Durability of OPS Lightweight Aggregate Concrete Containing Palm Oil Fuel Ash after Long Term Exposure in Sulphate Environment

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Abstract—As one of the world largest palm oil producers, Malaysia continuously generates a large amount of by-product namely oil palm shell (OPS) and palm oil fuel ash (POFA) which disposed as environmentally polluting waste. In order to reduce amount of waste disposed, researchers manage to use these wastes in construction material production leading to development of oil palm shell lightweight aggregate concrete containing palm oil fuel ash as partial cement replacement. The present research was conducted to investigate the sulphate resistance of oil palm shell lightweight aggregate concrete containing finely ground palm oil fuel ash. Two types of mixes of Grade 30 are prepared. Oil palm shell lightweight aggregate concrete (OPS LWAC) is a control specimen and another one containing twenty percent of palm oil fuel ash (POFA) as partial cement replacement. Both mixes were water cured for 28 days before immersed in sodium sulphate solution for a period of 47 weeks. This test was conducted for a long period as demand for long service lives construction in harsh environments increases. The mass of the specimens were measured from time to time in order determine the behavior of the specimens upon sulphate attack. Compressive strength test and microstructure study was also carried out at the end of immersion period. The result shows that oil palm shell lightweight aggregate concrete containing finely ground palm oil fuel ash exhibit lower percentage in mass change and strength deterioration compared to plain specimen. Integration of palm oil fuel ash as partial cement replacement enhances the resistance of oil palm shell lightweight aggregate concrete towards sulphate attack although left in the sulphate environment for a long period. Inclusion of finely ground palm oil fuel ash contributes towards densification of concrete microstructure through formation of secondary C-S-H gel by pozzolanic reaction and filling effect.

Keywords—OPS Lightweight aggregate concrete; palm oil fuel ash; partial cement replacement; sulphate resistance; concrete properties

1. INTRODUCTION

As one of the world largest palm oil producers, annually Malaysian palm oil mills generates abundant palm oil fuel ash (POFA) of about 4 million tonnes [1] and oil palm shell (OPS) 6.89 million tonnes [2] which disposed as wastes. Continuous dumping of these materials would create more need for landfill and environmental problems. Utilizing these wastes in producing construction materials would benefit the palm oil industry through reduction in waste management cost as well as healthier environment. At the same time, the increase in concrete production to cater the construction demand has also poses negative impact to the environment. Increase in the production of also results in the release of colossal carbon dioxide to the atmosphere and more natural aggregates are quarried. The negative impact of cement manufacturing industry to the environment has been well elaborated by Meyer [3]. The environmental problems posed by the industries have led to the development of many types of environmental friendly concretes containing these waste materials as mixing ingredient. Oil palm shell has been used as coarse aggregate to produce lightweight concrete of various grades. Palm oil fuel ash has been discovered to have pozzolanic properties and used as partial cement replacement to produce many types of concrete having enhanced strength and durability. However, both wastes has not been used together in one mix. Recently, these wastes were brought together in a lightweight concrete mix leading to development of oil palm shell lightweight aggregate concrete (OPS LWAC) containing palm oil fuel ash. Muthusamy and Nur Azzimah [4] found that inclusion of 20% POFA as partial cement replacement enhances the concrete strength. The durability performance and behaviour of this concrete when exposed in sulphate environment for a long term need to be looked in detail. Thus, this paper discusses the durability performance of this lightweight concrete containing POFA exposed to sulphate environment in terms of its changes in mass, strength and internal structure.

2. EXPERIMENTAL PROCEDURE

A. Materials

Among the materials used for preparation of concrete specimens were ordinary Portland cement (OPC), sand, oil palm shell, palm oil fuel ash, water, and superplasticizer. Both oil palm shell (OPS) and palm oil fuel ash (POFA) were collected from a palm oil mill factory nearby. Fig. 1 and 2 illustrates the process of collecting oil palm shell and palm oil fuel ash in the vicinity of the mill. The oil palm shell (OPS) was processed to remove foreign particles. The processed palm oil fuel ash (POFA) was ground to be fine fulfilling the requirement in ASTM C618 [5] which enables it to be used as partial cement replacement material. Based on the chemical composition of POFA, this material can be classified as Class C pozzolan in accordance to ASTM C618 [5].

B. Mix Proportioning and Testing Procedure

Two types of mixes have been used in this experimental work. Plain oil palm shell lightweight aggregate concrete containing 100% OPC was act as control specimen (OPS LWAC). Another mix is oil palm shell lightweight aggregate containing 20% POFA as partial cement replacement identified as OPC LWAC with POFA. Details of the mixes are presented in Table 1. Specimens were water cured for 28 days before immersed in 10% sodium sulphate solution for a period of 47 weeks. The durability of the concrete mix was also investigated by observing the physical changes, measure mass change and compressive strength. The compressive strength test is conducted on the specimen at the end of testing period following the procedure in BS-EN 12390 [6].

3. RESULTS

The experimental results presented in Fig. 3 and 4 show the integration of palm oil fuel ash enhances the resistance of OPS LWAC against sulphate attack. At the early stage of experiment, the mass for both types of concrete was increasing. This is due to the formation of ettringite that fills in the pores of the concrete. OPS LWAC experienced larger amount of weight gain as compared to the specimen with POFA. After 20 weeks, the first sign attack appeared as the control OPS LWAC starts to show cracking at the edge and corners. This observation is similar to the research done by Lea and Davey [7] who observed that damage due to sulphate attack usually starting at the edges and corners of the concrete. At this juncture, OPS LWAC with POFA did not show any change in shape and remained structurally intact without visible deterioration. After a few weeks, it is apparent that the degradation of the ordinary specimen became more extensive. Simultaneously, OPS LWAC with POFA started to show early signs of deterioration with fine cracking appearing at the edge of the concrete. It is evident that the expansion and cracking that is greater in plain concrete were attributed to the formation of a larger amount of ettringite as compared to OPS LWAC with POFA.

At the 31st week, the mass of the OPS LWAC started to decrease whilst the OPS LWAC with POFA only began to decrease on the 34th week. This event is essentially due to the concrete cracking resulting from internal pressure created by ettringite that fills in the voids of concrete leaving the aggregate to detach from the concrete. This process reduces the total mass loss of the concrete specimens. It is interesting to note that the mass loss of OPS LWAC with POFA is lower compared to the control specimen throughout the experimental period. The strength deterioration of the control OPS LWAC is 15.6 %, and OPS LWAC with POFA is 10%. Microstructural study also highlight the presence of ettringite in larger amount in control OPS LWAC (Fig. 5) which causes more deterioration as compared to OPS LWAC with POFA (Fig. 6) consisting lower quantity of ettringite.

The inclusion of POFA has caused the $Ca(OH)_2$ from hydration process to be consumed during the pozzolanic reaction, making the concrete denser and more durable. More importantly, the lower amount of $Ca(OH)_2$ available in OPS LWAC with POFA causes the sulphate ion to produce lower quantity of ettringite. This eventually causes a much lower mass increase in the OPS LWAC containing POFA than the plain OPS LWAC. On the other hand, the control specimen that possesses appreciable amount of $Ca(OH)_2$ that transforms into ettringite as a result of sulphate, causing it to exhibit higher weight gain. Ettringite formation results in a volume increase as it requires more space than the original compounds that they replace. This creates internal pressure that causes expansion. Since ettringite causes expansion in cement concrete upon exposure to sulphate solution [8] the larger expansion and cracking resulting more strength deterioration of the control specimen is justified. The superior behavior of concrete which has been added with POFA as partial cement replacement against sulphate was observed in other types of concrete containing this pozzolanic material [9, 10, 11]. Conclusively, this study shows that the integration of POFA as partial cement replacement in OPS LWAC enhances the durability of the concrete towards sulphate attack.

Figure 1: Process of collecting oil palm shell

Figure 2: Collection process of palm oil fuel ash

Table 1: Mix Proportion of the mixes (kg/m^3)

Material	Plain OPS LWAC	OPS LWAC with POFA
Cement	500	400
POFA	0	100
OPS	360	360
Water	225	225
Superplasticizer	5	5

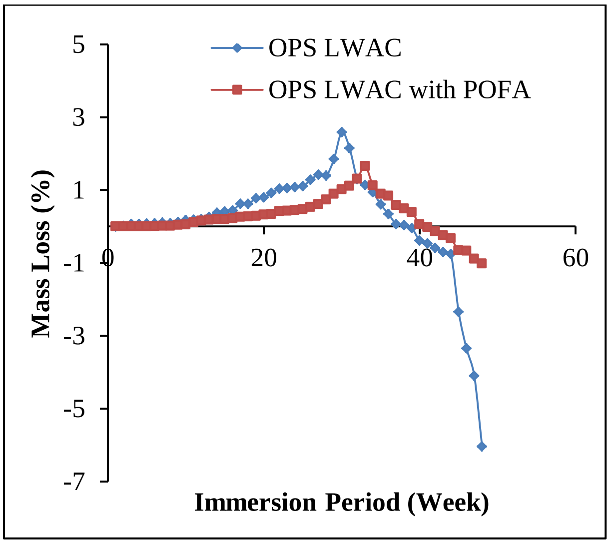

Figure 3: Mass change of concrete

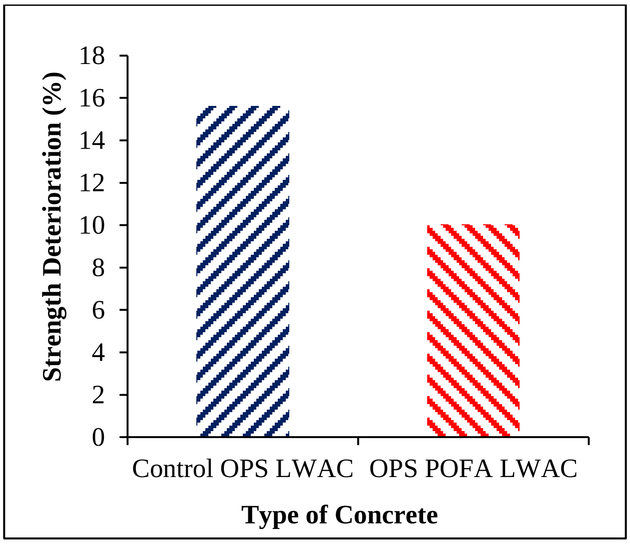

Figure 4: Strength deterioration of concrete

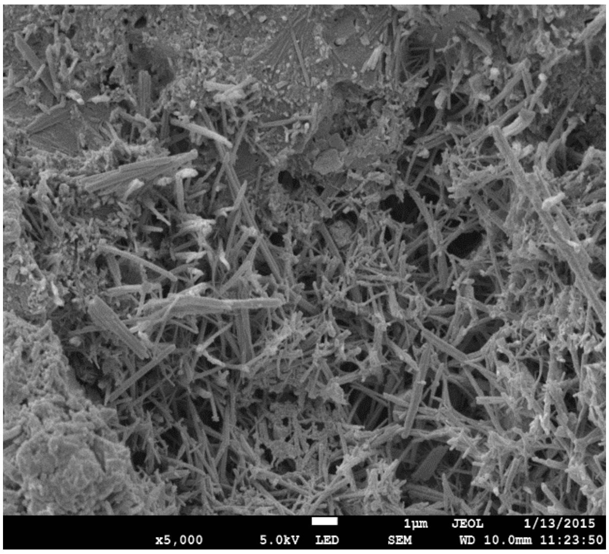

Figure 5: Microstructure of OPS LWAC

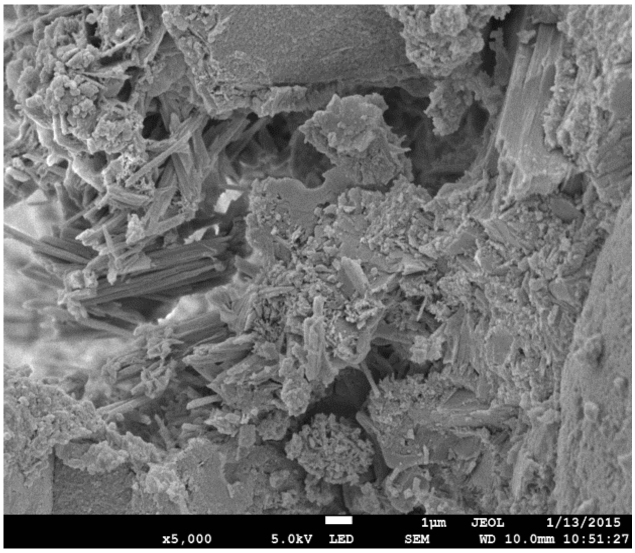

Figure 6: Microstructure of OPS LWAC with POFA

4. CONCLUSION

Integration of palm oil fuel ash as partial cement replacement enhances OPS LWAC durability through consumption of the vulnerable $Ca(OH)_2$ and densification of concrete microstructure. Incorporation of palm oil fuel ash in concrete production would reduce numbers of dumping site needed for palm oil waste disposal and also reduce the cost spent by industry for their waste management. On top of that, the high dependency of lightweight concrete production industry for cement supply could be reduced.

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