Faculty of Engineering

HIGH STRENGTH OF BRICKS MADE UP OF POFA AND FLY ASH AS CEMENT REPLACEMENT

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Bachelor of Engineering with Honours

(Civil Engineering)

2017

UNIVERSITI MALAYSIA SARAWAK

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This project is submitted in partial fulfilment of the requirement for the degree of Bachelor of Engineering with Honours

(Civil engineering)

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UNIVERSITI MALAYSIA SARAWAK

2017

Dedicated to my beloved ones

ACKNOWLEDGEMENT

Alhamdulillah, praise to Allah for giving me the strength, blessings and the patience to complete this research successfully. I am grateful to myself for not giving up for this challenge is real. I am also grateful to Dr. Raudhah Ahamad, my supervisor for my final year project. I am extremely thankful and indebted to her for sharing expertise, sincere, valuable guidance and encouragement extended to me. Besides, I would also like to appreciate the guidance and invaluable co-operation provided by Dr. Idawati Ismail. I also like to thank the technical staffs in Civil Engineering Department, Chemical Engineering Department and Faculty of Applied & Creative Arts especially to Mr Adha, Mr Zulfika and Mr Hisyam at Universiti Malaysia Sarawak.

I take this opportunity to express gratitude to my final year project member, Muhmmad Faiq and Faris Nur for their endless help and support. I also thank my beloved parents and friends for the unceasing encouragement, support and attention throughout this venture.

ABSTRACT

Palm Oil Fuel Ash (POFA) is known as the by-product from palm oil industry while fly ash is a by-product of coal-fired power stations which both are substituted for Ordinary Portland Cement (OPC). The plenty amount of these waste products creates an opportunity for researchers to discover the potential of these materials as partial cement replacement. Both materials have pozzolanic properties which like Ordinary Portland cement (OPC). The properties are alumina, silica and hydrogen bond which give strength to the concrete or mortar bricks. This alternative way is not only could contribute to extra income for palm oil mill and coal mill but helps in reducing the environmental pollution. Previous studies have successfully proved that the substitution of cement with POFA and fly ash will give benefits to the construction industry especially the concrete and brick manufacturer. Thus, this research is carried out to produce ultrafine size POFA is 0.24 µm in a short period and compare with fly ash as cement replacement too. After collect POFA at mill, the raw POFA will undergo oven drying process at 100 degrees for 24 hours. Then, the POFA will sieve to remove fibre and large particle before burning process. Next, POFA will undergo burning process at 500 degrees by using kiln for 6 hours in two days. This process to eliminate the excessive carbon content that leads to decrease the mortar brick and concrete strength. The production of ultrafine sized POFA is conducted using a 25000-rpm electric grinder to grind POFA for 30 minutes. Samples of the grinded burned POFA are analyzed to check its particle size at D50 by using the Particle Size Analyzer. The accepted size of burned POFA is then implemented into the production of the mortar brick samples for the purpose of the experimental test which compressive test on 7th, 14th, 28th and 56 days.

ABSTRAK

Abu bahan api minyak sawit (POFA) dikenali sebagai hasil sampingan daripada industri kelapa sawit manakala abu arang (fly ash) adalah merupakan hasil sampingan kepada stesen-stesen janakuasa berasaskan arang batu yang keduanya dijadikan sebagai bahan pengganti untuk simen (OPC). Jumlah yang banyak terhadap bahan buangan ini mewujudkan peluang kepada para penyelidik untuk menerokai potensi bahan-bahan ini sebagai bahan pengganti simen. Kedua-dua bahan ini mempunyai sifat-sifat pozzolanic yang sama seperti simen (OPC). Sifat-sifat seperti alumina, silika dan ikatan hidrogen memberi kekuatan konkrit atau batu bata. Cara alternatif ini bukan sahaja dapat menyumbang kepada pendapatan tambahan kilang minyak sawit dan arang batu malah dapat membantu dalam mengurangkan pencemaran alam sekitar. Kajian sebelum ini telah berjaya membuktikan bahawa gantian simen dengan POFA dan abu arang akan memberi faedah kepada industri pembinaan terutamanya pengeluar konkrit dan batu-bata. Oleh itu, kajian ini dijalankan dengan menghasilkan size ultrafine POFA iaitu 0.24µm dalam tempoh yang singkat dan akan dibandingkan dengan abu arang sebagai simen gantian juga. Selepas mengumpul POFA di kilang, di POFA mentah akan menjalani ketuhar pengeringan proses di 100 darjah selama 24 jam. Kemudian, POFA yang akan diayak untuk membuang serabut dan zarah besar sebelum proses pembakaran. Seterusnya, POFA akan menjalani proses pembakaran pada 500 darjah dengan menggunakan tanur elektrik (electric kiln) selama 6 jam dalam masa dua hari. Proses ini bertujuan untuk menghapuskan kandungan karbon berlebihan yang membawa kepada penurunan kekuatan batu-bata dan konkrit. Pengeluaran POFA bersaiz ultrafine dijalankan menggunakan sebuah pengisar elektrik, 25000-rpm untuk mengisar POFA selama 30 minit. POFA yang telah dikisar akan dianalisis untuk memeriksa saiz zarah di D50 dengan menggunakan 'Particle Size Analyser'. Akhir sekali, POFA yang dibakar kemudian diteruskan dengan pengeluaran dan penghasilan sampel bata mortar untuk tujuan eksperimen dalam ujian mampatan kekuatan pada hari ke-7, 14, 28 dan 56.

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LIST OF ABBREVIATIONS

POFA	Palm Oil Fuel Ash
FA	Fly Ash
RHA	Rice Husk Ash
SCMs	Supplementary cementing materials
ASTM	American Society for Testing and Materials
OPC	Ordinary Portland Cement
HSC	High Strength Concrete
PSA	Particle Size Analysis
V	Voltage
μm	Micro Meter
°C	Degree Celcius
CILAS	French company (specialized in laser and optics technologies)
CMS	Cahaya Mata Sarawak
OPC	Ordinary Portland Cement

CHAPTER 1

INTRODUCTION

1.0 Background Study

In this era of technologies, the developing phase for construction industry is rapidly increased. It creates a lot of new technologies as well as finds new research that can give great impact for the industry. It also helps to reduce the environmental impact. In construction industry, the main element is about the materials such as cement, sand, concrete, bricks and steel bar. The usage of cement in construction industry had been widely used around the world. It becomes an essential for each construction, thus it will give bad impacts to the environment due to increasing of cement production. Therefore, the utilization of waste materials is an alternative way to replace the usage of cement in construction industry.

1.1 High Strength Concrete (HSC)

The use of high strength concrete (HSC) in structures is increasing worldwide. In Malaysia, normal concrete is in the range of 30 MPa and 40 MPa. Many projects particularly in high rise construction has been determined their concrete strength which is 50, 60 and even 70 MPa especially for load bearing segments. The most significant use of high strength concrete in Malaysia is the Petronas Twin Tower project where 80 MPa (characteristic cube strength) concrete for the lower level columns has been specified (Gurusamy, 1995).

Malaysian standards are based on British Standards which refer to concrete up to grade 60 (28-day characteristic cube strength). Hence, in Malaysia, high strength concrete can be defined as concrete with a cube strength of 70Mpa or more. Higher grades (55 and 60) are also more common in precast elements. According to Kribanandan Gurusamy (1995) the achievement of high strength concretes which is greater than 70Mpa has been possible primarily through the introduction of two new materials which is superplasticiser and micro silica.

Superplasticiser is used to increase the workability without changing the water cement ratio and to increase the ultimate strength of concrete by reducing water content while maintaining adequate workability (Alsadey, 2015). Superplasticiser is a type of water reducers. According to Neville (2012) the difference between superplasticiser and water reducer is that superplasticiser will significantly reduce the water required for concrete mixing. The disadvantage of having superplasticiser is less flexibility and limited use when an accelerating or retarding effect is not desired.

1.2 Ordinary Portland Cement (OPC)

The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming (Reddy, 2013). It also reduces the supply of good quality limestone and clay. As Good engineers, we must reduce the use of Portland cement in concrete (Malhotra, 2004). The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Substantial energy and cost savings can result when industrial by products are used as a partial replacement of cement. Fly ash, ground granulated blast furnace slag, rice husk ash, silica fume is some of the pozzolanic materials which can be used in concrete as partial replacement of cement.

1.3 Palm Oil Fuel Ash (POFA) and Fly Ash (FA)

Nowadays, the use of recycled materials as concrete ingredients is gaining popularity and interest due to increasingly strict environmental legislation (Ekolu et al., 2014). Furthermore, there is significant research on many different materials for cement usage substitutes and replacement such palm oil fuel ash (POFA), fuel ash (PFA), rice husk ash (RHA) and many others fiber and pozzolanic material. These pozzolanic also known as secondary cementitious materials or supplementary cementing materials

(SCMs). The use of these materials in concrete reduces the amount of resources required as the ash act as a cement replacement. Malaysia is second largest producer in palm oil industry, its generate large amount of palm oil waste which is the biggest contributor to the nation's pollution problem (Ariffin et al., 2014). From Table 1.1, 0.06 million tonnes of POFA is produced every year in Malaysia and these POFA can be used as cementitious material in concrete.

Table 1.1: Generated of palm oil fuel ash (POFA) in Malaysia (MPOB, 2011)

Materials	Waste generated (million tones)				
	2007	2008	2009	2010	Jan-June 2011
Oil Palm Kernel Shell (OPKS)	2.2	2.4	2.3	2.2	1.3
Oil palm kernel (fruit)	4.1	4.6	4.5	4.3	2.6
Palm Oil Fuel Ash (POFA)	0.06	0.06	0.06	0.06	0.04

For every 100 tonnes of fresh fruit bunches processed, approximately 20 tonnes of nut shells, 7 tonnes of fibers, and 25 tonnes of empty bunches are discharged from the mill (Yap et al., 2013). Production of POFA as a solid waste from palm oil industry is increasing and greenhouse gas emissions resulting from the manufacturing of cement which affect the environment (Obla, 2009). This waste materials have been integrated as partial amount of cement replacement to produce various types of concrete which consume less amount of cement, less pollution and low cost.

Fly ash is a by-product of coal-fired power stations which substituted for Portland cement to improve the properties of concrete and reduce the embodied greenhouse gas (GHG) emissions (O'Brien et al., 2009). Reducing emissions from the calcination process means looking to a material other than limestone. Blended cement replaces some of the limestone based clinker with other materials such as fly ash and blast furnace slag. According to Rubenstein (2012) fly ash could reduce CO_2 emissions by as much as 20%, but widespread use of blended cement is limited by other environmental regulations, the limited availability of substitute materials and building code restrictions which blended cement can take longer time to set.

1.4 Application of Mortar Brick

Selection of an appropriate mortar helps to ensure durable brickwork that meets performance expectations. Mortar type and mortar material selection should consider multiple aspects of a project, including design, brick or masonry materials, exposure and required level of workmanship. Improper mortar selection may lead to lower performance of the finished project.

Mortar bonds individual brick together to function as a single element. In its hardened state, mortar must be durable and must help resist moisture penetration. Mortar also must have certain properties in its plastic state so that it is both economical and easy to place. One property of mortar that is often overemphasized is compressive strength. Stronger is not necessarily better when specifying mortar. In fact, the opposite is often true. Mortar selection should be based on properties such as durability and workability in addition to compressive strength.

Mortars are classified by ASTM C 270 into four types which are M, S, N and O. Type N mortar usually for normal brickwork application while type S for stronger brickwork applications. Stronger applications are needed in high seismic, high wind areas and reinforced brickwork. The location uses for this brick as exterior in building This research focus on producing types S mortar brick with made up of fly ash and POFA as partial cement replacement.

1.5 Problem Statements

Bricks are one of the environmentally friendly building products because processing temperature is relatively low. Basically, mortar brick is made up of cement, sand and water. Selection of an appropriate mortar helps to ensure durable brickwork that meets performance expectations. The intention is to minimise the usage of Portland cement in mortar brick production and use waste materials such as POFA and fly ash as cement replacement into useful product. The life span of bricks is often mitigating due to the aggressive environment. This research will focus on producing high strength mortar bricks made up of ultrafine POFA and fly ash as partial cement replacement.

1.6 Aims and Objectives

The main aim of this project is to produce high strength mortar bricks for stronger applications by using palm oil fuel ash (POFA) and fly ash as cement replacement.

The objectives in accordance with the aims of the research are given as follows:

1. To design high strength mortar bricks which is using fly ash and POFA as cement replacement.
2. To compare the strength of mortar brick with concrete cube which is also using fly ash and POFA as cement replacement.

1.7 Scope of Works

In this research, an attempt to add the POFA and fly ash as partial cement replacement in mortar brick production. This research focus on investigating the effects of mortar bricks to the strength of mortar brick by using fly ash and POFA as cement replacement with varies percentage of the amount of POFA and fly ash. Scope of this study includes the following procedures:

i. The size of ultrafine POFA used as the cement replacement is below 2μm.
ii. Replacement of cement using normal size of fly ash from 10% to 70% by weight of cement.
iii. Replacement of cement using ultrafine size of POFA from 10% to 40% by weight of cement.
iv. To optimise the production of burned ultrafine size POFA by using kiln (± 500 °C for 6 hours in two days).
v. To optimise the production of ultrafine size POFA by using 25000-rpm electric powder grinder.
vi. Production of mortar bricks made up of fly ash and ultrafine size POFA as cement replacement with standard size.
vii. Determine the high strength of mortar brick by compressive test.
viii. Compare the strength of mortar brick with strength of concrete cube.
ix. Compare the strength of mortar brick with water adsorption of mortar bricks

1.8 Significance Study

The discovery of the potentials of POFA and fly ash as cement replacement in concrete and mortar bricks has triggered the researchers to do detailed studies on POFA as the utilization of POFA and fly ash may help to develop the construction industry. The most importantly is may aid in the conserving the environment. Researchers have discovered the application of micro fine size of POFA in the concrete can boost up its pozzolanic properties which is silica content resulting in the increasing of the compressive strength, workability and durability of the concrete as well as its performance under aggressive environment. Therefore, this research is focus more on application ultrafine size POFA, fly ash and normal size of fly ash in mortar bricks compare with normal mortar bricks design. The study to design high strength of mortar bricks made up with ultrafine POFA and fly ash as cement replacement material which can increase the lifespan of the mortar brick. The construction industry may start to practice applying POFA and fly ash into the mortar brick used in their construction to achieve a stronger structure with a longer lifespan, thus can reduce the pollution.

CHAPTER 2

LITERATURE REVIEW

2.0 General

This chapter discusses on the ordinary Portland cement (OPC), cement replacement materials, palm oil fuel ash (POFA), fly ash, durability of chloride attack and bricks.

2.1 Ordinary Portland Cement (OPC)

2.1.1 History of Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) is the most common cement used in general concrete construction when there is no exposure to sulphates in the soil or groundwater. A paste of Portland cement develops strength primarily by the hydration of the di-calcium and tri-calcium silicates (Bye, 1999). There are two products in the reaction which is calcium hydroxide sometimes referred as as calcium silicate hydrate.

According to G.C. Bye (1999) concrete is a composite material produced by using cement to bind fine and course aggregate which is sand and gravel or a crushed rock such as limestone or granite into a dense coherent mass. The name of Portland cement began from concrete looked like or could replace Portland stone. The volume of plastic material is smaller than concrete required then a fine sand and cement mix (mortar) is utilized.

2.1.2 Physical and Chemical Properties of Ordinary Portland Cement (OPC)

The main composition found in the ordinary Portland cement is lime (CaO). The lime in excess makes the cement unsound and causes the cement to expand and disintegrate. If lime is in deficiency, the strength of cement decreases and it causes cement to set quickly. Another important composition in cement **is s**ilica ($Si0_2$) because it gives or provides strength to the cement due to the formation of dicalcium and tricalcium silicates. If silica is present in excess quantity, the strength of cement increases but at the same time, its setting time is longed.

Alumina (AI_20_3) is another significant component of cement. This ingredient provides quick setting property to the cement. It acts as a flux and it lowers the clinkering temperature. However, the high temperature is essential for the formation of a suitable type of cement. Hence, the alumina should not be present in excess amount as it weakens the cement. Calcium sulphate ($CaS0_4$) is one of the ingredients in the form of gypsum to increase the initial setting time of cement. Iron oxide (Fe_20_3) is the ingredient that provides colour, hardness and strength to the cement. Lastly is magnesia (MgO). If this ingredient is present in small amount, therefore it will increase hardness and cause colour to the cement. A high content of magnesia makes the cement becomes unsound. Table 2.1 shows the chemical composition between ordinary Portland cement and palm oil fuel ash.

Table 2.1: Chemical composition of OPC and POFA (K.Abdullah, 2006)

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

The physical properties of ordinary Portland cement (OPC) is fineness, soundness, consistency, setting time, compressive strength, heat of hydration, loss on ignition, specific gravity and bulk density. Fineness is measured in terms of percentage of weight retained after sieving the cement through 90-micron sieve or by surface area of cement in square centimetres per gram of cement. According to A.M. Neville (2012) fine cement will develop strength and generate heat more quickly than coarse cement.

Soundness is referring to the ability of a hardened cement paste to retain its volume after setting without delayed expansion (Neville, 2012). This expansion can cause by excessive amounts of free lime (CaO) or magnesia (MgO). Cement paste setting time is affected by a number of items including cement fineness, water-cement ratio, chemical content and admixtures. For construction purpose, the initial set must not be too soon and the final set must not to be too late.

2.1.3 Cement Replacement Materials

Cement replacement materials are special types of naturally occurring materials or industrial waste products that can be used in concrete mixes to partially replace some of the Portland cement (Swan, 2008). Cement replacement materials are frequently called fine minerals or pozzolans. Pozzolan is defined as a siliceous and aluminous material which is in the presence of moisture and chemically acts with calcium hydroxide at ordinary temperatures to form compounds.

Natural pozzolan is a raw material that shows pozzolanic properties. Acoording to C. Swan (2008) concrete with cement replacement materials can actually be stronger and more durable than concrete with ordinary Portland cement (OPC). The example of cement replacement materials is palm oil fuel ash (POFA), fly ash (FA), cement kiln dust (CKD), ceramic waste, silica fumes, ground granulated blast-furnace slag and rice husk ash (RHA). Shiathas et al. (2003) also reported that these pozzolanic generally improve durability properties, reduce adverse environmental effects and also cost of concrete.

Cement kiln dust also known as cement bypass dust which is a by-product of manufacturing of OPC produced by the dry process (Sukesh et al., 2012). It is generated during the burning process in the kiln. Sukesh et al. (2012) stated that dust particles are produced after heated in the kiln and then carried out with the exhaust gases at the upper end of the kiln. The product comes out as a fine powder which is ready to use in cement mixes.

Ceramic waste can be separated in two categories. According to Sukesh et al., (2012) the first one are all fired waste generated by the structural ceramic factories that use only red paste to manufacture their product such as bricks, blocks and roof tiles. The second one is all fired waste produced in stoneware ceramic such as wall, floor, tiles and sanitary ware. The silica and alumina are the most significant oxides present in the ceramic paste. Figure 2.1 shows the mineralogical composition of ceramic waste.

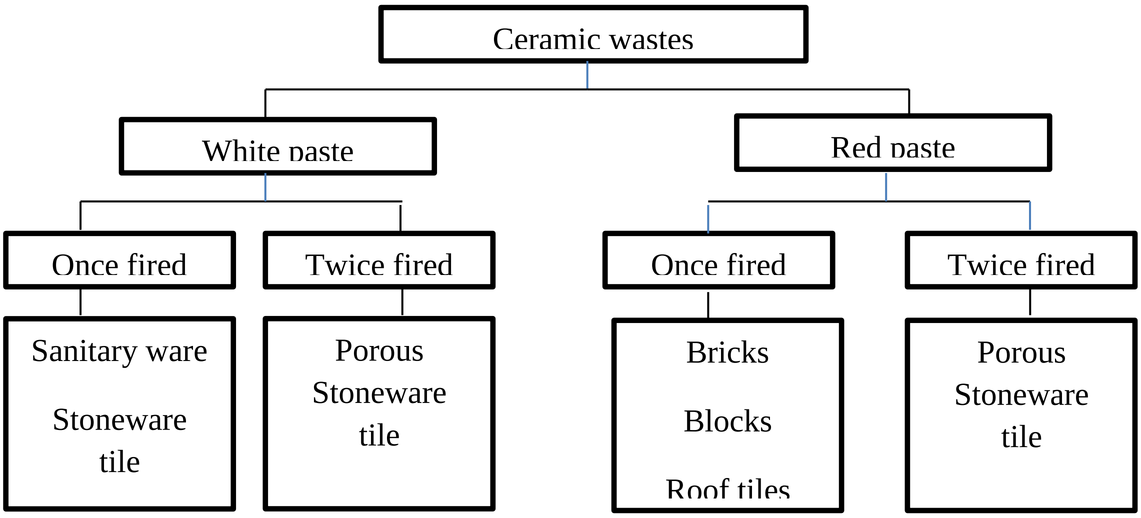

Figure 2.1: Classification of ceramic wastes by type and production process (Said, 2009)

Granulated blast furnace slag is the granular material formed when molten iron blast furnace slag is quenched. It is a granular product with very limited crystal formation. It is highly cementitious in nature when ground to cement fineness and hydrates like portland cement (Swan, 2008). Blast furnace slag cement which is made by intergrinding the granulated slag with portland cement clinker (blended cement), has been used for more than 60 years.

Silica fume also known as microsilica, is a byproduct of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys (Swan, 2008). Silica fume is also collected as a byproduct in the production of other silicon alloys such as ferrochromium, ferromanganese, ferromagnesium, and calcium silicon. C. Swan stated that due to the extreme fineness and high silica content, silica fumes are a highly effective pozzolanic material. Silica fumes improve compressive strength, bond strength, and abrasion resistance, reduces permeability and therefore helps in protecting reinforcing steel from corrosion.

According to Mutadhi & Kothandaraman (2010) most of the husk from the milling is either burnt or dumped as waste in open fields and a small amount is used for fuel. Rice husk ash is used as a highly reactive pozzolanic material in concrete production and the ash properties vary due to the differences in incinerating conditions, rate of heating, geographic location and fineness (Hwang et al. 2011). Mutadhi & Kothandaraman (2010) reported their finding on optimum incineration condition is 500°C and 120 minutes