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Evaluation of Sulphate Attack on Concrete Incorporating High Volume Palm Oil Fuel Ash

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***Abstract* - In recent years, the requirement of sustainability has given rise to application of high volume industrial waste in the production of building materials. Fly ash has been found to perform satisfactorily in this regard, and this development is expected to continue in the years ahead because of technological, economical and ecological advantages of the material. This study focuses the potentials of high volume palm oil fuel ash (HVPOFA) replacement of ordinary Portland cement (OPC) and presents experimental results on the effect of sulphate attack. Concrete cube specimens containing 50, 60 and 70% POFA were made alongside with mortar bars made of the same material composition were immersed in 10% magnesium sulphate ($MgSO_4$) solution. Mass and strength loss of concrete cube as well as expansion of mortar bars were studied using wet and drying circle method. The results obtained and observations made were compared with that of 100% OPC specimens. It has been found that the expansion and mass loss significantly decreased with the increase in POFA content, which clearly demonstrates that the replacement of cement with high volume POFA is advantageous particularly in aggressive sulphate environment.**

Keywords : Concrete, high volume, palm oil fuel ash, sulphate attack, weight and strength loss.

1. INTRODUCTION

The pressing need for the preservation of natural resources and reduction of carbon dioxide emission due to the rise of construction industry have fuelled the search for alternative solution to produce environment-friendly construction materials. During the past decades, numerous research works have been carried out on the use of agro waste ashes as supplementary cementing material in concrete construction. The utilization of these waste contributed to reduce the cost and negative impact to the environment [1-3]. Among others, palm oil fuel ash (POFA) is relatively a new member of the ash family, and is obtained on burning palm oil husk and palm oil kernel shells in palm oil mill boilers. Despite its application as a pozzolanic material in concrete, the problem of ash disposal still persists as major portion of the ash remains unused even after its maximum use of up to 30% as cement substitute [4,5]. With the expansion of palm oil plantation in South-East Asian regions, the production of palm oil and the consequent ash generation in the mills are expected to increase posing further problem. Although palm oil fuel ash has been identified to be a good supplementary cementing material research work and published data on sulphate resistance of concrete containing high volume palm oil fuel ash are not many. This paper presents experimental results of evaluation of sulphate attack on concrete incorporating high volume palm oil fuel ash.

2. MATERIALS AND TEST METHOD

2.1 Material

Palm oil fuel ash used in this study was obtained from Kilang sawit PPNJ Kahang of Johor, Malaysia. The ash was collected at the foot of the flue tower where all the fine ashes are trapped while escaping from the burning chamber of the boiler. The ash was sieved through BS standard sieve to remove larger particles as well as reducing the carbon content. Materials passing through 150μm sieve were pulverized using Los Angeles milling machine having 10 stainless bars of 12mm diameter x 800mm length.

Ordinary Portland cement conforming to ASTM C150 [6] was used in the study. A saturated surface dry river sand with fineness modulus of 2.9 passing through 4.75mm ASTM sieve with specific gravity and water absorption of 2.6 and 0.7% respectively was used as fine aggregate. The coarse aggregate was crushed granite of 10mm maximum size with specific gravity of 2.7 and water absorption of 0.5%.

2.2. *Mix Proportion*

The mix proportions of the concrete are shown in Table 1. Ordinary Portland cement (OPC) was replaced by POFA at replacement levels of 50, 60 and 70% by weight. Superplasitizer (SP) of sulfonated naphthalene formaldehyde type conforming to ASTM C 494 [7] was added to concrete mix at 2% by weight of cementicious material to obtain a moderate slump (80-160mm) for the concrete mix.

Table 1. Mix characteristics of OPC and POFA concrete

Materials	OPC	50% POFA	60% POFA
OPC (kg/m^3)	380	190	152
POFA (kg/m^3)	-	190	228
Coarse aggregate(kg/m^3)	1024	1024	1024
Fine aggregate (kg/m^3)	741	741	741
Water (kg/m^3)	171	171	171
Slump (mm)	160	140	110

2.3. Preparation of Specimens and Testing of Concrete

This test was performed to assess the physical characteristics and response of concrete to attack by sulphate solution. Concrete cubes and mortar bars specimen were cast and the assessment for sulphate action was made in terms of length change for mortar bars; while mass change, visual observation and strength deterioration factor were used to assess the concrete cubes.

Specimen for measurement of linear change was prepared in accordance with the procedures outline in ASTM C 1012 [8], using a bar size of 25 mm x 25 mm 250 mm. Mortar was cast in a metal mold in three layers, each layer was compacted using vibrating table. After casting, the surface of the specimen was protected by a plastic sheet against evaporation.

After 28 days of moist curing, the surface of the mortar bar was first made smooth by sand paper and cleaned with acetone. Two gauge studs were fixed on the surface of specimen bars with effective length between the gauge studs of 100 mm. The strain was then measured using comparator meter and this was noted as the reference strain with respect to the subsequent strain readings during immersion.

Similarly, cube specimens were wiped to surface dry condition and weighed with an electronic weighing balance to the nearest gram and this was noted as reference weight with respect to subsequent weight during immersion. Specimens made of 100% Portland cement and those replaced by 50, 60 and 70% POFA were submerged in a solution containing 10% $MgSo_4$ with alternate wet and dry cycle with the aid of JAB SUBMERSIBLE PUMP as shown in Figure 1. The pH of the solution was not controlled; however, the solution was replaced at regular interval of 5-6 weeks.

2.4 *Strength Deterioration Factor*

The deterioration of concrete specimens was investigated by measuring the strength distortion factor expressed in percentage and was measured after 56 weeks of immersion and calculated using equation 1.

$$SDF = \frac{Fcw - Fca}{Fcw} \qquad [1]$$

Where:
SDF = Strength deterioration factor
F_{cw} = The average compressive strength of companion specimen cured in water
F_{ca} = The average compressive strength of the specimen after immersion in sulphate solution.

Fig 1. Specimen in sulphate solution with alternate wet and dry cycle arrangement.

3. RESULTS AND DISCUSSION

3.1. *Physical and Chemical Properties of Palm Oil Fuel Ash*

The chemical composition and physical properties of ordinary Portland cement and palm oil fuel ash (POFA) are presented in Table 2. The POFA contains high amount of silica (SiO_2) of 62.60%, and very small proportions of other chemical compositions. Clearly the presence of higher silica content influences the pozzolanic reaction when it reacts with free lime thus creating extra C-S-H gels, which is beneficial to strength development of the POFA concrete. Specific gravity of Portland cement (3.15) is higher than that of POFA (2.42), which makes it more water demanding than Portland cement. Blaine fineness of POFA (4935 cm^2/g) is also more than that of Portland cement (3990 cm^2/g).

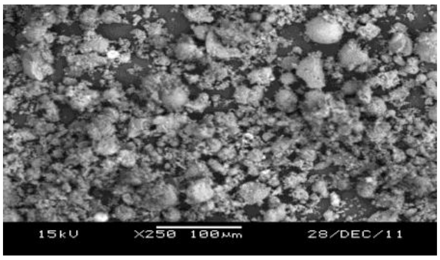
Table 2. Chemical composition of ordinary Portland cement and POFA

Chemical composition (%)	OPC	POFA
SiO_2	20.4	62.6
Al_2O_3	5.2	4.7
Fe_2O_3	4.7	8.1
CaO	62.4	5.7
MgO	1.6	3.5
K_2O	0.005	9.1
Na_2O	0.75	0.8
P_2O_5	0.3	3.9
CL	0.001	0.5
SO_3	2.1	1.2
LOI	2.4	6.3
Physical properties		
Specific gravity	3.15	2.42
Particle retained on 45µm sieve	4.58	4.98
Median particle d_{10}	--	1.69
Median particle d_{50}	--	14.58
Blaine fineness (cm^2/g)	3990	4936
Soundness (mm)	1.0	2.0
Strength Activity Index at 28 day (%)	--	112

The result suggested that POFA can be classified between class C and F based on ASTM 618 [9] recommendation. The SEM micrograph of POFA at magnification of x250 is illustrated in Figure 2. It can be seen that POFA contains round, angular and irregular shaped particles with clustered arrangement and some air space between particles.

Fig 2 .Scanning electron micrograph of POFA

3.2 *Mortar Bar Expansion*



The values of the expansion of mortar bars immersed in 10% magnesium sulphate solution for the period of 56 weeks is presented in Figure 3. From the figure it can be seen that with increase in the duration of immersion in $MgSO_4$ solution, the mortar bar expansion increased. It is clearly evident that mortar bar made with ordinary Portland cement showed considerably higher expansion throughout the period of immersion as compared to the specimen with HVPOFA. It is interesting to note that the expansion progressively decreases with an increase in the POFA replacement. For example, at 56 weeks the expansion attained by bars containing 50, 60 and 70% POFA are 22, 19.2 and 14.2 micro strain. Earlier finding of show that gypsum development during sulphate attack is expansive [10,11], whereas ettringite might develop afterwards, contributing to expansion within the paste matrix. High volume ash application as reduced the presence of $Ca(OH)_2$ would have otherwise influenced the expansion in HVPOFA specimens.

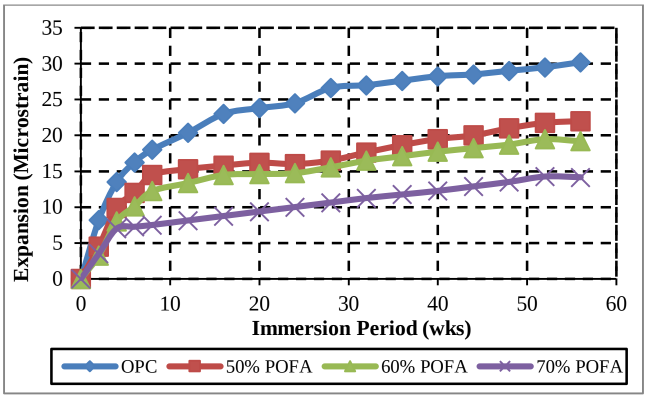


Fig 3. Expansion of mortar bar exposed to magnesium sulphate solution

3.3 Loss Mass

The result of change in mass versus time of exposure of the specimen is illustrated in Figure 4. It can be observed that the entire specimen exhibited the same behaviour (increase in weight). Initially, there was no change in weight of the specimen up the period of 4weeks.

At the period of 6 weeks, OPC, 50 and 60% POFA specimen developed a gradual change in mass. In the same solution, specimen made of 70 % POFA enjoined no change in mass up to the period of 24 weeks. It was also observed that concrete containing 70% POFA suffered less on the effect of changing mass throughout the period of immersion. Application of HVPOFA in concrete is therefore advantageous under sulphate environment due to the discontinuous pore structure of the ash concrete and amount of calcium hydroxide present in the concrete [12].

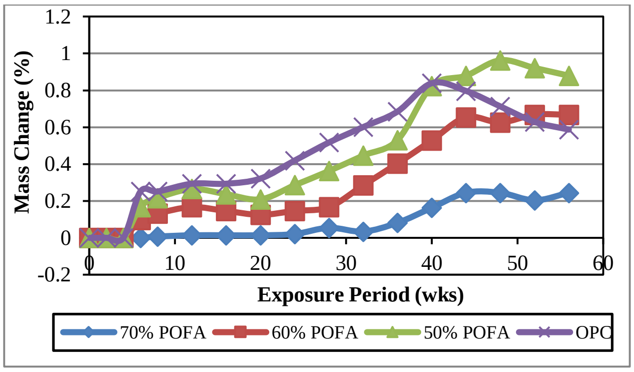


Fig 4. Mass variation of concrete cube specimen exposed to sulphate solution

3.4 Loss of Strength

Comparisons between strength loss of companion specimen and specimen immersed in sulphate solution are illustrated in Figure 5. While the test specimen suffers attack due to sulphate, the companion specimens enjoyed curing in water at room temperature. At the end of 56 weeks the strength of concrete specimens immersed in sulphate solution is compared with that of companion concrete. The difference in the strength between the companion specimen and those immersed in solution is regarded as the strength loss.

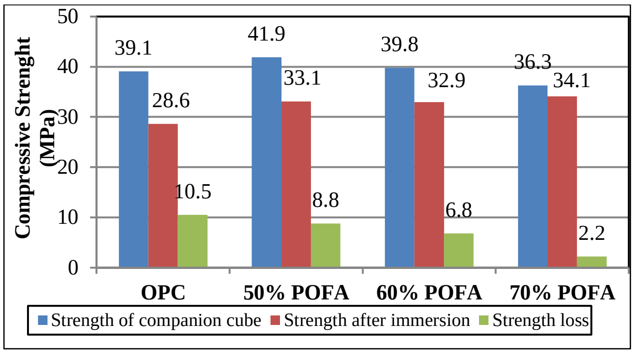


Fig 5: Strength losses between companion and test specimen in magnesium sulphate solution

From the figure, it is apparent that the entire specimen suffered strength loss. The loss was observed to be more in the OPC specimen as compared to those of high HVPOFA. For example a strength loss of 10.5, 8.8, 6.8 and 2.2MPa were observed for OPC, 50, 60 and 70% concrete respectively. The strength loss associated with the entire sample is understood to be the consequence of the prolonged immersion into sulphate solution. Whereas, OPC specimen developed fine cracks on the surface showing the effect of deterioration as explained earlier. Although, an earlier findings shows dissimilarity, where an increase in compressive strength of concrete containing large amount of low calcium fly ash immersed in 5% and10% Na_2SO_4 solution was observed [12,13].

3.5 Strength Deterioration Factor

The compressive strength deterioration of OPC specimen and those of high volume POFA due to sulphate attack was expressed in the form of strength deterioration factor (SDF). Figure 6 shows the SDF after 56 weeks immersion in sulphate. The entire specimens are affected by the sulphate action and generally developed SDF. The values are found to be higher in OPC, while minimal SDFs were observed in POFA specimen under the same condition and decreased with increase in cement replacement with POFA. The reason of SDF feature in the test specimens is similar to those stated earlier in strength loss.

This is to note that considerably higher C_3A content in the control specimen should in theory make it more prone to sulphate attack. High volume POFA thus chemically binds the CH in the form of calcium silicate hydrate making it unavailable for sulphate, gypsum and ettringite, thus reduces the specimen permeability and sulphate ion from penetrating into the concrete. Although

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there are very few test data on the influence of high volume POFA concrete in sulphate solution, the results obtained in this study are however in agreement with the findings of Donatello *et al.*, ; Jiang *et al.*, and Torii *et al.*, [12-14] on high volume fly ash concrete which has successfully been practiced since last decade.

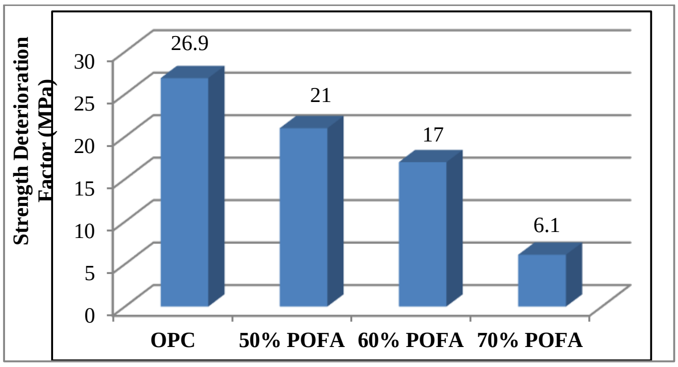

Figure 6: Strength deterioration of OPC and high volume POFA concrete

CONCLUSION

The results obtained and observation made in the study demonstrates that high volume palm oil fuel ash has potentials of reducing the effect of sulphate of concrete. The performance of high volume POFA is influenced by its lower calcium content which is consumed in the pozzolanic reaction, thus making the mixture free of expansive chemical when it come into contact with sulphate. While the control specimen suffers expansion due to high calcium oxide content. That infers that incorporating high volume POFA in concrete will offer credible advantage in performance of concrete in aggressive environment. Longer period of study of behaviour of concrete containing higher amount of palm oil fuel ash, however, has been put forward as recommendation for future investigation.

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REFERENCES

[1] J.J. Brooks, J.G. Cabrera, M. El-Badari, Properties of clay/PFA bricks. In proc. 8th Int. Bricks/Blocks Masonry Conference, Ireland. 1:(1998) 64-75.
[2] R.L. Day, J.W. Bergmen, Fly ash as substitute for clay in brick manufacture. In Proc. 8th Int. Bricks/Blocks Masonry Conference, Ireland. 1:(1998) 14-25.
[3] J.H. Tay, Ash from oil-palm waste as concrete materials. Journal of Materials in Civil Engineering, 2(2) (1990):94-105.
[4] R.S. Salihuddin, Relationship between engineering properties and microstructural characteristics of mortar containing agricultural ash. PhD Thesis. Universiti Teknologi Malaysia, 1993.
[5] A.S.M.A. Awal, K.N.A. Siew, A short-term investigation on high volume palm oil fuel ash (POFA) concrete. In proc. 35th Conference on Our world in Concrete and Structure, Singapore, August 25-27 (2010),185-192.
[6] ASTM, C 150. ASTM C 150 (2004). Stanadard specification for portland cement. *Annual Book of ASTM Standards, American Society for Testing and Materials.*
[7] ASTM C 494 (2005). Standard specification for chemical admixtures for concrete. *Annual Book of ASTM Standards, American Society for Testing and Materials*.
[8] ASTM C 1012 (2003). Standard test method for length change of hydrulic-cement mortars exposed to a sulphate solution. *Annual Book of ASTM Standards, American Society for Testing and Materials.*
[9] ASTM C 618. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture f o r Concrete. Annual Book of ASTM Standards, 2005.
[10] M. Santhanam, M. D. Cohen and J. Olek (2003). Modelling the effect of solution temperature and concentration during sulphate attack on cement mortars. *Cement and Concrete Research*. 32, 585-592
[11] B. Tian and M. D. Cohen (2000). Does gypsum formation during sulphate attack on concrete leads to expansion? *Cement and Concrete Research* 30, 117-123.
[12] Torii, K., Taniguchi, K. and Kawamura, M. (1995). Sulfate resistance of high fly ash content concrete. *Cement and Concrete Research*. 25(4), 759-768.
[13] L. Jiang, Z. Liu and Y. Ye (2004). Durability of concrete incorporating large volumes of low-quality fly ash. *Cement and Concrete Research*. 34(8), 1467-1469.
[14] S., Donatello, A. Palomo and A. Fernández-Jiménez (2013). Durability of very high volume fly ash cement pastes and mortars in aggressive solutions. *Cement and Concrete Composites*. 38(0), 12-20.