THE STUDY OF OPTIMUM RATIO OF MICRO SIZE OF POFA AS CEMENT REPLACEMENT

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ABSTRACT

Malaysia is the world's leading producer of palm oil. However, the advancement of the agriculture sector also leads to some bad effect especially to environment. Palm Oil Fuel Ash (POFA) is one of the by-products that produce from the combustion of the solid wastage that produced in palm oil factory. POFA had an ability to become the cement replacement in concrete. In order to find the optimum ratio of POFA used in concrete, some laboratory tests are conducted to determine the performance of POFA concrete in terms of workability, strength and durability. The result showed that POFA concrete had a lower workability compared to the control concrete G25. The compressive strength of the POFA concrete also lower compared to the conventional concrete. However, the flexural strength of concrete incorporated with 10% POFA was higher than the conventional G25 concrete. It means that 10% is the optimum ratio of POFA to substitute cement in concrete. In terms of durability, POFA concrete had a lower water penetration than conventional concrete G25. The result clarify that POFA had an ability to substitute 10% content of cement and improve the performance of concrete. For the suggestion, future details study of POFA in concrete should be carry out. Furthermore, the lower penetration of water in POFA concrete made it suitable to be used for the building that requires low water permeability of water like seaside construction.

ABSTRAK

Malaysia merupakan pengeluar utama minyak kelapa sawit di dunia. Walau bagaimanapun, kemajuan sektor pertanian turut membawa kepada beberapa kesan yang tidak baik terutamanya kepada alam sekitar. Abu kelapa sawit (POFA) adalah salah satu produk yang dihasilkan daripada pembakaran bahan buangan pepejal kelapa sawit di kilang minyak kelapa sawit. POFA mempunyai keupayaan untuk menggantikan sebahagian kandungan simen di dalam konkrit. Untuk mencari nisbah terbaik POFA untuk digunakan di dalam konkrit, beberapa ujian makmal dijalankan untuk mengenalpasati prestasi POFA konkrit dari segi kebolehkerjaan, kekuatan dan ketahanan. Hasil daripada ujian yang dijalankan menunjukkan bahawa POFA konkrit mempunyai kebolehkerjaan yang lebih rendah berbanding dengan kawalan konkrit G25. Kekuatan mampatan konkrit POFA juga lebih rendah berbanding konkrit konvensional G25. Walau bagaimanapun, kekuatan lenturan konkrit yang digabungkan dengan 10% POFA adalah lebih tinggi daripada konkrit kawalan. Ini bermakna bahawa 10% adalah nisbah optimum POFA untuk menggantikan simen di dalam konkrit. Dari segi ketahanan, konkrit dengan POFA mempunyai penembusan air yang lebih rendah daripada konkrit biasa. Hasil daripada ujian ini menjelaskan bahawa POFA mempunyai keupayaan untuk menggantikan simen di dalam konkrit sebanyak 10% dan berupaya untuk meningkatkan prestasi konkrit. Sebagai cadangan, kajian terperinci terhadap POFA hendaklah dijalankan untuk mengenalpasti keupayaan dan ketahanan POFA konkrit pada aspek yang berbeza.. Tambahan pula, penembusan air yang lebih rendah pada POFA konkrit menjadikan ia sangat sesuai untuk dijadikan bahan binaan di kawasan yang lembab seperti di tepi pantai.

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LIST OF SYMBOLS

^{o}C	Degree celcius
% max	Maximum percentage
% min	Minimum percentage

LIST OF ABBREVIATIONS

BS	British Standard
OPC	Ordinary Portland cement
LFC	Lightweight foamed concrete
FA	Ground pulverized coal combustion fly ash
FB	Ground pulverized coal combustion fly ash
RHBA	Ground rice husk-bark ash
POFA	Palm oil fuel ash
W/c	Water to cement ratio
H_2O	Water
SiO2	Silica oxide
$Ca(OH)_2$	Calcium hydroxide
SiO_2	Silicon dioxide
Al_2O_3	Aluminium oxide
FE_2O_3	Iron oxide
CaO	Calcium oxide
MgO	Magnesium oxide
K_2O	Potassium oxide
Na_2O	Sodium oxide

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Cement is one of the main components in concrete manufacturing. According to Malcom (2012), cement is firstly introduced on third millennium before century. The first cement was made up from the mix of sand, lime and gravel. Nowadays, the price of the cement is getting higher since the demand of concrete in the construction is increase. It is because concrete is easily to handle and suitable for many type of construction including high rise building and bridge.

Agriculture is the major sector in Malaysia. One of the important products that have generated most of economy and developed into a multibillion ringgit industry in Malaysia is palm. Palm oil and related product had brought a huge profit in Malaysia's economy. Many developers and communities are strongly believed that this industry can give bearable return and them willing to open new areas for oil palm cultivation, usually from virgin jungles and from the conversion of other plantations. Statistic of hectares of palm oil in Malaysia shown in Table 1.1 was collected from the Malaysian Oil Palm Board. The statistic had shown that the palm oil industry had growth drastically in Malaysia. From only 400 hectares planted in 1960, the hectares of palm planted in Malaysia are continuously increased from year to year.

Table 1.1: Hectares of oil palm in Malaysia

Year	Hectares
1920	400
1940	31400
1960	54838
1980	1023306
2000	3376664
2005	4021374
2011	5000109

Source: MPOB, Malaysian Oil Palm Statistics (2011)

Palm Oil Fuel Ash (POFA) is one of the by-products that produce from the combustion of the solid wastage that produced in palm oil factory. According to Thangchirapat (2007), about 3.1 million tons of POFA is produce every year. The POFA produced is usually manage by dumping it at the landfill site and not produce any profit at all. POFA is naturally containing reactive silica and have the ability to perform the pozzolanic reaction. The pozzolanic activity can be improved by increasing the surface area of POFA by grinding process. Because of those natural properties of POFA, it has the high chances to produce a higher strength and more durable of concrete compare to the conventional concrete.

1.2 PROBLEM STATEMENT

The advancement of the agriculture sector also leads to some bad effect especially to environment. POFA that cannot give the profit is usually managed by accumulate it at landfill site. The increasing of landfill activity can produce serious pollution including soil pollution, water pollution, air pollution and sound pollution. Landfill environment is one of the major factors that can lead to environmental problems. For example, landfill environment can lead to many spread disease since there is the suitable and strategic habitat for disease agent or vector.

Besides, the price of concrete is getting higher. Building based on concrete is well-known and always be chosen in the construction sector. Thus, the price of concrete is getting higher. The only ways to reduce the price of concrete is by replaced any material on the concrete without reducing its ability in term of strength and durability. According

to Sukesh (2004), about 45% of the cost of concrete is come from the cement. Actions should be taken by researcher to reduce the usage of cement of concrete by replace it by others material such as agriculture ash.

1.3 AIM AND OBJECTIVES

The aim of this research is to discover the effect of different percentage of POFA in the concrete's performances. Five manipulated percentage of POFA as cement replacement (0%, 10%, 20%, 30% and 40%) will be used on the research while the burning process and size of the POFA is remain fixed. The objectives of the research are stated as below:

- To discover the effects of micro size of Palm Oil Fuel Ash (POFA) on engineering properties of concrete in terms of compressive strength, flexural strength, durability for water penetration and workability.
- To investigates the optimum ratio of POFA used as cement replacement.

1.4 RESEARCH METHODOLOGY OF OBJECTIVES

In order to fulfill the objectives of this research, laboratory tests will be used to get the best and most accurate data. The POFA used will be controlled in term of its moisture and its size. All of the laboratory tests will be carried out following the British Standard guidelines. The result collected will be fully analyzed to make sure the conclusion made is accurate.

Objectives 1: To discover the effects of micro size of Palm Oil Fuel Ash (POFA) on engineering properties of concrete in terms of compressive strength, flexural strength, durability for water penetration and workability.

In order to achieve the first objective, five different ratio of POFA will be used on every mix of concrete which are 0%, 10%, 20%, 30% and 40%. Only the ratio of the POFA is different in every concrete meanwhile the size and the burning condition of the POFA is remain fixed. Then, the laboratory test will be conducted by referring the

British Standard. Slump test will be conducted to find out the workability of the concrete. Cube test and flexural test is conducted to know the strength of the concrete both in compression and flexural strength. The durability of the concrete will be finding out by conducting water penetration test.

Objectives 2: To investigate the optimum ratio of POFA used as cement replacement.

After the data and result is collected, graph will be plotted to find the optimum ratio of micro size of POFA used. Discussion and conclusion will be made based on the graph. The performance of the each concrete can be analyzed easily based on the graph plotted.

1.5 SIGNIFICANT OF STUDY

POFA is unused by-product that also can lead to harmful of environment if it is not managed cleverly. However, the nature of POFA must not be ignoring. It has a great potential to become a partial substitution of cement in concrete since it contain large amount of silica oxide. Silica oxide plays a great role for pozzolanic activity to be conducted. This research will prove that POFA can be use and alter the performance of conventional concrete. Besides, the landfill problems can be reducing if POFA can be use continuously as cement replacement. This research also can help other innovation of concrete that become popular subject nowadays.

1.6 SCOPE OF LIMITATION WORK

The research was focused on the laboratory test to find out the performance of the POFA concrete with different ratio. The POFA used was directly get from Palm Oil Mills Lepar Hilir, Kuantan, Pahang. The burning condition of the POFA is fixed for all concrete that be tested. The POFA collected will be grind and sieve passing through 300μm to get a smaller size of POFA. According to Awal (1998), finer POFA will produce the stronger concrete compare to the courser POFA. The higher surface area of POFA will increase the pozzolanic activity of concrete.

For the research, the performance of concrete will be analyze depend on its workability, compressive strength, flexural strength and durability in term of water penetration. The slump test will be conducted on the fresh concrete to find out the workability of concrete. Meanwhile, the compressive strength is conducted to find out the compressive strength of concrete. Flexural test also will be conducted to know the flexural strength of concrete. In term of durability, water penetration test will be conducted. The entire laboratory test is conducted following the British Standard.

1.7 THESIS OUTLINE

5 chapters are containing on this thesis as stated below:

Chapter 1: Introduction

This chapter discusses about the background of the palm oil fuel ash (POFA) and its potential to become the cement replacement in concrete. The problems that occur nowadays also state and discusses on the chapter. Besides, the objectives and main aim of the research is including on chapter 1.

Chapter 2: Literature Review

This chapter is discusses about the properties of the materials used for concrete manufacture. The information that related to this research also includes on the chapter. Furthermore, the past research about the cement replacement is discusses on the chapter as well.

Chapter 3: Methodology

The material used for the research is discusses from the chapter. The steps and sequencing of test conducted to determine the performance of the concrete is discusses as well. The slump test, compressive test, flexural test, and water penetration test is describe on the chapter.

Chapter 4: Results and discussion

In this chapter, the results that gained from the experiment are lists and discusses. The optimum ratio of POFA as partial cement replacement also will be stated on the chapter.

Chapter 5: Conclusion and recommendation

This chapter will conclude for the entire research. Recommendation also will be presents to improve the concrete evolution on the world.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will be focus on the information that gain from other resource such as previous study and the official source that be related to this research. The detailed of the used of waste material as cement substitution will be discussed on this chapter. Furthermore, the potential and why POFA is choose as cement replacement for this research will be explain in detail as well.

2.2 CONCRETE

Concrete is one of the important men made products in construction sector. Basically, concrete is made from the mixture of cement, water, course aggregate and sand in appropriate proportion and sometimes is combining with admixture to alter its properties. However, the evolution of concrete is continuously undergone to improve the properties of concrete. According to Weerachart (2004), fly ash is one of the famous cement substitution used in concrete because of its chemical properties that rich with alumina and silica. The present of silica and alumina is very important for the pozzolanic reaction.

2.2.1 Cement

Cement is one of the important material that be used for concrete manufacture. Cement act as a binder and can fill the void between the particles in the concrete. Nowadays, many types of cement can be found in the market, such as: Portland cement,

Portland silica fumes cement, Supersulfated cements and etc. The lower price of Ordinary Portland Cement (OPC) had made it become the most type of cement used in the construction.

2.2.2 Water

Water is another material in concrete composition. The strength of concrete is depending on the quantity of water used. According to Nawy (2008), lower of water to cement ratio (w/c) will lead to higher strength of concrete but will reduce the workability of concrete. Thus, the w/c ratio used in concrete need to examine correctly to produce concrete with the desired strength workability and strength. Although the used of high w/c ratio can increase the workability of concrete, it also can reduce the durability of concrete as well. High w/c ratio used in concrete also can lead to others problem such as will easier the corrosive process of steel bar used in concrete.

2.2.3 Fine aggregates

Fine aggregates are non-reactive material and act as one of the concrete compound. Fine aggregates are important to fill the open space of concrete. According to Portland Cement Association (2012), fine aggregate needs to be passing through a 4.75 mm sieve to increase its ability to fill void in particles.

2.2.4 Course Aggregates

Course aggregates play an important role in concrete production in term of strength, durability and properties. Course aggregates used need to be clean and dry to improve the properties of concrete. According to Portland Cement Association (2012), size of course aggregates need to be higher than 0.19 inch. Consideration of characteristic of course aggregates used need to be taken to produce the desire concrete such as its shape and voids content. Smooth and rounded shape of course aggregate is the best shape to be chosen cause its can produce higher workability and strength of concrete than other shape of concrete.

2.3 POZZOLANIC MATERIAL

2.3.1 General

Many studies had been conducted in order to reduce the cost of the concrete and to establish an environmental friendly condition. The studies had discovered many materials that have an ability to become partial cement substitution in concrete. The materials are called as pozzolanic materials.

2.3.2 Definition of Pozzolanic Materials

A pozzolan is the material that had quite similar properties like cement. It is rich with siliceous and aluminous element naturally and very reactive to react with calcium hydroxide in the presence of water. The cementitious properties of the pozzolanic material can be improved by reducing it cost. Pozzolanic material is becoming quite popular as an additive and cement replacement in concrete to reduce its cost and increase its performance.

2.3.3 Classification

Pozzolanic material can be categorized to three classes based on the ASTM C618-03 (2004). The class is class N, class F and class C. POFA can be classified as class F since it is produce from the burning. Class F is had an ability to undergo pozzolanic reaction.

2.3.4 Chemical and Physical Composition

According to ASTM C618-03 (2004) the chemical and physical composition for each class of pozzolanic material is different. Table 2.1 and Table 2.2 shows the chemical and physical requirement for each class respectively.

Table 2.1: Chemical requirement for pozzolanic materials

Chemical Requirement	Class		
	N	F	C
Minimum of $SiO_2+Al_2O_3+Fe_2O_3$ (%)	70.0	70.0	70.0
Maximum Moisture Content (%)	3.0	3.0	3.0
Maximum SO_3 (%)	4.0	5.0	5.0
Maximum loss on ignition (%)	10.0	6.0	6.0

Source: ASTM C618-03 (2004)

Table 2.2: Physical requirements for pozzolanic materials

Physical Requirements	Class		
	N	F	C
Maximum Amount Retained When Wet-sieve on 45μm sieve (%)	34	34	34
Strength Activity Index:			
With Portland Cement at 7 days (%)	75	75	75
With Portland Cement at 28 days (%)	75	75	75
Maximum Water Requirement (%)	115	105	105
Maximum Soundness (%)	0.8	0.8	0.8

Source: ASTM C618-03 (2004)

2.3.5 Pozzolanic Reaction

C-S-H gel is act as glue and become the binder of the materials in the concrete. C-S-H gel is produce from the hydration process and pozzolanic reaction as shown in equation 1 and equation 2 below. Pozzolanic material will react with calcium hydroxide in the presence of moisture. According to Saleh (2010), the effects of C-S-H in concrete can be seen at Figure 2.1.

Hydration process:

$$\text{Cement} + H_20 \longrightarrow \text{C-S-H gel} + Ca(OH)_2 \qquad (2.1)$$

Pozzolanic reaction:

$$SiO_2 + Ca(OH)_2 \longrightarrow \text{C-S-H gel} \qquad (2.2)$$

Where, H_2O = Water

SiO_2 = Silica Oxide

$Ca(OH)_2$ = Calcium Hydroxide

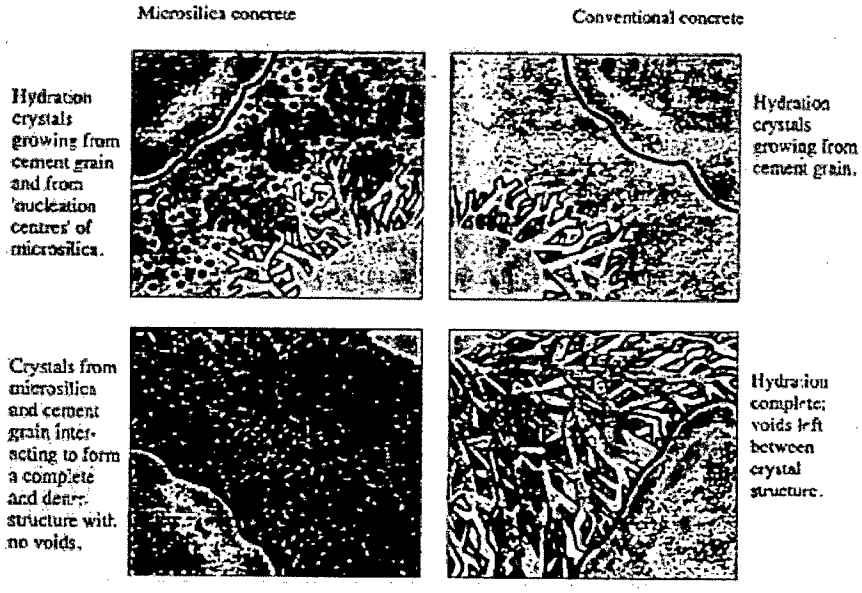

Figure 2.1: The Effects 0f C-S-H in Concrete

Source: Saleh (2010)

2.4 PALM OIL FUEL ASH (POFA)

Palm oil is one of the vital economy generators in Malaysia. On 2013, estimated around 4.85 million hectares of palm planted in Malaysia. It's obviously higher and will continuously increase since the demand of palm oil is never reduce. The increasing of palm oil sector in Malaysia will lead to waste management problems and it will become such a disaster if it is not been manage properly. Approximately, from the palm oil manufacturing, 61.1 million tonnes of solid waste product will produce every year in terms of fibers, kernels and empty fruit. In Malaysia, the solid product will be managed by combustion process to reduce it size. According to Thangchirapat (2006), the amount of POFA that produce from combustion process in Malaysia is totally high this is around 3.1 million tonnes.

2.4.1 Origin of POFA

High amount of solid waste product is produce in palm oil mills every year. The solid wastes products will be undergoing combustion process thus produce POFA. The solid waste that produces from the extracting process of palm oil is palm oil shell and palm oil husk. According to Sata (2004), POFA is dark grey in colour and need to be grind to produce higher surface of POFA and reduce it size. Usually, POFA produce will be dump in the landfill site because it cannot bring to any profit. Since Malaysia is one of the largest producers of palm oil, action should be taken to make sure the POFA produce can give benefit and reduce the landfill area in Malaysia

2.4.2 Ability of POFA as Cement Replacement

According to Awal (1993), POFA can be classified as pozzolanic material. It is because POFA had an ability to substitute certain amount of cement since it has little cementitious properties. Originally, POFA produce in palm oil mills has a little ability to perform pozzolanic reaction but its ability can be increase by increase it surface area by reducing its size. POFA content a high amount of silica, one of the important elements for pozzolanic reaction.

POFA naturally had high amount of silica. Silica fume is common admixture that is used in concrete to increase the strength and workability of the concrete. However, the addition of silica fumes in concrete may increase the cost of concrete since the cost of silica fumes is too much. Referring to Mehtal (1992), most of the fly ash had quite similar properties since the natural composition of fly ash that rich in silica content. Thus, at the same time, using of POFA in concrete is quite similar with the concrete that mix with the silica fumes besides its ability to replace cement.

According to Thomass et al. (2003), hydration process while the cement production will produce the calcium silicate hydrate or known as CSH gel. The existing of CSH gel in produce will increase the strength of concrete since its act as a binder and will hold tightly between particles in concrete. The chemical composition of the Ordinary Portland cement and others pozzolanic materials are present in Table 2.3.

Table 2.3: Chemical composition of Ordinary Portland cement

Chemical Compositions (%)	**Cement**	**Ground Pulverized Coal Combustion Fly Ash (FA)**	**Ground Pulverized Coal Combustion Fly Ash (FB)**	**Ground Rice Husk-bark Ash (RHBA)**	**Ground Palm Oil Fuel Ash (POFA)**
Silicon Dioxide (SiO_2)	20.9	43	44.5	65.3	65.3
Aluminium Oxide (Al_2O_3)	4.8	21.8	26.7	2.6	2.6
Iron Oxide (FE_2O_3)	3.4	10.7	2.7	2.0	2.0
Calcium Oxide (CaO)	65.4	14.0	11.8	6.4	604
Magnesium Oxide (MgO)	1.2	2.8	0.7	3.1	3.1
Potassium Oxide (K_2O)	0.4	2.6	0.7	5.7	5.7
Sodium Oxide (Na_2O)	0.2	1.8	0.7	0.3	0.3

2.5 PREVIOUS RESEARCH OF CEMENT REPLACEMENT MATERIAL

The ability of waste material to perform cementituous properties had increase the interest of researcher to study of new material as cement replacement. The higher demand of concrete in the construction work had increase the cost of concrete. This happen cause of the price of cement is getting higher. Besides, the higher production of cement also leads from the production of cement. Table 2.4 shows the previous research that using agriculture waste material as partial cement replacement.

Table 2.4: The previous research in cement replacement material

No	Types of waste material as cement replacement	Researcher (Year)
1	Sugar Cane Bagasse Ash	Cordeiro (2008)
2	Rice Husk Ash	Gemma (2006) Hwang et al. (2011)
3	Groundnut Husk Ash	Alabadan et al. (2002)

2.5.1 Sugar Cane Bagasse Ash as Cement Replacement

Sugar cane bagasse ash contain large amount of silica (SiO2). Quite similar with POFA, sugar cane bagasse ash had potential to substitute partial ratio of cement. According to the research that conducted by Eduardo (2010), the substitution of sugar cane bagasse ash had proven increase the compressive strength and flexural strength of the alter concrete. The research also showing that the size of the ash was influenced the strength of the concrete. The smaller size of the sugar cane bagasse ash had increase the strength of the concrete.

2.5.2 Rice Husk Ash as Cement Replacement

According to Gemma (2006), rice husk ash is one of the pozzolan material produce in agriculture industry. The production of large amount of rice husk ash can bring to environmental problem if it is not managed properly. The ability of the rise husk as a pozzolan material was made it choose to become the main component of the