denser due to larger quantity of total C-S-H gel generated from hydration process and pozzolanic reaction. Unlike the control specimen, most of the pores of P-30 have been filled by C-S-H gel causing lesser available voids in the concrete and the remaining hydrated lime is very little. As a result, P-30 only experience mass increment for a shorter period as compared to P-0.

It is apparent, P-0 and P-30 demonstrate different rate of mass loss. P-30 losses its mass very slightly and gradually throughout the experimental work. On the other hand, P-0 exhibit rapid and larger mass loss value than P-30. The margin difference between the mass of those mixes become larger as the immersion period become longer. Presence of higher amount of calcium hydroxide in P-0 leads to active reaction with sulphate ion resulting in bigger weight increment and faster failure of the material than POFA specimens. The formation of more ettringite makes the material expand faster, and also slowly

disintegrate the hardened structure which started with fine cracks at its edges. This followed with detachment of particles from the concrete which result in mass loss. As the immersion become longer, more aggregates were detached from the concrete leading to larger mass loss. At the end of experimental period, the total mass loss of P-0 is almost 13 times larger than P-30. The effectiveness of palm oil fuel ash in mitigating sulphate attack which has been observed through mass changes of cubes in sulphate solution has been reported by Abdul Awal (1998), Hussin *et al.* (2009) and Muthusamy (2009) previously.

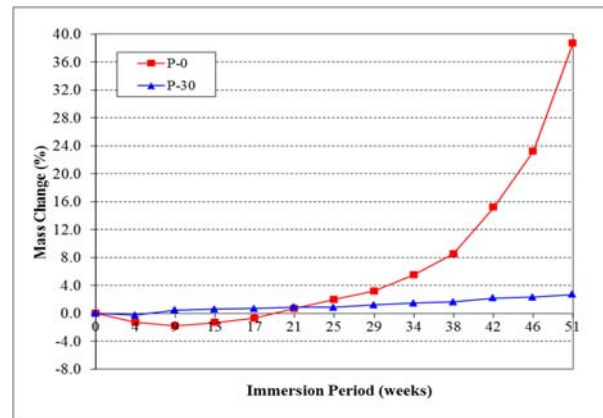


Figure-6. Mass change of concrete cubes immersed in 10% Sodium sulphate solution for 51 weeks.

CONCLUSIONS

Water curing is the most suitable curing for aerated concrete containing palm oil fuel ash to achieve better compressive strength. Occurrence of undisturbed hydration process and pozzolanic reaction leads to formation of larger amount of total C-S-H gel that fills in the internal structure. As a result, aerated concrete containing palm oil fuel ash is denser and capable to sustain larger load as compared to plain concrete. The consumption of calcium hydroxide through pozzolanic reaction reduces amount of portlandite that is vulnerable to sulphate attack. On overall, integration of fine palm oil fuel ash as partial sand replacement increases resistance of concrete towards sulphate attack through densification of microstructure and reduction in the amount of calcium hydroxide content in the concrete. Integrating palm oil fuel ash as partial substitute of sand in aerated concrete production would reduce natural sand consumption and decrease the amount of ash disposed by successfully converting it to be profit making element to the palm oil industry.

REFERENCES

- [1] Abdul Awal A.S.M (1998). A study of strength and durability performances of concrete containing palm oil fuel ash. Doctor Philosophy, Universiti Teknologi Malaysia, Skudai, Malaysia.



- [2] Abdullah, K., Hussin, M.W. and Zakaria, F. (2009). Effect of curing regimes on the properties of lightweight concrete containing palm oil fuel ash. „Proceedings of International Conference on Building Science and Engineering (ICON BSE 2009), pp. 1-10
- [3] Aprianti, E., Shafigh, P., Bahri, S. and Farahani, J.N.(2015). Supplementary cementitious materials origin from agricultural wastes – A review. *Journal of Construction and Building Materials*, 74, pp. 176-187.
- [4] ASTM C618-12a. 2012. Standard specification for fly ash and raw material or calcined natural pozzolan for use as a mineral admixture in Portland cement concrete. Part 5. ASTM Internationals, West Conshohocken, PA.
- [5] ASTM C1012-13. 2013. Standard test method for length change of hydraulic-cement mortars exposed to a Sulfate solution. Internationals, West Conshohocken, PA.
- [6] Asyraf, M. A., Maah, M. J., Yusoff, I., Wajid, A. and Mahmood, K. (2001). Sand mining effects, causes and concerns: A case study from Bestari Jaya, Selangor, Peninsular Malaysia. *Scientific Research and Essays*, 6(6), pp. 1216-1231.
- [7] Bonen, D. and Cohen, M.D. (1992) Magnesium sulfate attack on Portland cement paste: II. Chemical and mineralogical analysis. *Cement and Concrete Research*, 22, pp. 707-718.
- [8] BS EN 12390-3. (2009). Testing hardened concrete. Compressive strength of test specimens. London. BS EN 12390-3.
- [9] Hussin, M.W., Abdullah, K. and, Zakaria, F. (2008). Performances of palm oil fuel ash cement based aerated concrete in acidic and sulphate environments. *Proceedings of the 11th DBMC International Conference on Durability of Building Materials and Components*. pp.
- [10] Hussin, M.W., Ismail, M.A., Budiea, A. and Muthusamy, K. (2009). Durability of high strength concrete containing palm oil fuel ash of different fineness. *Malaysian Journal of Civil Engineering*, 21(2), pp. 180-194.
- [11] Hussin, M.W., Muthusamy, K. and Zakaria, F. (2010). Effect of mixing ingredient towards engineering properties of POFA cement-based aerated concrete. *Journal of Materials in Civil Engineering*, 22(4), pp. 287-295.
- [12] Ismail, Z.Z. and Al-Hashmi, E.A. (2008) Reuse of waste iron as partial replacement of sand in concrete production. *Waste Management*, 28 (11), pp.2048-2053.
- [13] Jaturapitakkul, C., Kiattikomol, K., Tangchirapat, W. and Saeting, T. (2007). Evaluation of the sulfate resistance of concrete containing palm oil fuel ash. *Journal of Construction and Building Materials*, 21, pp.1399-1405.
- [14] Malaysian Standard. (2003). Portland cement (ordinary and rapid-hardening): Part 1. Specification (Second revision). Malaysia. MS 522: Part 1.
- [15] Manap, N. and Voulvoulis, N. (2015). Environmental management for dredging sediments. *Journal of Environmental Management*, 147, pp.338-348.
- [16] Mat Yahaya, F. (2003). Pengaruh abu terbang kelapa sawit terhadap kekuatan mampatan dan ketahananlasakan konkrit berudara. M.S.Thesis. Universiti Teknologi Malaysia, Skudai, Malaysia.
- [17] Mohamed, A .R., Lee, K.T., Noor, N.M. and Zainudin N.F. (2005). Oil palm ash/ $\text{Ca}(\text{OH})_2$ / CaSO_4 absorbent for flue gas desulfurization. *Chemical Engineering and Technology*, 28, pp. 939-945.
- [18] Muthusamy, K., Zulkepli, N.A. and Mat Yahaya, F. (2013). Exploratory study on oil palm shell as partial sand replacement in concrete. *Research Journal of Applied Science, Engineering and Technology*, 5(7), pp. 2372-2375.
- [19] Muthusamy, K. (2009). Properties of palm oil fuel ash cement based aerated concrete. Doctor Philosophy, Universiti Teknologi Malaysia, Skudai, Malaysia.
- [20] Muthusamy, K., Zulkepli, N.A. and Mat Yahaya, F. (2013). Exploratory study on oil palm shell as partial sand replacement in concrete. *Research Journal of Applied Science, Engineering and Technology*, 5(7), pp. 2372-2375.
- [21] Prabhu, G.G., Jung H.H. and Yun, Y.K. (2014). Effects of foundry sand as a fine aggregate in concrete production. *Construction and Building Materials*, 70, pp.514-521.
- [22] Sales, A. and Lima, S.A (2010). Use of Brazilian sugarcane bagasse ash in concrete as sand replacement. *Waste Management*, 30(6), pp.1114-1122.
- [23] Singh, M. and Siddique, R (2013). Effect of coal bottom ash as partial replacement of sand on properties of concrete *Resources, Conservation and Recycling*, 72, pp.20-32



- [24] Sumadi, R. S., Hussin, M. W. and Bonner, D. G. (1996). Strength, pozzolanic reaction and microstructures of hardened mortar pastes containing palm oil fuel ash (POFA). Proceedings of the 3rd Asia-Pacific Conference on Structural Engineering and Construction. Johor Bahru, Malaysia. pp.405 - 416.
- [25] Tan, P. Y and Rohasliney, H. (2013). Status of water quality subject to sand mining in the Kelantan river, Kelantan. Tropical Life Science Research, 24(1), pp. 19-34.
- [26] Tay, J. H. and Show, K. Y. (1995). Use of ash derived From oil palm waste incineration as a cement replacement material. Resources, Conservation and Recycling, 13, pp. 27 - 36.
- [27] Yang, E.I., Kim, M.Y., Park, H.G. and Yi, S.T. (2010). Effect of oyster shell substituted as fine aggregate on concrete characteristic : Part 1 . Fundamental Properties. Cement and Concrete Research, 35(11), pp.2175-2182.