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Effect of Waste Materials in Lightweight Concrete

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ABSTRACT

The experimental study evaluated performance of lightweight aerated concrete which incorporated various percentages of palm oil fuel ash (POFA) and pulverized fuel ash (PFA) as partial cement replacement and sand was replaced with bottom ash. Performance evaluation of the aerated concrete was done in terms of ultimate compressive strength, density and strength development. Twelve mixes were developed and tested at ages 7 and 28 days. In this experiment, two different curing regimes namely air curing and water curing were applied to monitor their effects. The results showed that the mixes produced by replacing cement with POFA and PFA could be compared with the mix without cement replacement. Furthermore, this study demonstrated that the cement-POFA-PFA based lightweight aerated concrete could be produced as lightweight non-load bearing concrete units, because hazard of ashes (POFA, PFA and bottom ash) might be a serious issue for human health. Disposal of ashes contributes to shortage of landfill space all over the world, especially in Malaysia.

INTRODUCTION

One of the concretes that is becoming famous among the contractors and has been used in many civil engineering applications as a very useful replacement for conventional concrete due to its lightness is aerated concrete that falls in the category of lightweight concrete (Cavaleri *et al.*, 2003; Memon *et al.*, 2006). Originating from Sweden, aerated concrete had quickly spread to different parts of the world after the end of the Second World War (Bave, 1983) and is continuously subjected to research to modify this existing material to meet the demands of the construction industry.

The most important components of concrete production is cement. But cement manufacturing is at an excessive environmental cost. According to Falade *et al*, and Mehta (Falade *et al.*, 2013; Mehta, 1999), cement manufacturing is the largest producer of carbon dioxide (CO2) accounting for over 50% percent of all industrial CO2 emissions. Also very large amount of natural resources which are not renewable are required in the production of cement. This bothers on consumption and depletion of non-renewable resources which raises a serious environmental concern as the usage of cement continues unabated (Falade, *et al.*, 2013). On the other hand, industrial and agricultural wastes are also becoming a health and environmental problem especially in the developing nations where technology for efficient waste disposal is lacking.

Recent discovery that these wastes can be processed and later used as a partial replacement of cement in the production of concrete is not only helping to cleanse the environment but also gradually reducing the volume of cement being consumed (Mehta, 2001; Moriconi, 2007). According to Ecosmart (ecosmart concrete, 2012), about 30% of cement used globally is needed to be replaced with supplementing cementitious materials to achieve, a zero percent increase in CO_2 emission from cement manufacturing.

Some of the researcher studied on aerated concrete incorporation of blended cement originating from industrial and agriculture by-product (Arreshvhina, 2002; Hauser *et al.*, 1999; Holt and Raivio, 2005; Hussin *et al.*, 2010; Khairunisa, 2009; Memon, *et al.*, 2006; Narayanan and Ramamurthy, 2000a).These industrial and agriculture by-product (silica fume, blast furnace slag and POFA and PFA) can also improve concrete durability. Comprehensive studies have been carried out on use of POFA, PFA, blast furnace slag, rice husk ash, etc. as cement replacement materials in concrete (Abdul Awal, 1998; Hossain *et al.*, 2011; Khairunisa, 2009; Noor Ahmed, 2007; Sumadi, 1993).The abundantly produced industrial by-product ending as waste that causes considerable pollution toward the environment and the diminishing level of a healthy surrounding is among the reasons that stirred the awareness of scientists to make use of this type of item for innovating products that can be used in building projects. Application of lightweight concrete in structures reduces overall self-weight, resulting in reduction of the foundation size; thus, cost and other specifications are reduced as well (Memon, *et*

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al., 2006; Paryati, 2013). Lightweight aerated concrete can be used in constructions on soil with lower load-bearing capacity (Memon, *et al*., 2006). Reduced self-weight of the structures in which lightweight concrete is used reduces risk of earthquake damage because earthquake forces that influence civil engineering structures and buildings are proportional to the mass of structures and buildings. Therefore, reducing mass of a structure or building is the most important issue for reducing their risk due to earthquake acceleration (Hossain, *et al*., 2011).

Aerated concrete of wide range of densities (300-1800 kg/m3) can be produced depending upon method of production (Benazzouk *et al*., 2006; Narayanan and Ramamurthy, 2000b). Density of concrete decreased by partially replacing solid content of the mix with air voids (Suryavanshi and Swamy, 2002). Thus, concrete without coarse aggregates and a large number of air voids induced using some aeration agents within the concrete mass has been known as aerated concrete. Aerated concrete refers to the concrete with excessive amounts of air voids that provides very good thermal insulation and good thermo-acoustic properties. Therefore, it is applied in both hot and cold countries and aerated concrete was especially very good for tropical countries such as Malaysia (Hussin, *et al*., 2010; Memon *et al*., 2007). Generally, autoclaved aerated concrete (AAC) meaning aerated concrete is cured under steam curing regime. Modern AAC have porosities between 60 and 90% of total volume of concrete which corresponds to bulk densities of 1 to 0.3 g/cm3 (Narayanan and Ramamurthy, 2000a). AAC is produced by molding and hydrothermal processing of different raw materials which contain fine sand, Portland cement and lime with small percentage of aluminum powder. In the mold process, Equation (1) shows that mix slurry generates hydrogen gas by a chemical reaction between fine aluminum powder and lime (Mostafa, 2005):

$$2AL+3Ca\,(OH)_2+6H_2O \rightarrow 3CaO.AL_2O_3.6H_2O+3H_2\uparrow \qquad \text{Equation (1)}$$

Anyway, use of by-products in autoclaved building materials is controlled not only by suitability of these materials for this purpose but also by local economy and competitive position of other building materials within the area. With regard to technology, it may be possible to partly replace sand or binding material with by-products if it is accompanied by improving end products or reducing production cost through decreasing autoclaving time and temperature (Mostafa, 2005). Autoclave treatment performed under high temperature and high pressure is an economically and environmentally costly approach for producing aerated concrete; however, non-autoclaved aerated concrete does not modify influence of the induced porosity and mechanical anisotropy. Some researchers have reported little information about investigating non-autoclaved aerated concrete in Malaysia (Hussin, *et al*., 2010; Memon, *et al*., 2006).

This experiment aimed to investigate suitability of POFA and PFA as a partial replacement of cement and bottom ash as a replacement of sand in lightweight non-autoclaved aerated concrete. The main objective of this work was to determine effect of incorporating different percentages of POFA and PFA on compressive strength and density of the specimens in 7 and 28 days. Effect of curing regime was investigated by applying two curing regimes of water curing and natural air. In addition, strength development of the specimens was examined by testing them on 7 and 28 days of curing.

MATERIALS AND METHODS

Cement: Ordinary Portland Cement (OPC) of Tasek Corporation Berhad –Malaysia Cement Industry has used during the study. The OPC was used classified as Type I Portland Cement according to ASTM standard (ASTM C 150 – 05, 2005).

POFA: Palm oil fuel ash (POFA) used is obtained from Kahang palm oil mill in Kluang Johor, Southern state of Malaysia. The material was ground using a modified Los Angeles abrasion test machine having 8 stainless bars, each of which is 12 mm diameter and 800 mm long in order to acquire finer particles (Awal and Abubakar, 2011; Hussin and Awal, 1996).

PFA: Pulverize fuel Ash (PFA) is a by-product of the combustion of pulverized coal in thermal power plants. The material was obtained at the power plant dust collection systems from the exhaust gases of fossil fuel power plants. PFA was supplied by Sultan Abdul Aziz Generation Station Kapar, located from Klang, Selangor, Malaysia. In this research, PFA, Class F which is low calcium PFA under (ASTM C 618 – 05, 2005), “Standard Specification for Coal Fuel Ash and Raw or Calcined Natural Pozzolon for Use in Concrete” was used.

Fine aggregate: In the case of preparing aerated concrete specimens, the aggregate used only comprises Bottom Ash from Tanjung Bin power plant in Pontian, Johor. The bottom ash is transported from the bottom of the boiler to the ash pond as liquid slurry in a 200-250mm diameter pipes. Initially the bottom ash was dried in an oven at the temperature of 105 °C ± 5 °C for 24 hours. Then, the oven dried bottom ash is sieved passing 1.18 mm sieve before store in the airtight container.

Superplasticizer: The superplasticizer trade name SIKAMENT NN and high range water reducing admixture was used in this study as chemical admixture, according to (ASTM C494/C494 M – 05, 2005). This

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material belongs to the group of Sulphonated Naphthalene Formaldehyde condensates (SNF) in dry powder form.

Aluminum powder: The aluminum powder Y250 was used during the study as the gaseous agent to insert the porosity within the mass of aerated concrete.

Table 1 and Table 2 illustrated chemical combination and physical properties of OPC, POFA and PFA.

Table 1: Chemical combination of OPC, POFA and PFA

Chemical combination (%)	OPC	POFA	PFA
SiO_2	16.40%	63.70%	53.60%
Al_2O_3	4.24%	3.68%	26.60%
Fe_2O_3	3.53%	6.27%	5.36%
CaO	68.30%	5.97%	7.28%
K_2O	0.22%	9.15%	1.30%
P_2O_5	--	4.26%	1.51%
MgO	2.39%	4.11%	0.67%
CO_2	0.10%	0.10%	0.10%
SO_3	4.39%	1.59%	0.63%
Cl	--	0.50%	
TiO_2	--	0.30%	1.94%
Mn	--	0 < LLD	0 < LLD
Na	--	0 < LLD	--
Mno	0.15%	--	--
Ti	0 < LLD	--	--
SrO	--	--	0.33%
BaO	--	--	0.20%
Zr	--	--	0 < LLD

Table 2: Physical properties of OPC, POFA and PFA

Specific gravity	3.15	2.42	2.62
Particle retained on 45μm sieve	4.58	4.98	6.92
Median particle d10	--	1.69	--
Median particle d50	--	14.58	--
Blaine fineness (cm^3/g)	3999	4935	3205
Soundness (mm)	1.0	2.0	--
Strength Activity Index (%)			
At 7days	--	80	84
At 28 days	--	84	92

Specimen Preparation And Testing:

All twelve batches including one control batch, each batch contained 12 cubes (total 144 cubes) with standard size of 100 x100 x100 mm which were cast and tested. Mix ratio 1:1 (binder: Fine bottom ash) was considered the basic mix proportion. The cement replacement was adjusted between POFA and PFA by varying proportions. Control specimen without cement replacement was also cast to compare the values. Details of batches and mix proportions are presented in Table 3. Based on the trial and error mix series, value of water/dry mix ratio was fixed at 0.24 throughout the study while dosage of aluminum powder was fixed at 0.3% by weight of dry mix; also, the superplasticizer was fixed at 0.55% by weight of the binder. Sand was replaced with bottom ash passing 1.18 mm (sieved). All the weighed constituents were mixed in a mixer for about 8 min to achieve a uniform mix because superplasticizer must to reacts with the mix and then was poured in the specimen to fill the specimen approximately up to 80% of its height. Immediately after pouring the mix in the mould, expansion started and continued for the following 35-50 min. Four hours after casting specimens became hard enough to trim the expanded portion on top of them. All the specimens were demoleded 24 hr after casting and subjected to water and air curing until it is time to be tested.

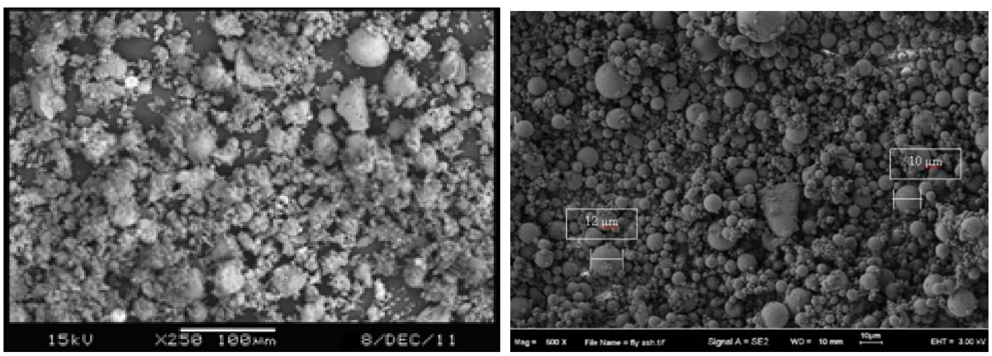
Table 3: Detail of the mix proportion

Number of batch	Mix proportion	Cement %	POFA %	PFA %
1	1 : 1	100	0	0
2	1 : 1	50	0	50
3	1 : 1	50	5	45
4	1 : 1	50	10	40
5	1 : 1	50	15	35
6	1 : 1	50	20	30
7	1 : 1	50	25	25
8	1 : 1	50	30	20
9	1 : 1	50	35	15
10	1 : 1	50	40	10
11	1 : 1	50	45	5
12	1 : 1	50	50	0

Specimens were removed from curing regime approximately 5 hr before testing. Before compressive strength, all the specimens were weighed to determine density of them at the time of testing. The compressive test were done by the MATEST Hydraulic test equipment with capacity of 3000 KN. The testing machine is available in Materials and Structures Laboratory, UTM, Malaysia, to conduct test of compressive strength for the specifications of ASTM C109 - 12 (ASTM C109 / C109M - 12, 2012) . For each test a set of 3 specimens was tested and the average of three was calculated nearest to the two digits after decimal.

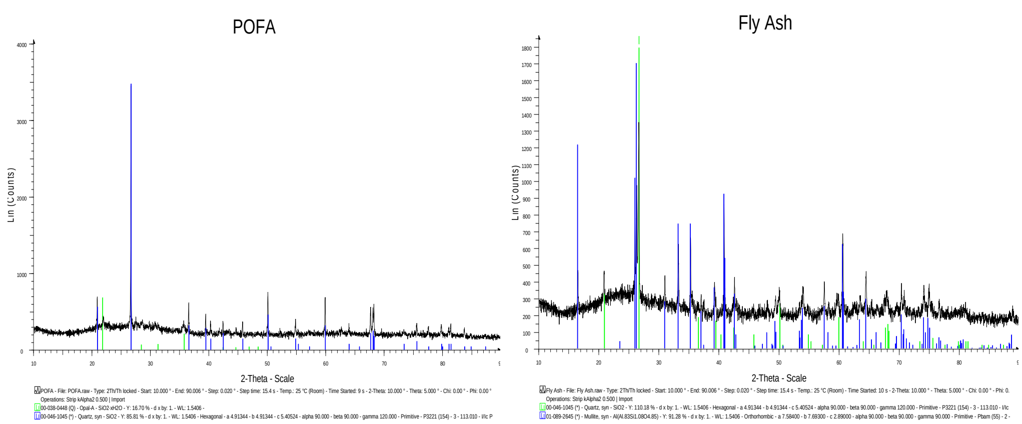
RESULTS AND DISCUSSION

The physical and chemical composition of POFA and PFA is shown in Table 1 and Table 2. From the table it can be seen that the materials contain high silica oxide which influences pozzolanic reaction when it reacts with free lime thus creating extra C-S-H gels, which is beneficial to strength development of the pozzolanic concrete. The sum of silica, aluminium and iron oxide of POFA and PFA is greater than 75% of the total chemical composition, that make this pozzolanic material to be classified between class C and F pozzolan (ASTM C 618 – 05, 2005). However the material contains low CaO in the range of 4-8% and low SO2 within the minimum allowable by the standard. The materials have relatively spherical, irregular particles in shape; a typical electron micrograph and x-ray diffraction pattern of the ashes is shown in Figure 1a- d.



(a) (b)

Fig. 1a and b: Scanning electron micrograph of POFA and PFA



(c) (d)

Fig. 1c and d: X-ray diffraction pattern POFA and PFA

Table 4 illustrated summarizes of compressive strength results the specimen at different ages and curing regimes. After compressive strength was concerned, it can be observed from Table 4 that compressive strength of all samples decreased in compare of control sample. Among all batch except control batch, Maximum compressive strength belong to AC2 (0 % POFA + 50 % PFA) and Minimum strength belong to AC12 (50 % POFA + 0 % PFA).The optimum compressive strength was achieved when 50% weight of cement was replaced with combination of POFA and PFA (respectively, 30% and 20%) in the case of AC8 compressive strength reached 11.28 MPa in air curing and 10.08 in water curing. Further decrease or increase in ratio of POFA to PFA affected on the compressive strength. However, cement replacement with pozzolanic material up to 50% could be considered the most appropriate in terms of compressive strength. Therefore, regarding to compressive strength, it can be concluded that aerated concrete of compressive strength ranging from 8.68 to 11.65 MPa can be produced by incorporating different dosages of POFA and PFA and different curing regimes; this range of compressive strength is much higher in comparison to the minimum compressive strength specified for the non-load bearing concrete units ASTM C 129 - 11 (ASTM C 129 – 11, 2011).

Comparing compressive strength values of the specimens tested in 28 days cured by two curing regimes as presented in Table 4 demonstrated that compressive strength of the specimens cured in air for 28 days exhibited better performance than the specimens cured initially in water. Svanholm and Hussin *et al*, (Hussin and Abdullah, 2009; Svanholm, 1983) reported that in aerated concrete samples air cured specimen exhibits the highest strength. Natural weather specimen performs better than wet dry cycle and water cured specimen gives the lowest strength value. Also Svanholm (Svanholm, 1983) who highlighted that reduction in moisture content would lead to strength increment of about 40% to 70%.

Table 5 illustrated summarizes density of samples, increase in ratio of POFA to PFA cause reduction in density of samples. Discussing on the density of specimens studied, Figure 8 clearly shows that application of different type of curing influence the density of the panel. Density of water cured specimen higher than the specimens were cured in the natural air condition, due to water absorption of specimens continuous contact with water.

Table 4: Compressive strength:

Batch Cement replacement		Initial water curing		Air curing	
		7 Days	28 Days	7 Days	28 Days
AC 1	0%	10.52	14.49	11.1	15.8
AC 2	0 % POFA + 50 % PFA	5.22	10.72	6.34	11.65
AC 3	5 % POFA + 45 % PFA	5.22	10.24	6.12	11.32
AC 4	10 % POFA + 40 % PFA	4.64	9.85	5.52	10.53
AC 5	15 % POFA + 35 % PFA	4.48	9.28	5.53	10.27
AC 6	20 % POFA + 30 % PFA	4.61	9.55	5.29	10.6
AC 7	25 % POFA + 25 % PFA	4.78	9.88	5.8	10.78
AC 8	30 % POFA + 20 % PFA	4.98	10.08	5.74	11.28
AC 9	35 % POFA + 15 % PFA	4.44	8.95	5.14	10
AC 10	40 % POFA + 10 % PFA	4.52	8.21	5.36	9.68
AC 11	45 % POFA + 5 % PFA	3.81	7.22	4.9	8.9
AC 12	50 % POFA + 0 % PFA	3.8	7.1	4.65	8.68

Table 5: Density of specimens in water and air curing

Batch Cement replacement		Initial water curing		Air curing	
		7 Days	28 Days	7 Days	28 Days
AC 1	0%	1475	1295	1238	1209
AC 2	0 % POFA + 50 % PFA	1387	1214	1139	1119
AC 3	5 % POFA + 45 % PFA	1379	1208	1135	1114
AC 4	10 % POFA + 40 % PFA	1364	1200	1130	1110
AC 5	15 % POFA + 35 % PFA	1355	1186	1130	1104
AC 6	20 % POFA + 30 % PFA	1336	1170	1126	1100
AC 7	25 % POFA + 25 % PFA	1307	1154	1110	1084
AC 8	30 % POFA + 20 % PFA	1298	1140	1091	1060
AC 9	35 % POFA + 15 % PFA	1296	1129	1075	1051
AC 10	40 % POFA + 10 % PFA	1300	1120	1064	1033
AC 11	45 % POFA + 5 % PFA	1284	1112	1052	1024
AC 12	50 % POFA + 0 % PFA	1273	1095	1048	1012

Conclusions:

According to this experiment, the following conclusions can be drawn:

Increasing ratio of POFA to PFA weakens compressive strength that contradicts with our goals and decreases concrete samples density which is a good achievement.

Among all batch except control batch, Maximum compressive strength belong to AC2 (0 % POFA + 50 % PFA) and Minimum strength belong to AC12 (50 % POFA + 0 % PFA).

Optimum result of compressive strength was obtained in contents of 30% POFA and 20% PFA.

Replacement of 50% OPC cement weight by pozzolanic waste may achieve Green Concrete that is environmental friendly and economic.

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