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Research Article

Short Term Investigation on Sulphate Resistance of Oil Palm Shell Lightweight Aggregate Concrete Containing Palm Oil Fuel Ash as Partial Cement Replacement

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Abstract: This research aims to produce an environmental friendly oil palm shell lightweight aggregate concrete containing palm oil fuel ash of good strength and durability against sulphate attack which is suitable to be applied in construction industry. This study discusses the performance of oil palm shell lightweight aggregate concrete containing palm oil fuel ash as partial cement replacement in sulphate environment. Concrete cubes produced using ranges of palm oil fuel ash from 0 to 40% were water cured for 28 days before tested for determination of compressive strength. The compressive strength test was conducted in accordance to BS EN 12390:3. Sulphate resistance test was conducted on plain specimen and mix containing 20% POFA which strength performance is the best. Both specimens were immersed in sodium sulphate solution for 45 weeks. The results indicate integration of suitable percentage of palm oil fuel ash enhances the compressive strength and sulphate resistance of oil palm shell lightweight aggregate concrete. Inclusion of this ash consumes calcium hydroxide through pozzolanic reaction generating secondary calcium silicate hydrate gel thus assisting the concrete to be denser, stronger and more resistance to sulphate attack compared to plain specimen.

Keywords: Lightweight aggregate concrete, oil palm shell, palm oil fuel ash, partial cement replacement, sulphate resistance

INTRODUCTION

Malaysia being one of the largest palm oil producers in the globe has been generating abundant by-products known as Oil Palm Shell (OPS) and Palm Oil Fuel Ash (POFA). These solid wastes were thrown at the dumping site thus causes environmental pollution. The oil palm shells which left to rot at the dumping site create environmental pollution (Teo *et al*., 2006) and it takes long time to biodegrade. Palm oil fuel ash also pollutes the environment since its ends-up in the atmosphere (Aprianti *et al*., 2015) owing to its light ash which is easy to be carried by the wind. Unless this waste is used in material production industries, larger volume of ash is predicted to be disposed (Hussin *et al*., 2010). Continuous dumping of oil palm shell and palm oil fuel ash would have greater negative impacts to the environment and community in future.

Annually, around 6.89 million tonnes of Oil Palm Shell (OPS) (Chong *et al*., 2013) and 2.6 million tonnes of Palm Oil Fuel Ash (POFA) were produced (MPOB, 2010). Looking at these scenarios, dumping of these wastes is not suitable approach to be applied for long term waste management plan as more sites would be needed for disposing this waste which would hike the cost of waste handling. Integrating waste in production of construction material is one of the ways to reduce amount of these by-products ending at dump site which indirectly saves the waste management expenditure of industry. Realizing it, Muthusamy and Zamri (2014) produced a greener oil palm shell lightweight aggregate concrete containing palm oil fuel ash as partial cement replacement. Using suitable amount of palm oil fuel ash as mixing ingredient reduces amount of cement which contributes to green house gases and most importantly increases the strength of this lightweight aggregate concrete. However, the effect of palm oil fuel ash content on the sulphate resistance of oil palm shell lightweight aggregate concrete remains unknown.

Therefore, this study discusses the performance of oil palm shell lightweight aggregate concrete containing palm oil fuel ash when exposed to sulphate environment for a short term period of study. The experimental work was conducted at laboratory of Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang. The discussion in this paper elaborated the behavior of oil palm shell lightweight aggregate concrete containing palm oil fuel upon exposure to sulphate environment.

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METHODOLOGY

Ordinary Portland Cement (OPC), local river sand, supplied tap water, oil palm shell, palm oil fuel ash and superplasticizer are among the materials used to produce the specimen in this experimental work. Supply of Oil Palm Shell (OPS) and Palm Oil Fuel Ash (POFA) were obtained from a local palm oil mill in the state of Pahang, West Malaysia. At the laboratory, both materials were processed to ensure it is free from debris. Palm oil fuel ashes were ground using Los Angeles abrasion machine to increase its fineness. Figure 1 illustrates the original palm oil fuel ash obtained from the factory before sieved and grind to fine ash as shown in Fig. 2. Ground palm oil fuel ash used in this experimental work is classified as pozzolanic material Class C in accordance to ASTM C 618-05 (2005). The chemical composition of both OPC and POFA is tabulated in Table 1.

In this experimental work, two types of oil palm shell lightweight aggregate concrete mixes were used. Through trial mix method, the reference mix of Grade 30 were produced by using 100% ordinary Portland cement as sole binder. Another set of mix contains various percentage of palm oil fuel ash as partial cement substitute beginning from 10, 20, 30 and 40%, respectively. The mixes were prepared in form of cubes (100×100×100 mm) and water cured for 28 days. The compressive strength test was conducted at 28 days by following the procedure in BS EN 12390-3 (2009). This short term investigation on sulphate resistance test was conducted by immersing the specimens in sodium sulphate solution up to 45 weeks. Then the durability of the specimens towards sulphate attack is evaluated by the measuring the mass change. Similarly, previous researcher Al-Akhras (2006) measured the mass of cubes after placed in sulphate environment to determine the degree of sulphate attack.

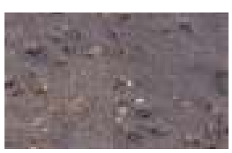

Fig. 1: Original palm oil fuel ash at the mill

Fig. 2: Finely ground palm oil fuel ash

Table 1: Chemical composition of Ordinary Portland Cement (OPC) and Palm Oil Fuel Ash (POFA)

Chemical composition	OPC	POFA
Silicon dioxide (SiO_2)	16.05	51.55
Aluminium oxide (AL_2O_3)	3.41	4.64
Ferric oxide (Fe_2O_3)	3.41	8.64
Calcium oxide (CaO)	62.28	5.91
Magnesium oxide (MgO)	0.56	2.44
Sodium oxide (Na_2O)	0.06	0.07
Pottasium oxide (K_2O)	0.82	5.50
Sulphur oxide (SO_3)	4.10	0.61
Loss of Ignition (LOI)	1.20	5.00

RESULTS AND DISCUSSION

Compressive strength: As can be observed in Fig. 3, only right formulation of concrete mix with appropriate content of palm oil fuel ash would serve to enhance the strength properties of oil palm shell lightweight aggregate concrete. The presence of the pozzolanic ash promotes pozzolanic reaction which increases the amount of secondary C-S-H gel contributing towards densification of concrete internal structure leading to strength enhancement. Realizing that calcium silicate hydrate is a major strength-providing reaction product of cement hydration, which also act as a porosity reducer resulting in a dense microstructure in concrete (Safiuddin *et al*., 2007), it justified that larger amount of C-S-H products would contribute to higher strength achievement as can be observed in specimen produced using 20% of palm oil fuel ash which outshines all the mixes. However, inclusion high amount of palm oil fuel ash 40 and 50% have adverse effect on the strength of concrete which is in line with findings of Massazza (1993). The lower content of calcium oxide in the ash produces lower amount C-S-H gel and calcium hydroxide during hydration process. Then, the free hydrated lime is also not sufficient for complete pozzolanic reaction to take place and finally, the total amount of C-S-H gel ends up to be lower compared to the mix containing lesser amount of pozzolanic ash. Generally, adding palm oil fuel ash up to 20% as partial cement replacement contributes to the strength development of concrete. The contribution of palm oil fuel ash in enhancing the sulphate resistance of concrete has also been reported by previous researchers Abdul Awal (1998) and Hussin *et al*. (2008, 2009).

Sulphate resistance: The total mass change of the specimens after immersed in sulphate solution is displayed in Fig. 4. Generally, use of palm oil fuel ash as partial cement replacement influence the sulphate resistance of oil palm shell lightweight aggregate concrete which manifested through variation in the total

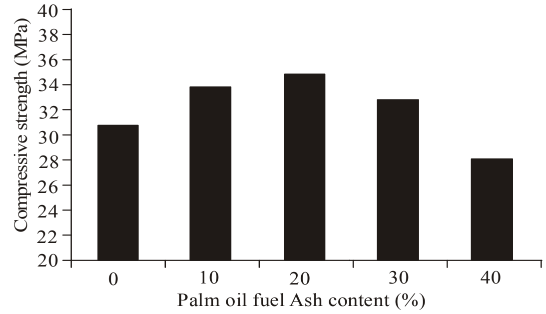

Fig. 3: Compressive strength of oil palm shell lightweight aggregate containing various palm oil fuel ash content at 28 days

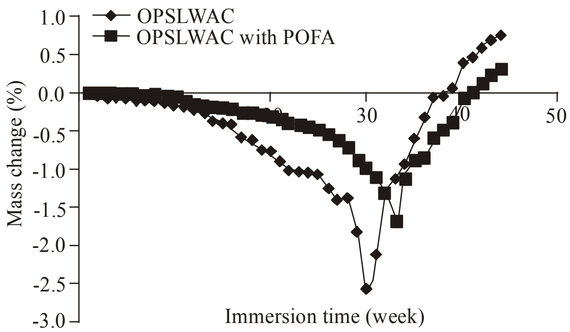

Fig. 4: Mass change of oil palm shell lightweight aggregate specimens after immersed in sodium sulphate solution for 45 weeks

mass change. At the early stage of experiment, mass for both types of concrete increases. The increment in the mass of the concrete is a result of ettringite formation which fills in the pores of concrete. Previous researcher, Ho (2003) has highlighted that ettringite formation results in the increase of concrete volume. Plain specimen demonstrated larger mass gain in contrast to the one containing POFA. This is because control specimen produced using 100% has higher amount of calcium hydroxide, a by-product of hydration process. The absence of pozzolanic material left the hydrated lime remains in the concrete internal structure. When exposed to sulphate environment, the abundantly available free hydrated lime in plain specimens allows the sulphate ion to react and transform it into ettringite filling in the pores of concrete, thus increasing the concrete mass.

On the other hand, the inclusion of palm oil fuel ash in oil palm shell lightweight aggregate concrete leads to pozzolanic reaction which consume the calcium hydroxide, thus leading to lower quantity of ettringite which in turn lower the value of mass increment. At the 31st week, the mass for control specimen started to decrease while specimen with POFA experience reduction in the mass few weeks later. The mass loss is due to the concrete cracking resulting from internal pressure created by ettringite that fills in the voids of concrete leaving the aggregate detached from the concrete. This process reduces the total mass loss of the concrete specimens. In the case of control specimen, the availability of calcium hydroxide in larger amount causes the sulphate ion react to form plenty of ettringite resulting this plain concrete to experience mass loss earlier and larger value in comparison to specimen produced using POFA. Conclusively, inclusion of palm oil fuel ash as partial cement replacement successfully increases the durability of oil palm shell lightweight aggregate concrete towards sulphate attack.

CONCLUSION

This investigation reveals that inclusion of palm oil fuel ash which is up to 20% as partial cement replacement increases the compressive strength and sulphate resistance of oil palm shell lightweight aggregate concrete production. Integration of palm oil fuel ash in oil palm shell lightweight aggregate concrete production is hoped to successfully reduces consumption of cement, asisst palm oil industry to be more environmental friendly and most importantly able to be an alternative construction material to the local construction industry.

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