POFA : A POTENTIAL PARTIAL CEMENT REPLACEMENT MATERIAL IN AERATED CONCRETE

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ABSTRACT: The ever popular issue on environmental preservation and sustainability all over the world has lead to innovations of new material using by-products generated from various sectors resulting from never ending researches conducted. In Malaysia, Faculty of Civil Engineering of Universiti Teknologi Malaysia has been conducting researches for more than 14 years in attempt to utilize of palm oil fuel ash (POFA), a local by-product produced abundantly by palm oil mill. Recently attempts have been carried out to incorporate POFA to produce a new type of aerated concrete known as POFA aerated concrete. The objective of this investigation is to study the effects of increasing the levels of palm oil fuel ash (POFA) replacement towards the compressive strength of aerated concrete. Experiments have been conducted by replacing 10%, 20%, 30%, 40% and 50% of POFA by weight of Ordinary Portland Cement. All specimens were tested for the compressive strength at 28 days in accordance to BS1881: Part 116. Findings will be able to reveal the compressive strength performance in aerated concrete when incorporated with various level of POFA quantity as partial cement replacement in aerated concrete.

Keywords: Palm Oil Fuel Ash, Partial Cement Replacement, Aerated Concrete, Compressive Strength

1. AERATED CONCRETE AND PALM OIL FUEL ASH : A UNIQUE COMBINATION

Concrete is one of the oldest manufactured construction material used in construction of various structures globally until today. However, continuous research in area of concrete material has resulted in production of many types of concrete known in various name each having unique characteristic to fulfill the current construction industry demand. One of the concrete that becoming famous nowadays among the contractors is aerated concrete due to it’s lightness and versatility. Base on the documented history, Sweden is the first country to produce aerated concrete commercially in 1929 (Kinniburgh & Short, 1978). Originating in Sweeden, aerated concrete quickly spread to different parts of the world after the end of the Second World War (Bave, 1983). It is produced in various types and methods for the use of construction in many countries.

Aerated concrete which is light, contribute to the reduction of building dead weight thus resulting in more economic structural design (Short & Kinniburgh, 1978) and (Narayanan & Ramamurthy 2000b). Production of more economic structural design will reduce the amount of material used and eventually cutting down the cost of construction project itself resulting in profit increase to the contractor. Besides that, other researchers Short & Kinniburgh (1978) and Holt & Raivio (2005) added that the lightness of the aerated concrete structure makes it easier to be transported and handled.

In addition, aerated concrete also has a very low thermal conductivity that makes it an excellent fire protection property (Taylor, 2000 and Narayanan & Ramamurthy, 2000b). Short & Kinniburgh (1978) and Holt & Raivio (2005) supported the above fact and also highlighted that aerated concrete possesses few characteristic of a timber in which it is also easy to work with because it can be sawn, chiseled, planed, screwed and nailed. In other words, structure component made of aerated concrete offers more flexibility to the contractors when comes to easier modifying process which this unique characteristic is not possessed by the existing normal concrete.

Although, there are a large number of studies done and papers published on aerated lightweight concrete (Tam et.al, 1987; Hauser et.al, 1999; Narayanan & Ramamurthy, 2000a; Goual et,al, 2000; Kearsley & Wainright, 2002; Holt & Raivio, 2005; Jones & McCarthy, 2005) but until now there's no study done on aerated concrete produced using agricultural ash particularly POFA as partial cement replacement material. Success in incorporating POFA as partial cement replacement material in producing new type of lightweight concrete could reduce amount of cement used as compared to ordinary aerated concrete thus could reduce high dependency on cement. Moreover, usage of POFA in this product could also prevent the by-product generated by palm oil industry from causing considerable pollution to the environment besides becoming more environmental friendly.

2. AERATED CONCRETE

2.1 TYPES OF CONCRETE

In the the early days, aerated concrete is also known as cellular concrete, cellular aerated concrete, gas concrete or foamed concrete. According to past researcher, Tam et.al (1987), this type of concrete is essentially an aerated cement paste or mortar made by introducing air or gas in the form or small bubbles (diameters from 0.1 to 1.0mm) into a plain a cement paste or mortar mix during the mixing process. The air bubbles are uniformly distributed and are retained in the matrix on setting and hardening to produce a cellular structure (AAC 1.1, 1990). Basically, aerated concrete can be divided to two types that are gas concrete and foamed concrete. Aerated concrete is classified based upon the method of formation (Narayanan & Ramamurthy, 2000b).

Gas concrete is produced using gas-forming materials, which is mixed into lime or cement mortar during the liquid or plastic stage, resulting in a mass of increased volume and when the gas escapes, leaves a porous structure (Narayanan & Ramamurthy, 2000b). It is a mixture of very fine aggregates, water, and cement with final addition pore-forming chemical that will produce air-voids within the aqueous mix at atmospheric pressure resulting it to expand to certain extent depending on the amount of gas produced and entrapped inside the structure. Meanwhile, foamed concrete is manufactured by entraining relatively large volumes of air into the cement paste by the use of a chemical foaming agent (Kearsley & Wainright, 2001). In other words, it is a mortar mix containing air voids that been produced by adding foaming agents which plays the role of creating pores within the concrete without chemically reacting to the cement.

2.2 STRENGTH AND DENSITY OF AERATED CONCRETE

Narayanan & Ramamurthy (2000b) summarized that composition and method of curing influence the physical and mechanical properties of aerated concrete. Aerated concrete can be found in a wide range of density that is about 300 to 1800 kg/m^3 (Narayanan& Ramamurthy, 2000b). Meanwhile another researcher Holt & Raivio (2005) added that air content of 3% to over 50% compared with normal concrete will give low density for aerated concrete. In other words, the more voids confined in the hardened aerated concrete so the more porous the concrete structure will be thus leading to a lower density of the concrete having lesser ability to sustain compressive load. Therefore, in order to achieve the desired density of aerated concrete, precautions need to taken during preparation of materials and mixing process besides considering its composition.

Generally, the compressive strength for aerated concrete is ranging from 2 to 5 N/mm² (Taylor, 2000). Studies done by Holt & Raivio (2005) stated that aerated concrete has lower strength and higher moisture content compared to standard concrete. The elimination of coarse aggregate from being used as one of the ingredient in aerated concrete is one of the factors that lead to lower strength as compared to standard concrete. Besides, the existence of air voids entrapped among the hardened mortar matrix is one of the reasons of aerated concrete porous structure which is very different due to the condition of concrete which is usually filled with compacted fine and coarse aggregate that was cement bonded with the presence of water. However, this condition of aerated concrete has been studied by one of the researcher, Narayanan & Ramamurthy (2000b) whom stated that compressive strength of aerated concrete increases linearly with density but increase in moisture content of aerated concrete will cause decrease in its compressive strength.

3.0 PALM OIL FUEL ASH

3.1 ORIGIN OF POFA

Palm oil fuel ash is a by-product produced in palm oil mill. After palm oil is extracted from the palm oil fruit, both palm oil husk and palm oil shell are burned as fuel in the boiler of palm oil mill. Generally, after combustion about 5% palm oil fuel ash by weight of solid wastes is produced (Sata et.al, 2004). The ash produced sometimes varies in tone of colour from whitish grey to darker shade based on the carbon content in it. In other words, the physical characteristic of POFA is very much influenced by the operating system in palm oil factory. In practice, POFA produced in Malaysian palm oil mill is dumped as waste without any profitable return (Sumadi & Hussin, 1995). Either in 20th or 21st century, POFA is still considered as a nuisance to the environment and disposed without being put for any other use as compared to other type of palm oil by-product. Since Malaysia is continuous to increase production of palm oil, therefore more ashes will be produced and failure to find any solution in making use of this by-product will create severe environmental problems.

3.2 CHEMICAL COMPOSITION OF POFA

Both physical properties and chemical analysis indicated that POFA is a pozzolanic material (Awal & Hussin, 1997; Sumadi & Hussin, 1993). This pozzolanic material is grouped in between Class C and Class F as specified in ASTMC618-92a (Awal & Hussin, 1997). POFA is moderately rich in silica content meanwhile lime content is very low as compared to OPC (Awal & Hussin, 1997). However, the chemical composition of POFA can be varied due to operating system in palm oil mill.

3.3 STRENGTH AND DURABILITY OF POFA

20th century has been a meaningful one for researchers from Faculty of Civil Engineering of Universiti Teknologi Malaysia when they successfully discovered that the palm oil ash that been considered worthless can actually be made used in construction industry specifically in concrete technology. Starting from the time onwards until this century the POFA use in concrete production continued to be studied and revealed by researchers in Asian region especially. Until now, some researchers (Hussin & Awal (1996); Awal & Hussin (1997); Sata et.al (2004)) that has been diligently studying on POFA use has able to successfully reveal the benefits of POFA in concrete technology in terms enhancement towards the properties of concrete either strength or durability aspect.

Abu (1990) the pioneer in POFA research has embarked on studying agricultural ash in Malaysia and finally acknowledged that POFA is a pozzolanic material and able to be replace as partial cement replacement up to 35% in mortar mix that could exhibit similar strength as control mortar. Then studies have been continued by Hussin & Awal (1996) & Awal & Hussin (1996) that highlighted that POFA concrete gain maximum strength when 30% of the cement was replaced with POFA. It is reported that the maximum strength gain occurred at the replacement level of 30% but further increase in the ash content would reduce the strength of concrete gradually (Awal & Hussin, 1996). However, the result of POFA performance once added in aerated concrete still yet to be studied. Besides that Hussin & Abdul Awal (1996) added that increasing in fineness of POFA would lead to greater concrete strength development than the coarser one.

It also has been found that POFA could produce a more durable concrete. POFA possess good characteristic towards chemical attack especially sulphate and acid and also other chemical agent when it is used as partial cement replacement in concrete mix Awal (1998). As an additional benefit Awal & Hussin (1997) also stated that incorporation of POFA as partial cement replacement in concrete result in significant increase in chemical resistance to acidic environment. Moreover, despite the higher alkali content POFA, it has been effective in suppressing expression due alkali-silica reaction. However, performance of POFA when incorporated as partial cement replacement in aerated concrete still remains undiscovered.

4. MATERIALS AND TEST METHODS

4.1 PALM OIL FUEL ASH

In this present study, POFA was collected from a factory processing palm oil owned by Yayasan Pembangunan Johor in Ladang Alaf at the area of Bukit Lawang, Johor Darul Takzim. The ash was found at the flue of tower where all the fine ashes that were trapped while escaping from the burning chamber of the boiler. Among the available ashes there, only the one looks greyish were sorted out and collected. Firstly, collected POFA were dried in the oven at the temperature of 110ºC ± 5 for 24 hours in order to remove moisture in it.

Secondly, the dried ashes were sieved through a 300µm sieve in order to remove bigger size of ash particles and impurities. Only the fine ashes passing through 300µm sieve were collected and ground in a modified Los Angeles abrasion test machine having 10 stainless bars which each of it is 12 mm diameter and 800mm long in order to acquire finer particles. The fineness of the ash was checked by wet sieving through 45µm sieve at every half-hour grinding of 4kg ash. Finally the grounded ashes were stored in airtight container and kept in a humidity-controlled room to isolate from the atmospheric humidity. Table 1.0 shows the chemical composition of palm oil fuel ash.

4.2 CEMENT

A single batch of Ordinary Portland Cement (OPC) which is produced by HOLCIM under the brand name of “SELADANG” was used throughout the experiments. The OPC to be used throughout this research was stored in airtight container in order to maintain the quality of cement. Chemical composition of OPC is displayed in Table 1.0..

4.3 FINE AGGREGATE

In order to produce POFA cement based aerated concrete only fine sand was used. The sand obtained was dried in the oven at the temperature of 110ºC ± 5 for 24 hours in order to remove moisture in it. Then, the oven dry sand was sieved passing the 600µm sieve before it was stored in an airtight container from atmospheric humidity.

4.4 ALUMINIUM POWDER

Aluminium powder was used as the gas-forming agent to create air voids in the POFA cement based aerated concrete. Table 2 shows the specification and chemical composition of Aluminium powder used.

4.5 SUPERPLASTICIZER

A chemical admixture was used in preparing POFA cement based aerated concrete in order to decrease water content and to achieve early high strength. The superplasticizer incorporated in this research is in a form of dry powder known as Sulfonated Naphthalene Formaldehyde condensate.

5. MANUFACTURE AND COMPRESSIVE STRENGTH TEST

Six mixes of OPC/POFA concrete containing various proportions of POFA were cast and tested for compressive strength. POFA was mixed as weight-for-weight replacement cement, the replacement levels being 10%, 20%, 30%, 40% and 50%. A normal aerated concrete mix containing 100% OPC was used as control specimen. All specimens were produced by adding with required sand, cement, Aluminium powder, Superplasticizer and adequate water dry mix ratio and cast in form of cubes (70.6x70.6x70.6mm).

For compressive strength 70.6mm cubes were cast, three specimens were being tested for a particular mix. All freshly cast specimens were left in the formwork for 24 hours before being demolded and then subjected to water curing until it is time to be tested. Compression tests were conducted at the age of 7 and 28 days. All methods of sampling, making and testing of specimens were in accordance with BS1881: Part 116.

6. RESULTS AND DISCUSSION

6.1 CHEMICAL AND PHYSICAL PROPERTIES OF POFA

The raw palm oil fuel ash collected is greyish in colour due to unburned carbon content in it. However, whitish ash is the best due to absence of unburnt carbon. The chemical analysis of palm oil fuel ash (POFA) and ordinary Portland Cement (OPC) used in this study are shown in Table 1.0. The chemical analysis reveals that POFA, in general, satisfies the requirement to be pozzolanic and may be classified into Class F. This justification is made base on the percentage of Calcium Oxide content in this POFA is only 4.12 and both silica, Aluminium and ferric oxide is 65.12. According to Nagataki (1994), fly ash from Class F should have calcium oxide less than 5%. Therefore, it is concluded that the POFA used in this study is from Class F. Besides that, in order to improve the reactivity of ash, the POFA was ground until it possesses 99% fineness when it was subjected to wet sieve.

Table 1 : 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

Table 2 : Specification and Chemical Composition Of Aluminium Powder

Properties	
Specification	No.300
Color	Silver
Particle Size	Mesh 220
Chemical Composition	**(%)**
Aluminium	Min 99.3
Copper	Max 0.1
Iron	Max 0.4
Silica	Max 0.2

6.2 INVESTIGATION OF STRENGTH (EFFECT OF ASH)

It is mentioned earlier that the test specimens were cast with OPC and OPC with POFA added at various percentage replacement level. Here, all the specimens were tested for compression at the age of 7 and 28 days. Generally, Table 3 and Fig.1 reveal that increase in the level of POFA replacement lead to the reduction of compressive strength in aerated concrete. Besides that, it can be observed that replacement of POFA 10 to 40% exhibit significant development in strength of aerated concrete from 7 days to 28 days. Due to this fact, the researcher wishes to observe the strength development of this specimen for long term period. Therefore, conclusion to be made on the exact percentage of POFA replacement for achievement of optimum strength in POFA aerated concrete still yet to be reserved.

On the other hand, this early study clearly presented that too much of POFA added as cement replacement will result in very low strength as compared to specimen that consist lower percentage of POFA. This is reasonable because according to Massazza (1993), too high pozzolana content reduces strength at all ages. However, in the case of aerated concrete, replacement from 10 to 35% of POFA as partial cement replacement is still able to produce aerated concrete. This is because Taylor (2000) mentioned that, normally compressive strength of aerated concrete ranges between 2 to 5N/mm². However, this present study able to conclude that POFA has the potential to be used as partial cement replacement in producing concrete known as POFA cement based aerated concrete

Table 3 : Compressive strength Performance Of aerated Concrete Without and With Various Level Of POFA Replacement At 7 and 28 days

% POFA Replacement	OPC Aerated Concrete Strength (MPa)	
	7days	28 days
0	5.49	7.70
10	4.89	6.10
20	3.16	5.84
30	2.54	3.81
40	0.83	1.95
50	0.63	0.96

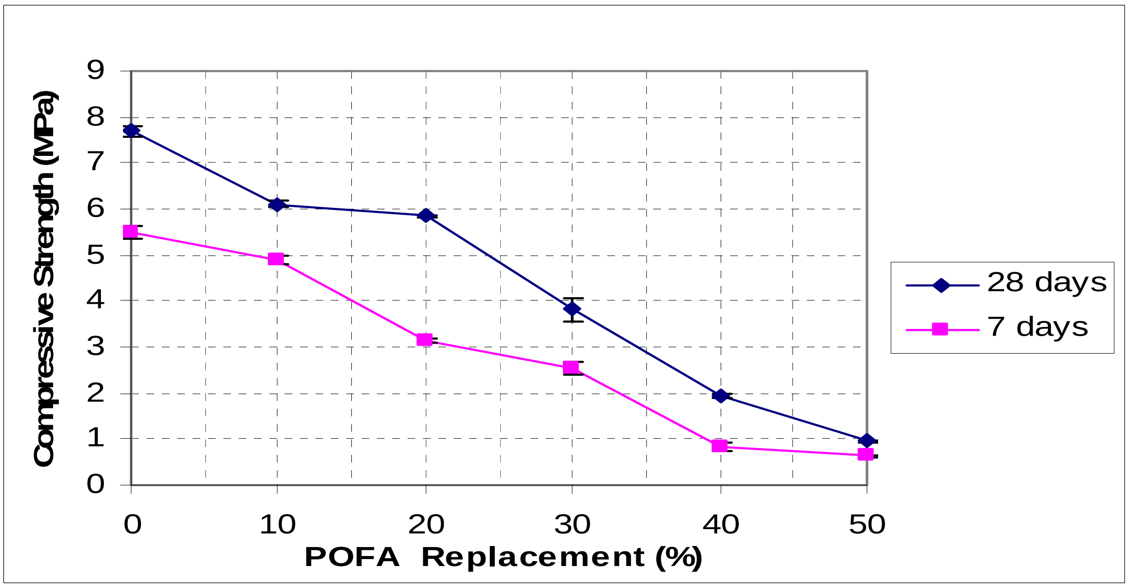

Figure 1: Effect Of POFA Content on Compressive Strength of Aerated Concrete at 7 and 28 days

7. CONCLUSION

Success in incorporating certain percentage of POFA as partial cement replacement that either produce POFA aerated concrete having same strength as ordinary aerated concrete or higher strength than existing aerated concrete definitely will benefit the contractors in terms of reducing cement consumption in their construction work. Starting of with the discovery of POFA ability to be used as partial cement replacement in ordinary concrete then followed by Sata et.al (2004) who incorporated it in high strength concrete production and now the ash usability is increased when it has been found that POFA also suitable for producing aerated concrete.

All these findings, begin to highlight that there is possibility that POFA would no more be considered as problematic by-product by any one. Now, the palm oil factory could finally manage to put use of this by-product as one of the money generating element that definitely able to contribute extra income to the company besides being a more environmental friendly industry. It is hoped, this finding will encourage other researchers to discover more ways to make use the industrial or agricultural by-product for the benefits of mankind.

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