THE EFFECT OF POFA AS CEMENT REPLACEMENT MATERIAL TOWARDS MECHANICAL PROPERTIES OF AERATED CONCRETE

SITI NORBAYA BINTI MUSTAFA

A report submitted in fulfilment of the requirements for the award of the degree of
B.ENG. (HONS.) CIVIL ENGINEERING

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2014

ABSTRACT

Aerated concrete is homogenous compared with ordinary concrete because it does not contain coarse aggregate phase but showed wide variation in properties. The main advantage of aerated concrete is lighter than normal concrete. This lightweight concrete can make the construction work done more easily and quickly. In addition, the design of structures such as foundations, column and beams can be reduced. Malaysia is the major palm oil exporter and has been facing problem in disposing palm oil fuel ash since many years ago. The challenge to produce Palm Oil Fuel Ash (POFA) by a palm oil processing factory will take a very long time. In this study, POFA was used as a pozzolanic material in concrete. A portion of Ordinary Portland Cement (OPC) was replaced by POFA at 0 %, 10 %, 20 % and 30 % by weight to reduce the cement. Compressive strength, modulus of elasticity, drying shrinkage and degree of hydration of concretes containing ground POFA were tested. The rate of hydration of cement and POFA has been tested to know the reaction of concrete hydration. The results showed the compressive strength of concrete is influenced by POFA content and the curing period with a 20 % replacement of POFA as partial cement to produces the higher strength compared to other mixtures. In addition, there was also a strong correlation between the compressive strength and the drying shrinkage of the POFA concrete. As a conclusion, the overall result for all testing conducted showed that the concrete with 20 % replacement of POFA material give the best result compared to control, 10 % POFA and 30 % POFA.

ABSTRAK

Konkrit berudara adalah homogen berbanding dengan konkrit biasa kerana ia tidak mengandungi fasa agregat kasar tetapi menunjukkan variasi yang luas dalam sifat-sifatnya. Kelebihan utama konkrit berudara adalah ringan berbanding dengan konkrit biasa. Ini boleh menjadikan kerja-kerja pembinaan dilakukan dengan lebih mudah dan cepat. Di samping itu, penjimatan terhadap rekabentuk struktur seperti asas, tiang dan rasuk boleh dikurangkan. Malaysia merupakan pengeksport utama minyak sawit dan telah menghadapi masalah dalam melupuskan abu bahan api kelapa sawit sejak bertahun-tahun yang lalu. Cabaran untuk menghasilkan minyak kelapa sawit abu (POFA) dengan sebuah kilang pemprosesan minyak sawit akan mengambil masa yang sangat lama. Dalam kajian ini, POFA telah digunakan sebagai bahan pozzolanic di dalam konkrit. Sebahagian daripada simen Portland (OPC) telah digantikan dengan POFA pada 0 %, 10 %, 20 % dan 30 % mengikut berat untuk mengurangkan jumlah simen. Kekuatan mampatan, modulus keanjalan, pengecutan pengeringan dan tahap penghidratan konkrit yang mengandungi POFA telah diuji. Kadar penghidratan simen dan POFA telah diuji bagi melihat tindakbalas penghidratan konkrit. Hasil kajian menunjukkan kekuatan mampatan konkrit dipengaruhi oleh kandungan POFA dan tempoh pengawetan dengan penggantian 20 % POFA sebagai gentian separa simen menghasilkan kekuatan yang lebih tinggi berbanding dengan campuran yang lain. Di samping itu, terdapat juga korelasi yang kuat antara kekuatan mampatan dan pengecutan pengeringan konkrit oleh POFA. Kesimpulannya,

keputusan keseluruhan bagi semua ujian yang dijalankan menunjukkan bahawa konkrit dengan penggantian 20 % POFA memberikan hasil yang terbaik berbanding dengan campuran 0 %, 10 % POFA dan 30 % POFA.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Al_2O_3	Aluminium Oxide
ASTM	American Society of Testing Materials
BS	British Standard
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium Hydroxide
C-S-H	Calcium Silica Hydrate
Fe_2O_3	Iron Oxide
HCL	Hydrogen Chloride
K_2O	Potassium Oxide
MgO	Magnesium Oxide
MnO	Manganese Oxide
MS	Malaysian Standard
Na_2O	Sodium Oxide
Na_2Co_3	Sodium Carbonate
OPC	Ordinary Portland Cement
POFA	Palm Oil Fuel Ash
P_2O_5	Phosphorus Pentoxide
P_2O_2	Phosphorus Oxide
RHA	Rice Husk Ash
SiO_2	Silicon dioxide
SO_3	Sulphur Trioxide
TiO_2	Titanium Oxide

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Aerated concrete is classified as a lightweight concrete in which air voids in cement or lime mortar were entrapped in the mortar matrix into a suitable aerated agent. In previous research, the characteristic of lightweight concrete is typically exhibits low strength, low stiffness and low ductility. Besides, aerated concrete is widely accepted but it is limited in the size and strength of the product that can be produced. (Hanson, 1958)

Aerated concrete is also used in the construction industry because of its lightness and it is using of alternative building materials to improve the technology in Malaysia. This lightweight material can give the good economic structural design and will be more benefit to local contractors. (Short and Kinniburgh, 1978; Narayanan and Ramamurthy, 200b).

According to Zakaria (1997) and Abdul Awal (1998), the palm oil fuel ash (POFA) was used as replacement cement in concrete mixes for reduced the amount of cement. Compared with normal aerated concrete, it will reduce the high dependence on cement. Therefore, the creation of new materials not only offers advantages for the palm oil industry and reduces the ash in landfills, but it also can contribute to the improvement of technology in Malaysia.

1.2 PROBLEM STATEMENT

Malaysia has large number of palm oil waste producer and exporter in the world. This concern towards preserving POFA for future generation has lead to increase the integrating POFA as partial cement replacement in concrete material. Pozzolana reaction will take place after hydration process complete to produce secondary C-S-H gels which improve the compressive strength of concrete. In addition, POFA is waste 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. To reduce disposal of POFA, this research will studied the replacement cement using POFA cement based on aerated concrete. Other than that, aerated concrete which was introduced under construction in Malaysia market and it is a product that has been produced and used in different countries climate. However, the imported products will be expensive because of the cost production and transportation.

Table 1.1 Production of Oils and Fats (million tonnes) Sources: MPOB (2004); Oil World (various issues)

	1962		**2004**		**Annual Growth**	**2015**		**2020**	
	Million tonnes	**% Share**	**Million tonnes**	**% Share**	**% Per annum**	**Million tonnes**	**% Share**	**Million tonnes**	**% Share**
World oils and fats	30.78	0	129.14	0	3.47	165.66	0	184.8	0
Palm oil	1.23	4	29.78	23.05	7.87	37.41	22.58	43.3	23.43
Malaysia	0.108	8.8	13.6	45.67	11.79	16	42.72*	18	41.57*
Indonesia	0.142	11.54	10.02	33.65	10.38	14.9	39.83*	17	39.26*
Soyabean oil	3.43	11.14	31.56	24.44	5.42	37.15	22.43	41.1	22.24
Rapeseed oil	1.16	3.8	14.23	11.01	6.14	20.3	12.25	22.7	12.28
Sunflower oil	2.29	7.44	9.81	7.6	3.52	14.72	8.89	17	9.2
Animal fats	12.04	39.12	22.82	17.67	1.53	8.56	5.17	9.14	4.95

Basiron and Simeh (2005) reported that Malaysia, the current number one palm oil producer is forecast to maintain its lead position over the next one and the half decades producing 18 million tones or 42 % of the world palm oil in 2020. It is predicted that the quantity of palm oil fuel ash (POFA), a profitless by-product generated by palm oil mill will increase as the production of palm oil continue to grow over the year. Therefore, it is anticipated that the success in discovering the utilization of this material in any type of material making process would be able to reduce quantity of waste thrown and assist palm oil industry to be more ecological friendly sector. To reduce disposal of POFA, this research studies that the replacement cement using POFA cement based on aerated concrete. This problem focused on the properties of aerated concrete in terms of mechanical properties such as compressive strength, modulus of elasticity, drying shrinkage and hydration characteristic.

1.3 OBJECTIVE OF STUDY

The objectives of the study are:

i. To determine the effect of POFA as a cement replacement material towards compressive strength and modulus of elasticity.
ii. To determine the effect of POFA as cement replacement method towards drying shrinkage.
iii. To determine the effect of POFA as cement replacement material towards degree of hydration of aerated concrete.

1.4 SCOPE OF STUDY

The purpose of this research is to study on performance of POFA as a cement replacement based on aerated concrete and to study the mechanical properties in POFA concrete. The investigation is by comparing the plain concrete with 0 % of cement replacement and 10 %, 20 %, 30 % respectively that consist with POFA as a replacement ingredient to concrete.

All of this testing is measured under the standards under the standards based on Malaysian Standard (MS) and ASTM standard. This research will be conducted at Concrete Laboratory in Universiti Malaysia Pahang (UMP). All specimens will be casting in a mould of 100 mm x 100 mm x 100 mm for 7, 28 and 60 days of curing age.

1.5 SIGNIFICANT OF STUDY

The purposes of the study are:

i. To reduce the cement content by replace palm oil fuel ash (POFA) as a cement replacement in concrete.
ii. To reduce waste from palm oil mill.
iii. To create new product from palm oil industry and increase economy of country.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 Aerated Concrete

Aerated concrete also known as autoclaved cellular concrete is a lightweight concrete that is lighter than regular concrete, caused to its low density. Aerated concrete is the one of the famous concrete among the contractors. Aerated concrete comes from Sweden, it quickly spread to different parts of the world after the end of the Second World War in which it is produced in many types for use in construction industries. (Bave 1983)

According to Hauser et al. (1999), Ramamurthy and Narayanan (2000), Arreshvhina (2002), starting of its existence, a large amount of literature has been published on various aspects of aerated concrete on the properties. Although aerated concrete was initially expected as an insulation material, there has been renewed benefit on its structural characteristics in view of its lighter weight, savings in material and potential for large scale utilization of wastes like pulverized fuel ash. However, until now research on producing aerated concrete incorporate agricultural ash such as palm oil fuel ash (POFA) and rice husk ash (RHA) are still very limited.

Normally compressive strength of aerated concrete range between 2 to 5 N/mm^2. 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. (Taylor 2000)

2.2 MECHANICAL PROPERTIES

2.2.1 Compressive Strength

Compressive strength is considered one of the most important natures of a concrete since as this characteristics determines the function of building material in a construction project.

Compressive strength can be obtained from aerated lightweight concrete has dried strength in the rate of 500-880 kg/m^3. According to Narayanan and Ramamurthy (200b), the parameter such as specimen size and shape, method of pore-formation, direction of loading, age, water content, characteristics of ingredients used and method of curing are the factors to influence the strength of aerated concrete. Generally, the factors that affect the compressive strength of this type of lightweight concrete are same to the normal concrete except for one additional factor for aerated concrete, which is method of pore formation. Compressive strength of aerated concrete varies inversely with the moisture content. There is an increase in strength but the increase in moisture content will cause reduction in its strength.

Besides, compressive strength of lightweight concrete using fly ash as a partial or complete replacement for the filler has been proved that the use of fly ash results is increase strength to the density ratio. Therefore, it can be summarized that increasing density does not have to provide a higher strength but the presence of moisture during the test also determines the performance of the material in terms of its ability to accommodate the load. Besides the effect of density, the application of method and curing age has direct influence towards the compressive strength of this lightweight concrete. Study by Narayanan and Ramamurthy (200b), they state that moist cured aerated concrete would contribute to slow strength development as compared to the one subjected to autoclaving method which could result in significant increase in the compressive strength.

2.2.2 Modulus of Elasticity

The modulus of elasticity is a very important in mechanical parameter because it's reflecting the ability of the concrete to deform easily. According to Narayanan and Ramamurthy (200b), most of the formula for the modulus of elasticity of aerated concrete in compression is a function of the compression report strength.

According to ASTM C 469, the "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," describes modulus of elasticity as a stress to strain ratio value for hardened concrete at whatever age and curing condition that may be designated. This standard also states that the modulus of elasticity is applicable with the customary working stress range of 0 to 40 % of the ultimate concrete strength. The modulus of elasticity is often used in sizing reinforced and non-reinforced structural members, establishing the quantity of reinforcement, computing stress for observed strain.

2.2.3 Drying Shrinkage

Drying shrinkage is a one of the main causes of cracks that directly affect the strength and durability of concrete. It usually occurs in hot and dry environments due to the loss of internal water in the concrete to the environment. This results in the reduction of concrete volume and leads to crack formation in hardened concrete. Furthermore, most of this drying shrinkage cannot be regained by rewetting the concrete.

According to Ziembika H. (1977) drying shrinkage is defined as the contracting of a hardened concrete mixture due to the loss of adsorbed water. This is caused an increase in tensile stress and is significant in aerated concrete because of its high total porosity (40-80 %) and specific surface of pores around 30 m^2/g.

All Portland cement concrete undergoes drying shrinkage or hydral volume change as the concrete ages. The hydral volume change in concrete is very important to the engineer in the design of structure. Drying shrinkage can occur in slabs, beams, columns, bearing walls, prestressed members, tanks, and foundations. The total drying shrinkage depends on various parameters such as density, chemical composition, water comentitious material ratio, relative humidity, duration of curing, type and size of aggregate, aggregate content, size and shape of the member and type of exposure.

According to Narayanan and Ramamurthy (200b), this concrete has a higher shrinkage compared to conventional concrete. Shrinkage is increased when porosity is decreased. This is explained by the fact that crystalline is also decreased. Besides that, shrinkage of aerated concrete is also influenced by both method and duration of curing applied towards this particular material.

2.3 POZZOLANA MATERIAL

POFA is a pozzolanic material is a product of palm oil mill as a partial cement replacement in aerated concrete. After palm oil has been product from the palm oil fruit. Then, both of palm oil husk and palm oil shell are burned as fuel in the boiler of palm oil mill. it is estimated the annual production of POFA is greater than 100,000 tons. According to Ganesan et al. (2008); Rukzon et al. (2009); Sata et al. (2004); there are several researchers shown that the POFA are good pozzolanic materials and can be used to replacement cement.

Therefore, to be success in another new type of concrete consisting POFA would be able to broaden the utilization of this waste in production of building material and decrease the quantity of ash thrown as waste in the landfill.

2.4 FOAM

Foam concrete is classified as lightweight concrete in which air-voids trapped in the mortar by suitable foaming agent. With a wide range of densities (1600- 400 kg/m^3) of foamed concrete can be obtained for application to structural, partition, insulation and filling grades. The application of construction materials and semi- structure was increased in recent years. This research is the first comprehensive review on cellular concrete. It is presented by Valore RC (1954).

According to Ramamurthy et al (2009), lightweight foamed concrete is made of mixture of raw materials such as fine aggregate, Ordinary Portland Cement and water with pore structure created by air voids, which are entrapped in mortar or cement paste by suitable foaming agent. Moreover, many researchers have studied the use of agricultural residues contained in high amounts has been shown to be used as a pozzolanic material. (Tangchirapat et al. 2007)

In the mixture foam, surface active agent is added along with the basic ingredients and mix during the mixing process, bubbles are produced causing cell structure in concrete (Byun et al, 1998). Then, the preformed foam can be either wet or dry foam. The wet foam will be produced by spraying a solution of foaming agent over a fine mesh. It has 2.5 mm bubble size and it is not stable. While, dry foam will be produced by forcing the foaming agent solution into a series of high density and forcing compressed air simultaneously to mixing chamber (Aldridge, 2005). Figure 2.1 shows that the foam agent used in all the testing.

Figure 2.1 Foam agent

2.5 ORIGIN OF POFA

As discussed in a preview chapter, Malaysia is one of the main palm oil producer and exporter in the world. Palm oil fuel ash (POFA) is a product of palm oil industry. It is produced from the combustion of palm oil residues. Almost 100,000 tonne of POFA are generated annually in Malaysia. It is obtained from a small power plant by using palm fiber, palm shell and empty fruit bunches as a fuel and burned at 800 - 1000°C. (Chindaprasirt and Rukzon 2009). Generally, after combustion about 5 %, the weight of solid by POFA was produced (Sata et.al, 2004). Sometimes, the ash is produced in varies in tone of colour from white grey to dark shade based on the content of carbon in it. In other words, the physical characteristic of POFA is very much influenced by the operating system in palm oil factory.

Other than that, based on research from (Sumadi & Hussin, 1995), POFA is produced in Malaysia palm oil is removed as waste without any profitable return. Either in 20^{th} or 21^{st} 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.

Figure 2.2 Origin POFA

Figure 2.3 Palm oil fiber

Figure 2.4 Palm oil fuel ash

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will describe that material that used in carrying out the experimental work and laboratory test to achieve the objective in this project. There is variety of testing to be carried out for this project. At the beginning, sieve analysis is the first test to testing the replacement material which is palm oil fuel ash as a cement replacement. Then, the testing is to be follow by compressive strength, modulus of elasticity, drying shrinkage and hydration tests.

3.2 EXPERIMENTAL PROGRESS

The experiment process flow for an effectiveness of the mechanical properties and performance by using POFA is using in Figure 3.1

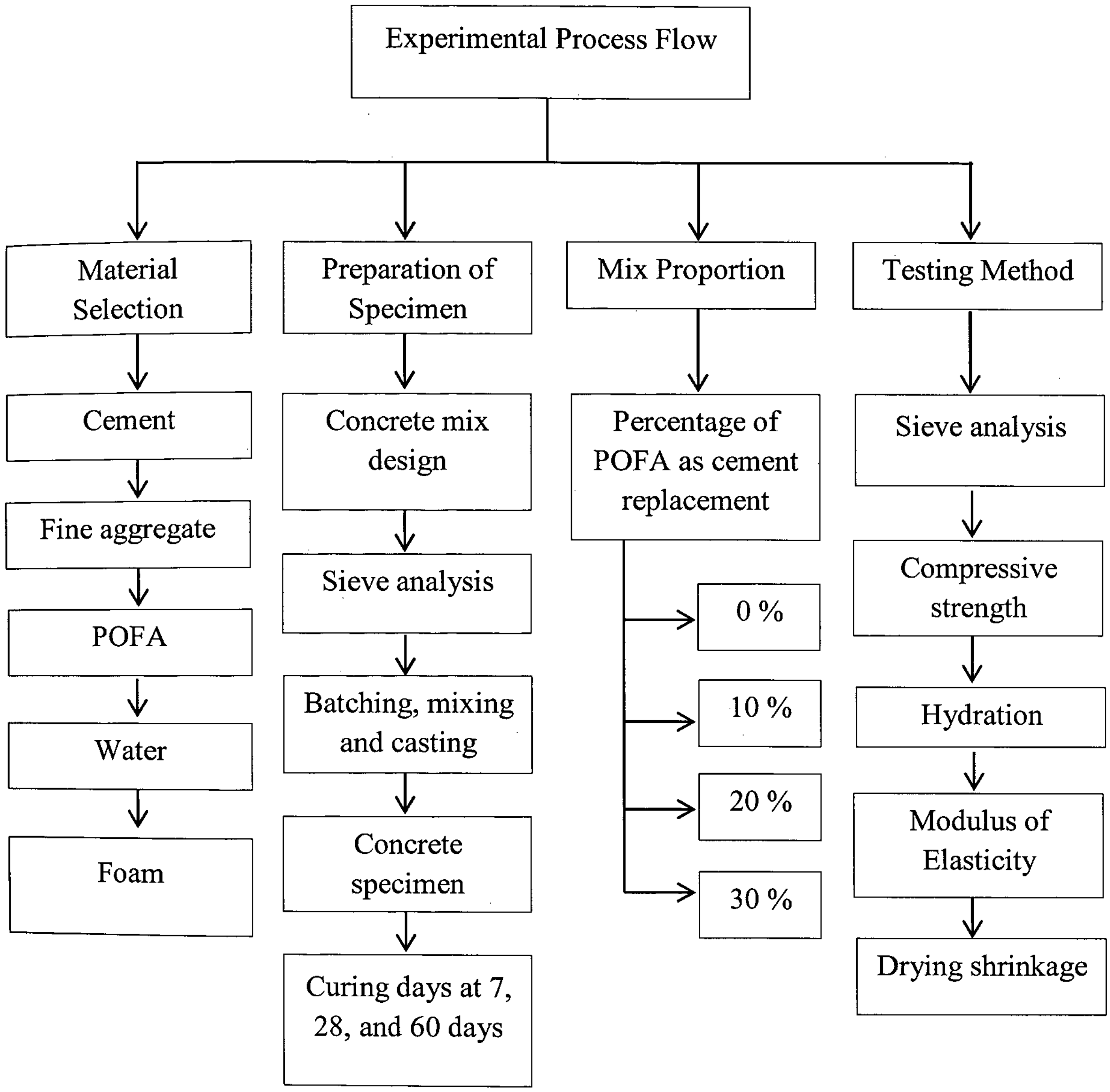

Figure 3.1 Flow chart of experimental process