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Sulphate Resistance of Aerated Concrete Containing Palm Oil Fuel Ash as Partial Sand Replacement

Fadzil Mat Yahaya[1], Khairunisa Muthusamy[2], Saffuan Wan Ahmad[3]and Mohd Warid Hussin[4]
[1,2,3]Faculty of Civil Engineering and Earth Resources, Lebuhraya Tun Razak, 26300 Gambang Universiti Malaysia Pahang, Malaysia
[4]Faculty of Civil Engineering, 81310 UTM Skudai, Universiti Teknologi Malaysia, Malaysia

***Abstract*:** *This research investigated sulphate resistance of aerated concrete containing palm oil fuel ash as partial sand replacement. Plain aerated concrete with 100% river sand was used as control specimen. Aerated concrete containing palm oil fuel ash was prepared by integrating 30% of the ground palm oil fuel ash as partial sand replacement. For strength determination, both mixes which cast in form of cubes were subjected to water curing up to 90 days. The compressive strength test was carried out in accordance to BS EN 12390-3 at 7, 28 and 90 days. The sulphate resistance of concretes was investigated by measuring the length change of mortar bars which immersed in 10% Sodium sulphate solution after water cured for 28 days. The measurement of length change was taken on weekly basis following the procedure outlined in ASTM C1012-13. Aerated concrete containing palm oil fuel ash exhibits continuous strength development as curing age become longer. Integration of palm oil fuel ash makes the concrete microstructure to be denser through formation of secondary C-S-H gel. The pozzolanic reaction also reduces amount of calcium hydroxide that can react with sulphate ion to form gypsum and ettringite which cause concrete deterioration. It is concluded that using ground palm oil fuel ash as partial sand replacement assist aerated concrete to exhibit higher compressive strength and better durability to sulphate attack.*

Keywords: *aerated concrete, palm oil fuel ash, sand cement replacement, sulphate resistance, mortar bar expansion*

1. Introduction

Due to flourishing Malaysian palm oil industry, palm oil fuel ash which is a solid waste was generated abundantly and the disposal of this waste needs to be managed by the industry. Mohamed et al. [1] reported that approximately 4 million tonnes of palm oil fuel ash (POFA) were produced every year. This light greyish ash does not have sufficient nutrient to be used as fertilizer, thus it is dumped in the vicinity of the factory or at landfill. Disposing this waste in huge amount has negative impact to the environment and local community living nearby. Winds can easily carry the ash which can cause air pollution and affect the health of people. Recent researcher, Aprianti et al. [2] addressed POFA as a pollutant which ends up in the atmosphere without being used and disturbs the environment. In addition, the continuous generation of palm oil fuel ash is expected to create demands for more landfill or area to be allocated for its disposal which may increase the waste management cost of the industry. The conventional approach applied to dispose this waste is seen to create bigger problem in terms of environmental pollution, health of local community and higher expenditure for waste management by industry. Unless this solid waste is used for production of material in industry, larger quantity of this solid waste is expected to be discarded as environmental polluting waste [3].

In the meantime, the demand for concrete which produced using a large amount of natural resources that is water, aggregate, and sand harvested from the nature is increasing throughout the years globally. Meyer [4] highlighted this construction material which is used worldwide has an enormous impact on environment. As the use of concrete increases, more natural resources were obtained from the environment to cater the need of construction industry. In relation to this issue, excessive use natural sand which is one of the concrete mixing ingredients may cause destruction of habitat for living things thus leading to ecological imbalance. High dependency of the industry on natural sand may result in the depletion of this material in future which finally affects the concrete industry. Approach taken to reduce utilization of natural sand by partially replacing it with other material would prolong the availability of this material for future generation and contribute towards well balanced ecosystem. As such, with the understanding that the best alternative to attain sustainable development of the concrete industry is through use of by-product instead of raw materials in concrete [5], there are researchers [6,7,8] who has attempted to integrate waste material as partial sand replacement in concrete.

In Malaysia, the freely available palm oil fuel ash has initiated Mat Yahaya [9] to incorporate 30% of this solid waste as partial sand replacement in aerated concrete production suitable for non-structural application. The mechanical properties of this aerated concrete containing fine palm oil fuel ash have been studied. However, the durability performance of this concrete upon exposure to sulphate environment yet to be investigated. Thus, this paper presents and discusses the behaviour of aerated concrete produced using palm oil fuel ash as partial sand replacement when subjected to sulphate attack.

2. Experimental Programme

2.1. Materials

A single batch of ordinary Portland cement (OPC) was used as binder throughout the experiments. The sand used was initially oven dried for 24 hours before sieved passing 300μm sieve. Potable water was used for concrete preparation and curing purpose. Aluminium powder was used to produce air voids inside the concrete to make it lower density. Palm oil fuel ash used as partial sand replacement in this research was collected from a local palm oil mill located in Bukit Lawang, Johor. The ash collected is the end product of pressed palm oil fiber and shell which burned in the incinerator shown in Fig. 1. It is then disposed in the vicinity of the mill as illustrated in Fig. 2. The collected ashes were sieved passing 300μm before oven dried for 24 hours. After that, modified Los Angeles Abrasion Machine was used to grind the coarse ash to be finer particle and ready to be used for aerated concrete preparation. 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 C618-12 [10].

Fig. 1: Incinerator producing palm oil fuel ash

Fig. 2: Palm oil fuel ash dumped as waste

TABLE I: Chemical Composition of Palm Oil Fuel Ash

Chemical Composition	%
Silicon dioxide (SiO_2)	82.07
Aluminium oxide (AL_2O_3)	6.04
Ferric oxide (Fe_2O_3)	2.70
Calcium oxide (CaO)	5.11
Magnesium oxide(MgO)	2.28
Sodium oxide (Na_2O)	1.34
Pottasium oxide (K_2O)	2.90
Sulphur oxide (SO_3)	2.20
Loss of ignition (LOI)	5.30

2.2. Mix Proportion

Two types of aerated concrete mixes have been used in experimental work. Plain aerated concrete was produced using 100% river sand and function as control specimen. The second mix, aerated concrete containing palm oil fuel ash was prepared by adding 30% ash as partial sand replacement. The ash was mixed as a weight-for-weight replacement of sand in a constant quantity. Table 2 presents the details of mix proportion used to produce aerated concrete containing palm oil fuel ash.

TABLE II: Mix Proportion of Aerated Concrete Containing Palm Oil Fuel Ash

Details	
Binder Sand Ratio	30 : 70
Ordinary Portland cement (%)	100
Sand (%)	30
Palm oil fuel ash (%)	70
Water dry mix ratio	0.45
Aluminium powder (%)	0.2

2.3. Testing Method

During the casting of aerated concrete specimens, all the dry mixing ingredients were mixed uniformly before finally adding the water. The mixture is mixed uniformly before poured filling 2/3 of cube mould (100 x 100 x 100mm). Then, mixture left to rise like a cake in the oven. After expansion of the concrete mix shown in Fig. 3 ceased to rise and the concrete become hardened, excess of concrete is trimmed. The specimens then covered with wet gunny for 24 hours as illustrated in Fig.4 before demoulded and immersed in water for curing process.

Specimens to be tested for compressive strength were subjected to water curing until testing age. Compressive strength test was conducted in accordance to BS EN 12390 – 3 [11] at the age of 7, 28 and 90 days. Specimens to be used for sulphate resistance test were prepared in form of mortar bars (25 x 25 x 250mm). After water cured for 28 days, the specimens were immersed in 10% Sodium Sulphate solution for duration of 9 weeks. The elongation of mortar bars were measured every week following the procedures outlined in ASTM C1012 - 13 [12].

Fig. 3: Expanded aerated concrete before trimming

Fig. 4: Aerated concrete covered with gunny sack

3. Results and Discussion

3.1. Compressive Strength

Fig. 5 shows the strength of aerated concrete mix containing palm oil fuel ash as partial sand replacement is higher than control specimen throughout curing age. It is interesting to note, in this research aerated concrete containing palm oil fuel ash performs better than plain specimen even at early curing age. There is no reduction in the amount of cement used and this causes the hydration process take place in aerated concrete with POFA as in plain concrete resulting same strength development. Since pozzolanic ash in finely divided form able to chemically react with calcium hydroxide at ordinary temperature to produce compounds possessing cementitious properties [10] inclusion of fine ground ash as partial sand replacement has allowed pozzolanic reaction to occur, when the silica from ash reacted with calcium hydroxide to produce secondary C-S-H gel. Occurrence of both hydration process and pozzolanic reaction in aerated concrete produced using palm oil fuel ash as partial sand replacement manage to reduce the voids in concrete microstructure through formation of extra C-S-H gel making it denser and stronger unlike to plain concrete which the strength just depends on hydration process. In addition, probably incorporation of fine ash has allowed the unreacted ash to fill in the existing voids which reduces the pores in concrete.

Continuous availability of moisture through water curing has provided conducive medium for uninterrupted pozzolanic reaction to take place thus producing aerated concrete containing POFA with denser internal structure enabling it to exhibit better strength performance up to later curing age. The significant role of water curing has been highlighted by Ozer and Ozkul [13] who reported that enough water is essential on the strength development for hydration and pozzolanic reaction to take place. Similarly, previous researchers [14, 15] has reported that concrete containing POFA is sensitive to the curing method applied and it only exhibit better compressive strength as compared to plain concrete upon subjected to continuous water curing. Conclusively, aerated concrete containing palm oil fuel ash as partial sand replacement able to exhibit better strength performance than plain concrete owing to the use of palm oil fuel ash which has been ground to be fine and application of continuous water curing.

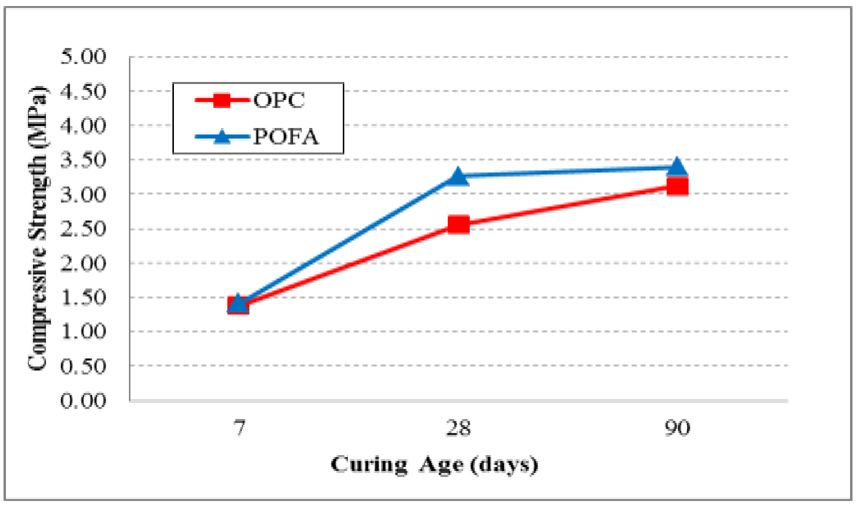

Fig. 5: Compressive strength development of aerated concrete mixes at the age of 7, 28 and 90 days

3.2. Sulphate Resistance

On overall, the result illustrated in Fig. 6 shows that both mortar bars made of plain aerated concrete and aerated concrete containing palm oil fuel ash exhibit expansion as the immersion period in sulphate solution become longer. Comparing the performance of both mixes, concrete produced using ground palm mil fuel ash as partial sand replacement demonstrate lower expansion value throughout the experimental period. The plain concrete specimen exhibit obvious increment in expansion value beginning from the first of week immersion period and so on. As the immersion period become longer, appearances of growing crack were noticed on the specimen until it broke apart at week 10^{th}. The stages in the crack development which begins from the surface of aerated concrete mortar bar and then further deeper into the material is a normal occurrence towards specimen exposed to sulphate. Basically, the present finding is similar with Binici and Aksogan's [16] findings which showed that sulphate attack is a layer by layer chemical reaction starting on the surface and moving inwards. Not only that, visible elongation as well as deformation of OPC specimen in comparison with the ones consisting POFA is also detected, as can be seen in Figures 7. Apparently, all OPC mortar bars suffered greater developing expansion, cracking and fractures on the whole specimen with the longer period of immersion, in contrast with POFA mortar bars. On the other hand, mortar bar produced using aerated concrete mix containing palm oil fuel ash exhibit very slight expansion value since the early days of experimental work and margin difference in the expansion between these two mixes remain big until the end of testing period.

Basically, utilization of ground palm oil fuel ash has transformed calcium hydroxide into secondary C-S-H gel through pozzolanic reaction that contributes towards densification of microstructure resulting in improvement of concrete durability. Most importantly, the lower amount of calcium hydroxide which the sulphate ion can react to form gypsum and ettringite in aerated concrete with palm oil fuel ash has resulted in lesser formation of ettringite that is responsible for expansion. On the other hand, plain concrete is rich with calcium hydroxide from hydration process which promotes generation of larger amount of ettringite leading to significant expansion value and cracks as well. This fact has been confirmed by Rasheeduzzafar et al. [17] who stated that the hardened cement pastes containing greater amount of calcium hydroxide would react more rapidly and to a greater extent with sulphates than those which contain less calcium hydroxide. The significant contribution of POFA towards improving resistibility of sulphate attack of aerated concrete is further verified by findings of Cao et al. [18] who proved that reduction in calcium hydroxide would lessen the effect of gypsum formation and the tendency of ettringite recrystallization. Besides that, occurrence of pozzolanic reaction leads to development of extra C-S-H gel making the internal structure denser in comparison with OPC specimen. The effectiveness of palm oil fuel ash in enhancing the durability of concrete towards sulphate attack has been reported by previous researcher [14, 19, 20]. This finding also support the idea of Santhanam et al. [21] who discovered that integration of mineral admixtures in concrete would increase the resistance of this material against sulphate attack. Conclusively, palm oil fuel ash is suitable to be used as partial sand replacement to produce aerated concrete possessing higher durability towards sulphate attack.

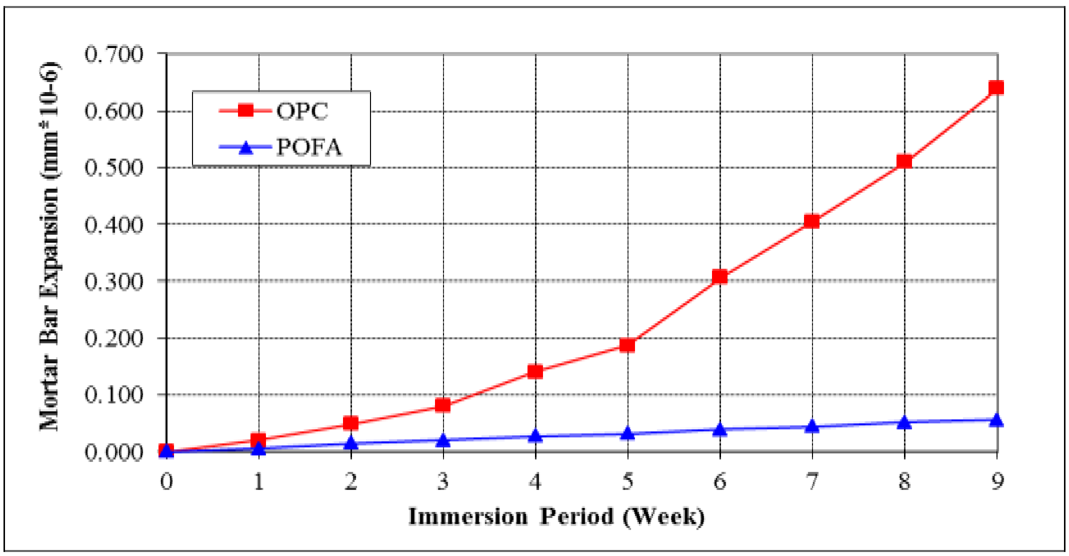

Fig. 6: Expansion of mortar bars when immersed in 10% Sodium Sulphate solution for 9 weeks

Fig. 7: Evident cracks and elongation of plain aerated concrete mortar bar (greyish specimen) in contrast to mortar bar containing palm oil fuel ash (black specimen)

4. Conclusion

Using finely ground palm oil fuel as partial sand replacement assist aerated concrete to exhibit higher compressive strength and better durability to sulphate attack than plain concrete. Application of continuous water curing has promoted better pozzolanic reaction which consumes the by-product of hydration process, calcium hydroxide that can react with sulphate ion to form gypsum and ettringite (an expansive gel) thus causing concrete deterioration. Occurrence of pozzolanic reaction contributes towards formation of secondary C-S-H gel that is responsible towards concrete strength development and better durability.

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