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Fire Resistance Properties of Palm Oil Fuel Ash Cement Based Aerated Concrete

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Abstract

POFA cement based aerated concrete, an agro based lightweight concrete containing palm oil fuel ash (POFA) as partial cement substitute; possess adequate strength suitable for non load-bearing element application. This paper discusses fire resistance properties of this material in the aspect of its combustibility, contribution towards fire and its tendency to spread flame over its surface that has been investigated in accordance to BS 476 : Part 4, Part 6. and Part 7 respectively. The findings indicate that the integration of POFA does not affect this agro based material to exhibit good fire resistance.

Keywords: palm oil fuel ash; partial cement replacement; aerated concrete; durability; fire resistance test.

1. Introduction

Palm oil fuel ash (POFA), an abundantly generated profitless by-product of palm oil industry [1] has initiated the ideas to incorporate this pozzolanic ash [2] in concrete production since last century. Beginning from the creation of POFA concrete [3], the recent years has witnessed several discoveries on the function ability of POFA to enhance the properties of other types of concrete such as high strength concrete [4,5] and lightweight concrete [6]. This agro waste which is classified as Class F pozzolanic ash [7, 8, 9] when integrated as one of the mixing ingredient in concrete at suitable amount able to enhance the performance of the concrete in terms of strength and durability.

In Malaysia, the amount of POFA disposed at landfill is expected to increase since Basiron and Simeh [10] has highlighted that this country which is that largest palm oil producer in the world is predicted to maintain it lead position over the next one and half decade. Therefore, continuous efforts has been taken to incorporate this waste in concrete making to assist the palm oil industry to cutting down the quantity of this hazardous waste thrown which in turn able to lessen the environmental pollution as well as reducing the landfill area required. To date, the latest finding

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reveals that certain amount of ash can be integrated in aerated concrete making thus improving its strength and durability properties compared to plain one.

Hussin *et al.* [11] reported that this new modified lightweight concrete containing 20% POFA which is known as POFA cement based aerated concrete possess the strength that fulfill the requirement in ASTM 129-85 (1990) enabling it able to be used for non load-bearing application. Other than better strength performance, integration of POFA also improves the durability of this lightweight concrete upon exposure to aggressive environment [12]. However, the application of this material for building construction would be more convincing if the behaviour of POFA aerated concrete upon exposure to fire is known. Therefore, the work presented herein focuses on the fire resistance properties of aerated concrete containing POFA.

2. Methodology

2.1 Materials

Materials used in this study consisted of Portland cement type I, ground POFA, fine aggregate, aluminium powder, superplasticizer and water. Originally POFA, a by product obtained from combustion of palm oil fibres and shells in the palm oil mill boiler was collected from palm oil mill located in southern Malaysia. This ash was processed before it is used whereby firstly it was sieved to remove foreign particles before subjected to grinding process. The fine aggregate was river sand obtained from Sungai Sayong, Malaysia which then sieved passing 600µm. Superplasticizer of type F high range water reducer was employed in all mixtures.

2.2 Mix Proportions

The mix proportion used to produce POFA aerated concrete specimens consist of 50 : 50 for cement and fine sand with constant amount of 0.30% aluminium powder by weight of total dry mix and 0.75% superplasticizer by weight of total cementitious material. Table 1 illustrates the detail of the POFA cement based aerated concrete mix having 20% palm oil fuel ash. All specimens were produced by adding required sand, cement, POFA, water, aluminium powder, and superplasticizer and then cast in various shapes in accordance to standards. All freshly cast specimens were left in the formwork for 24 hours before demolded and then subjected to water curing for 28 days. Commonly used symbol annotations for flow field variables should be followed (i.e. ρ : density, μ : viscosity, κ : turbulence kinetic energy…etc).

TABLE 1 : MIX PROPORTION OF POFA CEMENT BASED AERATED CONCRETE

Sand : Binder Ratio	50:50
Ordinary Portland cement (%)	80
POFA Replacement (%)	20
Sand Fineness (µm)	Passing 600
Water Dry Mix Ratio	0.24
Aluminium Powder (%)	0.30
Superplasticizer (%)	0.75

2.3 Test Methods

The combustibility of the POFA cement based aerated concrete is studied by testing a set of six specimens of (40 x 40 x 50 mm) using the equipment shown in Figure 1, following the procedures stated in BS 476 : Part 4 [14]. During the testing, the specimens are inserted into a vertical cylindrical furnace set at a temperature of 750°C and recordings are made to detect the extent of combustion. The parameters namely temperature rise within the furnace and

temperature rise in the core of the material are among the features observed throughout the testing period.

Figure 1 : Equipments used for non-combustibility test

As for studying the ability of agro cement based aerated concrete to spread fire, six specimens (885 x 270 x 25 mm) has been tested in accordance to BS 476 : Part 7 [15]. This test is intended to measure the lateral spread of flame along the surface of a specimen made of POFA aerated concrete orientated in the vertical position as shown in Figure 2. The classification system is based on the rate and extent of flame spread, whereby the material is graded from Class 1 (best) to Class 4 (worst) based on the criteria stated in Table 3.2 as per Clause 10.1 in BS 476 : Part 7 [15].

Figure 2: Surface spread of flame test is in progress

The performance of a POFA cement based aerated concrete in the early stages of fire is also studied by conducting the test in accordance to BS 476 : Part 6 [16]. During this test, the rate of heat release during combustion of the specimens (225 x 225 x 25 mm) is measured. The test result obtained is expressed in the form of Fire Propagation Index that would be able to provide a comparative measure of the contribution of aerated concrete mix with POFA to the growth of fire.

3. Results and Discussion

3.1 Properties of POFA

The grinding process reduces the particle size of coarse ash from large and spherical shape to fine and crushed shaped particles as can be seen in Figures 3 and 4 respectively. Most importantly, the amount retained on sieve No.324 during wet sieve test was changed from 98.5 to 1.5% thus fulfilling the requirement in ASTM C618-05a [13] allowing it to be used as partial cement replacement. Basically, the grinding of ash successfully produces finer particles of POFA which can take active role in pozzolanic reaction than the original one.

Based on the chemical composition of POFA that is tabulated in Table 2, this agro waste can be classified as Class F pozzolana in accordance to ASTM C618-05 [13]. This material which contains lower lime content as compared to OPC causes it could not be used as a partial cement replacement in a large amount. The lower content of calcium oxide tend to hinder the hydration process thus would give negative impact towards early strength development of concrete.

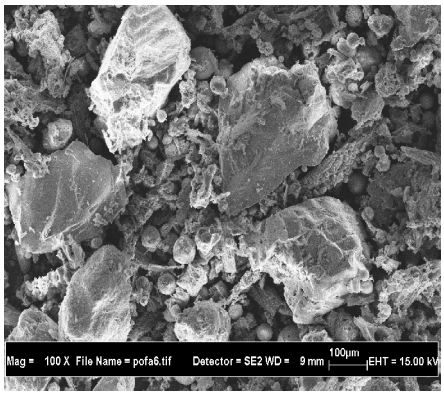

Figure 3 : Unground POFA at the magnification of 500x at the age of 28 days

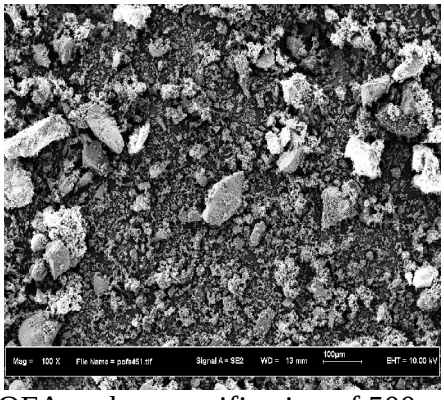

Figure 4 : Ground POFA at the magnification of 500x at the age of 28 days

TABLE 2 : CHEMICAL COMPOSITION OF OPC AND PALM OIL FUEL ASH

Chemical Constituents	OPC (%)	POFA (%)
Silicon Dioxide (SiO_2)	20.1	55.20
Aluminium Oxide (AL_2O_3)	4.9	4.48
Ferric Oxide (Fe_2O_3)	2.5	5.44
Calcium Oxide (CaO)	65	4.12
Magnesium Oxide (MgO)	3.1	2.25
Sodium Oxide (Na_2O)	0.2	0.1
Potassium Oxide (K_2O)	0.4	2.28
Sulphur Oxide (SO_3)	2.3	2.25
Loss On Ignition (LOI)	2.4	13.86

3.2 Fire Resistance Tests

Evaluation on the behaviour of a material when exposed to fire is significant from the life-safety point of view. The fire resistance test that has been conducted reveals that this agro based aerated concrete able to perform excellently in every test that has been conducted. Although the material tested shows changes in colour from black to grayish but this material still able to

exhibit good fire resistance. Not only that, it was discovered that inclusion POFA does not make the product to be combustible material or helps the spreading of fire. This present finding seems to be consistent with research conducted by Sabir [17] and Morsy [18] whom highlighted that the replacement of Ordinary Portland cement by pozzolanic material improves fire resistance properties.

3.3 Non Combustibility Test

The non-combustibility of a material is determined in order to ascertain whether it will contribute directly to fire development. The details of the test data that have been presented in Table 3 shows that this material can be classed as non-combustible product. The data indicates that the maximum temperature rise at the center of each specimen is influenced by density of the specimen whereby the temperature becomes lower as the density increases. However, the temperature difference between the maximum furnace temperature and stabilized temperated for all specimens is not more than 50 degrees. The ability of specimen meeting the requirements mentioned in Clause 8 in BS 476 : Part 4 [14] whereby the temperature rise in two thermocouples does not exceed 50 degrees and also no flame that continues to exist inside the furnace for more than 10 seconds has enable this material to be classified as non-combustible construction material.

TABLE 3 : RESULTS ON COMBUSTIBILITY TEST FOR POFA CEMENT BASED AERATED CONCRETE

Parameters	Test Results					
Specimen No.	1		2		3	
Temp. Measuremnt	CH 1	CH 2	CH 1	CH 2	CH 1	CH 2
Max.Furnace Temp., °C	770	760	793	775	763	780
Stabilized Temp. °C	750		750		750	
Temp. Difference,°C	20	10	43	25	13	30

3.4 Fire Propagation Test

This test is conducted to determine the fire propagation index, whereby it is one of the data that need to be acquired in order to classify the group of this material in accordance to Clause 204 in Uniform Building By-Law [19]. During the test, all the specimens successfully appear to be valid material that can be used to obtain data of fire propagation index. This is because the POFA aerated concrete specimens does not face any damage during testing in terms deformation, spalling, melting, falling or slumping of the materials whereby it fulfills the requirement stated in Clause 9.2 in BS 476 : Part 6 : [16].

The result presented in Figure 5 shows the rise of temperature during the testing of POFA specimen does not exceed the calibration curve. The average fire propagation Index for POFA cement based aerated concrete is 0.5 after the subindex i_1 is 0.5, subindex i_2 is 0 and subindex i_3 is 0.0. Basically, this material fulfilled one of the requirement in Clause 204A(b) in Uniform Building By-Law [19] which requires the average index of performance not exceeding 12 and a subindex (i) not exceeding 6 in order to be classed as Class 0. Conclusively, the very small propagation index of POFA aerated concrete specimen shows this material has a very low influence towards increasing the speed of the fire growth as been stated in BS 476:Part 6 [16].

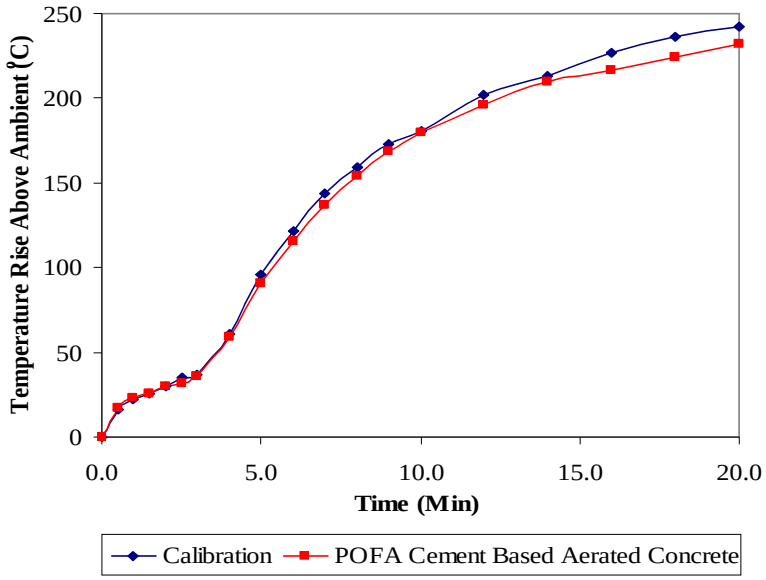

Figure 5 : Time – temperature curves for POFA cement based aerated concrete and calibration run obtained during the fire propagation test

3.4 Surface Spread Flame Test

During the experimental work, no melting, softening and disintegration were detected on the POFA aerated concrete specimens. This behavior of the specimen which does not face damages complies with the requirement stated in Clause 8.2.3 in BS 476: Part 7: 1997 in order to make it valid to be used for the measurement of flame spread. The most significant finding was that there is no spread of flame at all throughout the testing period as can be seen from the result presented in Table 4.

TABLE 4 : RESULTS ON SURFACE SPREAD OF FLAME TEST FOR POFA AERATED CONCRETE

Six Specimens	Average Result
Spread of flame at 1½ min (mm)	0
Distance (mm)	Time of spread of flame to indicated distance (min.s)
75	0
165	0
190	0
215	0
240	0
265	0
290	0
375	0
455	0
500	0
525	0
600	0
675	0
710	0
750	0
785	0
825	0
865	0
Time of maximum spread of flame (min.s)	0
Distance of maximum spread of flame (mm)	0

By referring to Table 2 mentioned in Clauses 10.1 in BS 476 : Part 7 : 1997 which listed the requirement to be fulfilled in order to be grouped in Class 1, 2, 3 or 4, this material falls in the highest class which is Class 1 product because the spread of flame that occurs are not more the 165 mm. In addition to that, as stated in Uniform Building By-Laws [19], this material can be used in all buildings since it possesses a very low ability to spread flame. A possible explanation for the excellent performance of these specimens is due to the character of the mixing constituent used to produce aerated concrete such as cement, POFA and fine sand are not combustible material. Generally, it can be summarized that integration of POFA does not affect aerated concrete to perform excellently in terms of fire resistance.

4. Conclusion

On overall, the studies indicate that this material can be classified as non combustible material and also has a very low ability to influence the growth of fire. In general, this material fulfills the requirement highlighted in Clause 204 in Uniform Building By-Law (1984) in order to be used for the construction of wall. The characteristic of this product which is non combustible and has fire propagation index of 0.5 with a subindex (i) which is 0.5 fulfills the condition stated in Clause 204A in Building By-Law (1984) leads it to be classed as Class 0 (Surface of no flame spread), regarded as the best class of the available Class 1, 2, 3 and 4. Conclusively, although this material has been declared to have good fire resistance ability and can be used for the application in the wall construction, another fire resistance test need to be conducted on an actual wall constructed in future studies.

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