PERPUSTAKAAN UMP
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EFFECT OF PALM OIL FUEL ASH (POFA) TOWARD FOAM CONCRETE COMPRESSIVE STRENGTH AND MICROSTRUCTURE

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A Report submitted in partial fulfillment 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

Malaysia is well known as the main crude palm oil producer and exporter in the world. Million tons of agro wastes such as palm oil fuel ash (POFA) is being produced every year with no commercial return on it. Due to the pozzolanic behavior possessed by POFA, it could be significance when the POFA is being recycled and used in production of lightweight foamed concrete (LWFC). Thus, the aim of this research is to study the effects of POFA on engineering properties and microstructure of LFC with 1600kg/m^3 until 1800kg/m^3 of density in terms of compressive strength, porosity, scanning electron microscope (SEM) and thermal gravimetric analysis (TGA). Four types of foamed concrete were prepared with different percentage LWC with 0%, 10%, 20% and 30%. All the specimens were water cured before being tested. At the 20% concrete containing of POFA had a highest strength which is 11.2, 15.15 and 29.20 MPa and lower porosity is 14.99, 11.94 and 9.54. It is proved that the percentage of porosity is lest and the strength of the other specimen is higher. Besides, it was found that the microstructure of LFC was denser and the pore size of the structure was refined with the presences of POFA, compared with that of control mix. Effective consumption of POFA as a pozzolanic material in concrete can decrease the cost of concrete production, save environmental and also can solve the landfill problem

ABSTRAK

Malaysia terkenal sebagai pengeluar minyak sawit mentah utama dan pengeksport terbesar di dunia. Berjuta-juta tan sisa pertanian seperti abu bahan api kelapa sawit (POFA) telah dihasilkan setiap tahun tanpa pulangan komersial keatasnya. Oleh kerana berlaku tindakbalas pozzolanic yang dimiliki oleh POFA, ia menjadi penting apabila POFA dikitar semula dan digunakan dalam pengeluaran konkrit berbusa ringan (LFC). Oleh itu , tujuan kajian ini adalah untuk mengkaji kesan POFA pada sifat-sifat kejuruteraan dan struktur mikro LWFC dengan 1600kg/m^3 sehingga 1800kg/m^3 ketumpatan dari segi kekuatan mampatan , keliangan, mikroskop imbasan elektron (SEM) dan analisis gravimetrik terma (TGA) . Empat jenis konkrit berbusa telah disediakan dengan peratusan yang berbeza diantaranya ialah LWC dengan 0 %, 10 %, 20 % dan 30 % POFA, kesemua kuib direndam dalam air sebelum diuji . Didapati konkrit yang mempunyai peratusan POFA sebanyak 20 % mempunyai kekuatan mampatan yang tertinggi iaitu 11.2 , 15.15 dan 29.20 MPa dan keliangan yang lebih rendah adalah 14.99 , 11.94 dan 9.54. Ia membuktikan bahawa peratusan keliangan rendah dan kekuatan mampatan konkrit yang mempunyai peratusan POFA sebanyak 20% adalah lebih tinggi daripada peratusan POFA yang lain. Selain itu, melalui struktur mikro telah mendapati bahawa LWFC yang mempunyai peratusan POFA sebanyak 20 % adalah lebih padat, berbanding dengan konkrit biasa. Penggunaan yang berkesan pada POFA sebagai bahan pozzolana dalam konkrit boleh mengurangkan kos pengeluaran konkrit, memelihara alam sekitar dan juga boleh menyelesaikan masalah tapak pelupusan.

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LIST OF SYMBOLS / ABBREVIATIONS

C-S-H	Calcium Silicate Hydrate
OPC	Ordinary Portland Cement
POFA	Palm Oil Fuel Ash
SEM	Scanning Electron Microscope
TGA	Thermal Gravimetric Analysis
UMP	University Malaysia pahang
w/b	water-to-binder ratio
SiO_2	Silicon dioxiode
Al_2O_3	Aluminum oxide
Fe_2O_3	Ferric oxide
CaO	Calcium oxide
MgO	Magnesium oxide
SO_3	Sulphur oxide
Na_2O	Sodium oxide
K_2O	Potassium oxide
LOI	Loss of ignition
DTG	Derivative Thermogravimatric
$Ca(0H)_2$.	Calcium Hydroxide
$CaCo_3$	Calcium Carbonate

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Malaysia is widely known around the world as a one of the largest product of palm oil. Palm oil is extracted from copra and fruit of the palm oil tree. Next after the extraction process, waste industry products like shells, fibers and palm oil are burnt to the boil water, to extraction process in palm oil mills. More two hundred palm oil mills operating only in Malaysia (Hussin and Awal, 1997). POFA in Malaysia has inspired research towards integrating this material as cement replacement in concrete production. POFA as replacement in concrete will indirectly minimize the environmental issues, scarcity of raw materials and the important thing can consumption of energy.

Waste generation from this industry reported that more two million tons of solid waste of palm oil residue as empty fruit bunches palm oil and also shells are produced annually (Office of the Agricultural Economics, 2002). At the same time, the increasing demand of construction material especially concrete has lead towards the use of natural aggregated. In order to reduce the consumption of this natural aggregate and to ensure environmental sustainability, they use of alternative constituent in concrete.

In conclusion, most of the concrete produced nowadays are multi component containing one, two or more admixtures in additional to the basic component such as water, cement, fine and coarse aggregate. The creation of the new material will definitely offer as extra boost to the palm oil industry

1.2 PROBLEM STATEMENT

Malaysia which is the major palm oil exported palm oil processing factory for a long time. So far the discovery on the utilization of palm oil fuel ash (POFA) as partial cement replacement in concrete research is limited to production of normal concrete (Hussin and Abdul Awal, 1996) and high strength concrete (Sata et al.2004). The dumping of palm oil fuel ash (POFA) has become a missive problem to palm oil because this wastage has not been recycled or reused in any work, this problem also been highlighted by Tay and Show(1990), who stated that this ash also caused environmental problems and potential health hazard. In this study aerated concrete will use to combine with palm oil fuel ash (POFA).

Aerated concrete has a very low thermal conductivity that makes it an excellent fire protection property (Narayanan & Ramamurthy, 2000b) than normal concrete. It is also known that tones of industrial waste are produced worldwide every day that cause environmental problems. Aerated concrete is generally regarded as a green and environmentally cause the main components of aerated concrete are sand, cement, water, aluminum powder and also Palm Oil Fuel Ash (POFA) and that there is o environmental pollution.

1.3 OBJECTIVE OF STUDY

The objectives of the study are:

i. To determine the compressive strength of foam concrete by using POFA content as partial cement replacement in aerated concrete.
ii. To investigate the Microstructure of foam concrete by using POFA as cement replacement material.
iii. To identify the POFA toward concrete hydration product.

1.4 SCOPE OF STUDY

The purpose of the research is an attempt to incorporate POFA in the production of lightweight concrete specifically known as aerated concrete. The density of the concrete must around 1800kg/m^3.

At the first stage of the laboratory work, the mix proportion of POFA as partial cement replacement in aerated concrete which is used as the control subject is developed. The set of test consist of water, sand, aluminum powder, cement and various content of POFA which replaces the cement partially by weight. The mix proportion percentage is 0 %, 10 %, 20 % and also 30 %.

The concrete mixes were cast and poured into the mould. All specimens were subjected to water curing. In this study, the test was used 100mm x 100mm x 50mm cube size for porosity test and compressive strength was used 100mm x 100mm x 100mm, was measured at 7, 28 and 90 days. For Scanning Electron Micrograph (SEM) and Thermal Gravimetric Analysis (TGA) test was conduct at concrete age 60 days.

1.5 SIGNIFICANT OF STUDY

Concrete is a one of important material in construction. Nowadays many development and modification have been made to replace concrete to industrial waste such as POFA. Findings from the research would provide more information on the properties of aerated concrete various content of POFA as partial cement replacement. Moreover, the usage of partial sand replacement material in concrete could reduce the amount of natural sand used in construction project and also can minimize the cost of the construction material.

1.6 LAYOUT OF THESIS

This thesis paper consists of five (5) parts. The first part is chapter 1 of research that elaborate briefly on the project introduction, problem statement, objective, scope of study, significance of study and also layout of thesis. Than for chapter 2 discusses the findings and previous work done by other researchers regarding the concrete properties and pozzolanic materials that are used in concrete. chapter 3 is methodology part presents the methodology, material and experimental approach used in this study. Next, chapter 4 is elaborates and discusses on the finding and result from the experimental that has been done in accordance to the methodology. Finally, chapter 5 is presents the conclusion of the all results and outlines recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete is one of the oldest manufactured construction material used in construction of various structures globally until now. Concrete production has certainly enormousness of natural resources such as which has caused substantial environmental losses. Therefore, it is seen that integrating palm oil fuel as as partial sand replacement material would reduce the utilization of natural sand in concrete production.

During recent decades, Ahmad et al. (2005) reported that, palm oil fuel ash which contain siliceous compositions and able to react as pozzolanic materials to produced a stronger and denser concrete when it is used as partial cement replacement material and about thousands of tons of palm oil fuel ash (POFA) are produced yearly by operation of 200 palm oil mills in Malaysia and most of these POFA are normally disposed for landfill without any commercial return (Awal, 1997).

In this fast paced world, addition of waste materials in concrete has rapidly increased due to the booming of construction industry. This is parallel to the effort in reducing consumption of energy from industries due to the greenhouse effect, high energy cost and diminishing energy sources in the world.

However, continuous research of concrete material has resulted many types of concrete having unique characteristic to fulfill the current construction industry demand. One of the concrete that becoming famous nowadays is aerated concrete due to it's lightness and versatility. 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). 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.

2.2 TYPE OF AERATED CONCRETE

Aerated concrete is also known as cellular aerated concrete, foamed concrete, cellular concrete or gas concrete. According to Tam et.al (1987), the type of concrete is essentially an aerated cement mortar or paste made by introducing gas or air in the form (diameters from 0.1 to 1.0mm) into a plain a cement paste or mortar mix during the mixing process.

According to the past research, Narayanan & Ramamurthy (2000b), aerated concrete can be divided to two types that are gas concrete and foamed concrete. Aerated concrete is classified based upon the method of 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.

Foamed concrete is manufactured by entertaining 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.

2.3 ORDINARY PORTLAND CEMENT CONCRETE

There are many advantages of concrete such as build in fire resistance, high compressive strength and also low maintenance, (Choo, 2003). It has been widely used because of it is rich resources of raw materials, good performance, simple production process, high strength and durability, low price and also can be combined with reinforcement to produce a strong reinforced concrete structure. Since global warming has emerged as the most serious environmental issues, the concrete industry will not be the new types of concrete manufactured with expensive materials and special methods but highly concrete mixtures and low cost containing largest possible amounts of industrial and urban by-products that are suitable for partial replacement of Portland cement, drinking water and virgin aggregate (Metha,2004).

During concrete mixing, the cement and water will cost the surface of the coarse and fine aggregates. When the concrete induce the hydration reaction, the specimen will hardens and gains strength to form the concrete. According Metha (2001), each one of these concrete primary constituents, to a extent has an environmental impact and give rise to different sustainability issues. Normal concrete has a comparatively low tensile strength and for structural application.

2.3.1 Main Compounds of Portland cement

Raw material used in manufacturing Ordinary Portland Cement such as alumina, iron oxide and more. Table 2.1 shown main compound of Ordinary Portland Cement according Neville,2009).

Table 2.1 : Main Compound of Ordinary Portland cement

Name of Compound	Oxide Composition	Abbreviation	Compound Composition%
Tricalcium Silicate	$3CaO.SiO_2$	C_3S	42 – 67
Dicalcium Silicate	$2CaO.SiO_2$	C_2S	8 - 31
Tricalcium Silicate	$3CaO.Al_2O_3$	C_3A	5 - 14
Tetracalcium Aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	6 - 12

Sources: Neville, 2009

2.3.2 Chemical Composition of Ordinary Portland cement

Ordinary Portland cement mostly contained chemical compositions like alumina, silica and limestone. The three type of chemical very important for the formulation of

calcium silicate hydrate during hydration process. Table 2 below shown the composition of cement according (Neville,2010).

Table 2.2: General Composition Limits of Portland cement

Oxide	Content, %
CaO	60 - 67
SiO_2	17 - 25
Al_2O_3	3 - 8
Fe_2O_3	0.5 - 6.0
MgO	0.5 - 4.0
Na_2O	0.3 - 1.2
SO_3	2.0 - 3.5

Sources : Neville,2010

2.4 PALM OIL FUEL ASH (POFA)

2.4.1 Definition of Palm Oil Fuel Ash

In Malaysia POFA 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. In practice, POFA produced in Malaysian palm oil mill is dumped as waste without any profitable return (Sumadi & Hussin, 1995).

Generally, after combustion about 5% palm oil fuel ash by weight of solid wastes is produced (Sata et.al, 2004). 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. The ash produced sometimes varies in tone of colour from whitish grey to darker shade based on the carbon content in it. The physical characteristic of POFA is very much influenced by the operating system in palm oil factory. Chindaprasirt et al., (2007) stated that the increasing amount of palm oil fuel ash disposed in landfills has noe becomes a burden and nuisance to the environment. There will be approximately 20 tonnes of nut shells, 7 tonnes of fibers, and 25 tonnes of empty bunches discharged from the mill for every 100 tonnes of fresh fruit bunches processed (Tay, 1995). 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.

2.4.2 Characteristics of POFA

POFA is a pozzolanic materials as indicated by both physical properties and chemical analysis (Awal and Hussin, 1997; Sumadi and Hussin, 1993). This characteristic is crucial in determining the suitability of using POFA as a partial cement replacement in concrete.

The physical properties of POFA are greatly influenced by the burning condition, particularly burning temperature (Abdullah et al., 2006). Next, the rate of pozzolanic reaction, hydration and development of POFA concrete strength depends on the fineness of particles. Underground POFA particles are mostly large, spherical and porous. In contrast, the ground POFA generally consist of smaller crushed particles with irregular and angular shape similar to the Portland cement (Chindaprasirt et al. 2007).

The chemical composition for pozzolanic material is grouped in between Class C and Class F as specified in ASTMC618-92a (Awal & Hussin, 1997). Both physical properties and chemical analysis indicated that POFA is a pozzolanic material (Awal & Hussin, 1997; Sumadi & Hussin, 1993).

Usually, the grinding process reduces not only the particles size but also the porosity of the POFA (Kiattikomol et al., 2001). Particles size of POFA can be reduced by the grinding process in Los Angeles abrasion machine using mild steel bar instead of steel ball (Abdullah et al. 2006). After grinding, POFA can be less porous with smaller particles (Paya et al., 1996). The general physical properties of raw and ground POFA are presented in Table 2.3 below.

Table 2.3 : Physical Characteristics of as received and the Blended Ground POFA

Physical Properties	**Ground POFA**	**Raw POFA**
Texture	Powdery	Hard, gritty, light, cellular
Shape	Round	Irregular
Appearance before ignition	Grayish, powdery	Dark spongy
Appearance after ignition	Brownish	Porous, grayish

Sources: Oyeleke Et Al., 2011

Particularly, as POFA contains lower lime content compared to OPC, large and hence amount of POFA could not be used as partial cement replacement. This is due to the lower content of calcium oxide which tends to hinder the hydration process which thus would give negative impact towards the early strength development of concrete. However, the chemical composition of POFA can still be varied because of the variability in the

nature of the product and because of various burning conditions due to different implementation of operating in the palm oil mail.

Researchers (Awal et. Al., 1996 ; Abdullah et al., 2006) have classified POFA as a class F pozzolan and POFA is quite rich in silica content while lime content is very low compared to OPC (Awal and Hussin,1997). The justification was made based on the percentage of CaO content in POFA. The major chemical composition of POFA is SiO_2 which contain about more than 50% of the constituents.

2.4.3 Chemical Properties of POFA

While the amount of POFA produced increase annually, allocation of transportation cost and landfills for the disposal of POFA is not an effective way to manage the waste as POFA has no commercial return value and it may lead to environmental problems in the future (Tangchirapat et al., 2006). Studies from researchers such as Tay (1995), Hussin and Awal (1997) and Tangchirapat et al.(2006) have proved that POFA can be reutilised as cement replacement material or as aggregate in concrete due to the pozzolanic properties it possesses.Supply of POFA from different palm oil mill will have separate chemical properties. However, silica is still the major chemical composition in POFA. The chemical composition of different POFA used in various research works are shown in Table 2.4

Table 2.4: Chemical Composition of POFA Used In Various Researches

Chemical Composition l	**Awal**	**Tangchirapat**	**Eldagal**
Silicon dioxiode (SiO_2)	43.60	57.71	48.99
Aluminum oxide (Al_2O_3)	11.50	4.56	3.78
Ferric oxide (Fe_2O_3)	4.70	3.30	4.89
Calcium oxide (CaO)	8.40	6.55	11.69
Magnesium oxide (MgO)	4.80	4.23	1.22
Sulphur oxide (SO_3)	2.80	0.25	
Sodium oxide (Na_2O)	0.39	0.50	0.73
Potassium oxide (K_2O)	3.50	8.27	4.01
Loss of ignition (LOI)	18.00	10.52	10.51

Sources: Awal,1997; Tangchirapat, 2007; Eldagal, 2008

2.4.4 Use of POFA in Concrete

According, Chindaprasirt et al. (2006) stated that the POFA can be applied as the new pozzolanic materials in concrete with an acceptable strength. That the optimum cement replacement by POFA is 20 % which if it is beyond this ratio, the compressive strength is

reduced and also tends to give higher permeability of concrete. However, it was suggested to use finer POFA in order to achieve better strength of POFA concrete (Hussin and Awal, 1996). According to (Tay, 1990; Tay and Show, 1995), they revealed that the compressive strength of concrete decrease as the POFA content increase. In the other researcher have found that the concrete made with POFA exhibit a higher compressive strength than OPC concrete (Tonnayopas et al; 2006).

Besides that, the durability of concrete is one of the most important properties a side from it is compressive strength because in concrete are mostly due to durability failures rather than insufficient strength. The research conducted by Awal and Hussin (1997) have becomes fruitful when they manage to enhance the durability of plain concrete thought the integration of 20 % of POFA by weight of cement. However, the high strength concrete containing ground POFA showed a better resistance to sulfate attack than normal POFA concrete (Tangchirapat et al., 2009) which thereby indicate that the fineness influenced the sulfate resistance of concrete.

Several studies were also conducted to investigate the effect of POFA towards the carbonation of cement paste (Chindaprasirt and Rukzon, 2009). Awal and Hussin (1999) have investigated concrete resistance to carbonation with and without ground POFA. They have found that there is a little difference between the carbonation values of POFA and OPC concrete. In addition, they have also mentioned that the results are not truly conclusive because POFA concrete appears to be more sensitive to the exposure condition. This situation indicates that the dryer the concrete, the deeper the carbonation in POFA concrete. Therefore, it can be concluded that the POFA of greater fineness and appropriate replacement percent should be used as supplementary cementing material in concrete in order to improve the properties of POFA concrete.