EFFECTS OF BY-PRODUCT MATERIALS (POFA AND PFA) AS PARTIAL CEMENT REPLACEMENT ON CONCRETE TOWARDS CORROSION RESISTANCE

FADZIL BIN MAT YAHAYA

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Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

The utilization of pulverized fuel ash (PFA) and palm oil fuel ash (POFA) in producing a new construction material is seen as one of the ways to reduce the quantity of these wastes or by-products disposed at landfills. These materials are identified as pozzolana which are used as a partial replacement of the Portland cement. This step enables building materials to be managed in a sustainable manner, thereby reducing pollutions and landfill areas in the future. PFA is a by-product material produced from the burning of coal in electric power plants, while, POFA is the residue obtained by burning husks or fibers, and palm kernel shells used as biomass in palm oil mills. This thesis presents an experimental study of the engineering properties and durability of concrete based cement blended using different by-product materials namely POFA and PFA in tackling the reinforcement corrosion problem in concrete. Seven types of mixes were prepared, which consisted of a control mix and other mixes consisting of 10, 20 and 30 percent of POFA and PFA as a partial cement replacement for each by-product. The influence of POFA and PFA replacement level and mixing constituents on the compressive strength of concrete have been investigated under different curing regimes namely water, control room, wet-dry cycle and outdoor up to one year concrete age. Studies on the durability aspect of the mix towards its porosity, microstructure, crystallization product and corrosion resistance are also investigated. The result shows the performance of concrete with 20 percent of POFA and PFA produces a comparable compressive strength with the control mix with water curing regime. The constant presence of moisture is significant for strength development of POFA and PFA concrete mixes since the pozzolanic reaction is only able to take place in the later age, after calcium hydroxide is available from the hydration process in the presence of moisture. Other than that, the utilization of POFA and PFA in concrete improves concrete porosity by improving the microstructure due to the densification of concrete by reducing voids inside the concrete. At the same time, POFA and PFA concrete mixes demonstrate a higher resistance to chloride ion penetrations than the control mix. Due to these reasons, the POFA and PFA concrete mixes have exhibited a good resistance towards corrosion after undergoing accelerated corrosion tests. In this test, the control concrete cracked and failed after two days as compared to POFA and PFA concrete, which took a longer period that are 14 and 21 days to crack due to the corrosion of steel reinforcements. Finally, the study shows that the utilization of PFA as a cement replacement material produces a better performance than POFA in all aspects of concrete properties due to its chemical compound and fineness. As a conclusion, the use of PFA and POFA at the level of 20 percent as the replacement of Portland cement is optimum in concrete and does not affect the compressive strength but also improves the durability of concrete, especially against corrosion resistance. The use and recycling of these materials not only reduces environmental problems and concrete production cost, it can also produce concrete with better properties and performance.

ABSTRAK

Penggunaan abu terbang (PFA) dan abu terbang kelapa sawit (POFA) dalam menghasilkan bahan binaan baharu dilihat sebagai langkah untuk mengurangkan bahan buangan atau sampingan daripada dilupuskan di tapak pelupusan. Langkah ini membolehkan bahan binaan diuruskan secara mampan dan seterusnya mengurangkan pencemaran dan kawasan tapak pelupusan. Bahan ini telah dikenalpasti sebagai bahan pozzolana yang membolehkan ianya digunakan sebagai bahan gantian separa simen. PFA merupakan bahan sampingan yang terhasil daripada pembakaran arang batu di loji janakuasa elektrik manakala, POFA pula ialah sisa hasil pembakaran tandan, sabut dan cengkerang biji kelapa sawit yang digunakan sebagai bahan api di dalam loji pemprosesan kelapa sawit. Tesis ini akan membentangkan hasil kajian terhadap sifat-sifat kejuruteraan dan ketahanlasakan konkrit yang menggunakan POFA dan PFA sebagai bahan gantian separa simen dalam menangani masalah karatan besi tetulang di dalam konkrit. Tujuh campuran rekabentuk telah digunakan dalam kajian ini, yang terdiri daripada campuran kawalan dan campuran yang menggunakan POFA dan PFA dengan gantian 10, 20 dan 30 peratus daripada setiap jenis bahan gantian. Kesan penggantian POFA dan PFA terhadap kekuatan mampatan telah diperhatikan dengan kaedah rejim pengawetan yang berbeza iaitu terhadap air, bilik kawalan, kitaran basah-kering dan semulajadi sehingga konkrit berumur satu tahun. Kajian mengenai aspek ketahanlasakan campuran terhadap keliangan, mikrostruktur, hasil penghabluran dan rintangan pengaratan juga telah dilakukan. Hasil kajian menunjukkan prestasi konkrit dengan 20 peratus penggantian POFA dan PFA menghasilkan kekuatan mampatan yang setara berbanding campuran kawalan dengan kaedah awetan menggunakan air. Kehadiran kelembapan secara berterusan amatlah penting untuk membantu peningkatan kekuatan konkrit yang menggunakan POFA dan PFA sebagai bahan gantian separa simen dengan membolehkan tindakbalas pozzolana berlaku dalam tempoh yang lewat selepas kalsium hidroksida terhasil daripada proses penghidratan pada peringkat awal umur konkrit. Selain daripada itu, penggunaan POFA dan PFA telah memperbaiki keliangan konkrit dengan menghasilkan mikrostruktur lebih tumpat dengan mengurangkan kadar keliangan konkrit. Campuran ini menunjukkan kadar rintangan yang tinggi terhadap penusukan ion klorida berbanding dengan campuran kawalan. Dengan sebab ini, konkrit POFA dan PFA menghasilkan rintangan yang amat baik terhadap karatan selepas menjalani ujian karatan secara terpecut. Dalam ujian ini, konkrit kawalan telah gagal dalam tempoh dua hari berbanding dengan konkrit POFA dan PFA yang mengambil masa 14 dan 21 hari. Akhirnya, kajian menunjukkan penggunaan PFA sebagai bahan gantian separa simen menghasilkan prestasi yang lebih baik daripada POFA dalam semua ciri-ciri konkrit yang diuji disebabkan kandungan kimia dan kehalusannya fizikalnya yang asal. Sebagai kesimpulannya, penggunaan PFA dan POFA pada tahap 20 peratus sebagai penggantian simen Portland di dalam konkrit tidak menjejaskan kekuatan mampatan malah ianya dapat meningkatkan ketahanlasakan konkrit terutamanya terhadap rintangan karatan. Penggunaan dan pengitaran semula bahan-bahan ini bukan sahaja mengurangkan masalah alam sekitar dan mengurangkan kos penghasilan konkrit malah dapat mengahasilkan konkrit dengan ciri lebih baik.

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LIST OF SYMBOLS

Ǻ	Angstrom
g	Gram
μ	Micron
^{o}C	Celcius
%	Percent

ABBREVIATION

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
BS	British Standard
DC	Direct current
EN	European Standard
FELDA	Federal Land Development Authority
kPa	Kilo Pascal
LOI	Loss in ignition
mA	Miliampere
MPa	Mega Pascal
PC	Portland cement
PCC	Pulverized coal combustion
PFA	Pulverized fuel ash
POFA	Palm oil fuel ash
PPM	Part permillion
RCPT	Rapid chloride permeability test
RHA	Rice husk ash
RM	Ringgit Malaysia
SEM	Scanning Electron Microscope
SIRIM	Standards and Industrial Research Institute of Malaysia
TIA	Timber industrial ash
UMP	Universiti Malaysia Pahang
USD	United State Dollar
VAS	Vacuum saturation
XRD	X- Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Concrete is the most widely used man-made construction material, obtained by mixing cement, water, aggregates and admixtures, which offers stability and flexibility in designing all building structures. There are many advantages of using concrete such as easy to construct, fire resisting, has high compressive strength and requires low maintenance. Unfortunately, concrete is not environmentally friendly materials, either to make, or to use, or to dispose of, or even it can be recycle. At the same time, concrete also has a disadvantage which is low strength in flexural and brittle materials and therefore reinforcement bars have been introduced to solve this weakness. However, the corrosion of reinforcement bars is one of the major problems with concrete structure and it is inevitable during its life span that can lead to structural integrity. It can be caused by internal and external factors such as being attacked by chloride ions from the environment and chloride from materials to produce concrete. Concrete with high porosity and permeability is also susceptible of harmful substances that easily penetrate and cause the corrosion of reinforcement bars.

Theoretically, bars embedded in concrete structures are protected both chemically and physically against environmental corrosion by the concrete cover. The high alkalinity of the pore solution ranging from pH 12.5 to 13.5 of the concrete cover provides a chemical protection by the formation of a protective oxide film or passive layer on the surface of the bars. The impermeability of the concrete cover is expected to provide a physical protection against the ingress of deleterious materials like chloride ions that are known to cause a breakdown of this passive layer when the $[Cl_2]/[OH_2]$

ratio at the surface of the bars reaches a threshold value of 0.3 (Diamond, 1986). The diffusivity of chloride through concrete therefore depends on the microstructure of the concrete cover.

The use of fly ash as a cement replacement material has become a common practice in the recent years. Fly ash is used in concrete for several economic and environmental reasons. Moreover, the fly ash particles react with calcium hydroxide, producing hydration products that strongly decrease concrete porosity and permeability by producing a dense microstructure (Kawamura and Torii, 1989) which is an improvement in the physical protection of any embedded bars. In addition to this, if there is chloride binding by the aluminate phase of the fly ash to form Friedel's salt, then the concentration of the free chloride ions in the pore water of concrete would be expected to decrease.

The growing Malaysian population along with the rapid development of the country has boosted the growth of the construction industry to meet the demands of end users. This scenario would lead to the consumption of more cementitious materials to be used in concrete productions. The rising cost of cement productions and environmental issues have resulted in the cement manufacturers and parties involvements in concrete production to find a solution that could allow the sustainability of concrete productions. It will provide an opportunity to researchers to explore and produce new materials in concrete productions. Therefore, by utilizing the previous research findings in the utilization of by-product materials, this study has developed a new cementitious material that can be used and improves concrete properties particularly in its strength and durability.

1.2 AIMS AND OBJECTIVES

The aim of this study is to develop concrete with high resistance towards chloride ions that could protect steel reinforcements from corrosion by using by-product materials namely palm oil fuel ash (POFA) and pulverized fuel ash (PFA). The specific objectives of the present study are as follows:

i. To determine the effects of POFA and PFA as a cement replacement on concrete compressive strength development.

ii. To determine the effects of POFA and PFA as a cement replacement on concrete porosity.

iii. To evaluate the performance of POFA and PFA as a cement replacement material towards chloride ion resistance of concrete and reinforcement corrosion.

iv. To determine the effects of POFA and PFA towards concrete hydration products namely C–S–H gel and $Ca(OH_2)$ which contribute to the concrete corrosion resistivity.

v. To find an optimal mix proportion of POFA and PFA as a cement replacement in concrete to resist the reinforcement corrosion without compromising the compressive strength.

1.3 PROBLEM STATEMENT

The common problem faced by reinforced concrete structures is the corrosion of steel reinforcements inside the concrete as time goes by and attacked by external corrosion agents. The severe tropical environment will accelerate the corrosion process that would lead to a shorter lifetime of a reinforced concrete structure. There are numerous examples of 'spalling concrete' found on reinforced concrete structures within marine and urban environments. Many concrete structures which have been exposed to aggressive environments, suffer from durability problems and fail to fulfill their design service life requirements. The problem is particularly serious in reinforced concrete structures where corrosion of the reinforcing steel can impair their safety and integrity. In a reinforced concrete structure, chloride ion penetration can be considered as a major cause of the corrosion of the reinforcing bars. Chlorides can penetrate through the concrete to reach the reinforcement bars and break down the passive oxide layer of the reinforcement bars to initiate corrosion. Due to this reason, concrete with high chloride resistance is required to produce durable concrete in order to preserve the reinforcements from corrosion caused by environmental and chemical effects.

Obviously, there is a need to implement effective corrosion control methods in order to extend long-term durability of steel reinforced concrete. The proposed methods of protecting steel reinforcements from corrosion in concrete are by using good quality materials and making a corrosion barrier protection against harmful agents from attacking the steel reinforcements. What is proposed in this work is that the materials used must be economical and practical at construction sites. In short, prevention is better than cure.

The cost of adequate prevention carried out during the stages of design and execution is minimal compared to the savings possibly made during the service life and, even more so, compared to the cost of rehabilitation, which might be required at later dates. The so-called De Sitter's law of five can be stated as follows: one dollar spent in getting the structure designed and built correctly is as effective as spending USD5 when the structure has been constructed but corrosion has yet to start, USD25 when corrosion has started at some points, and USD125 when corrosion has become widespread (De Sitter, 1984)

On the other hand, a new project of construction and development requires concrete in their planning to construct the structures. A statistical analysis shows the production of cement in Malaysia was stagnant from 2003 to 2007 but the price has increased up to 40% which is about RM 275 per ton (The Star, 2008) and the current price of cement is RM380 to RM400 in 2014 as noted by Master Builders Association Malaysia (MBAM) (The Star, 2014). In fact, the cement industry releases 5% carbon dioxide (CO_2) to the environment during its production and causes greenhouse effects to the environment (Worrell et al., 2001). Every ton of cement production emits 0.17 to 1.1 ton of CO_2. 50% of CO_2 can be resulted from the calcination of limestone; 40% from combustion of fuel in the kiln and 10% from transportation and manufacturing operations (Bosoaga et al. 2009). Concerns have been raised by several parties on these issues about the sustainability of cement as a construction material especially on the price which can lead to a high price of building structures. This problem should be addressed by identifying and producing low-cost concrete with good properties, particularly in strength and durability as well as sustainability.

In Malaysia, palm oil fuel ash (POFA) and pulverized fuel ash (PFA) are by-products produced by the combustion power plants. POFA is a by-product produced from the incineration of fibers, shells, and empty fruit bunches at a palm oil mills, meanwhile the PFA is a by-product produced by the combustion power plants to generate electricity. The amount of POFA and PFA generated are increasing year by year in Malaysia due to increasing demands and requirements from industries and domestic and these wastes can result in environmental pollutions. Both of these by-products are used minimally and most of them will end up in landfills especially for POFA. Nowadays, PFA has been intensively used in concrete manufacturing due to its advantages towards concrete strength and durability. However, POFA is still not used extensively as PFA in concrete although research has shown it can give about the same effect in concrete properties.

The aim of this study is to develop a highly resistant concrete towards chloride attacks that can protect reinforcement steel from corrosion by using by-product materials namely palm oil fuel ash (POFA) and pulverized fuel ash (PFA) as an attempt to utilize it as a cement replacement in a normal concrete mixture. PFA and POFA are wastes that technically have potentials as cement replacements due to their pozzolanic properties as reported by other studies. It can be used in concrete with proper process of collecting the waste until the mixing into the concrete. PFA and POFA might contribute to solving some issues related to cement industry in terms of high prices and green issues while maintaining its sustainability in the future. With the properties of these by-product materials, they can be a 'catalyst' to concrete in giving resistance to ion chloride that corrode reinforcements by improving the properties of concrete.

1.4 SCOPE OF STUDY

This research is a continuation of the studies on POFA and PFA usage in concrete productions that have been conducted by other researchers previously. The present research is an attempt to incorporate POFA and PFA in the production of concrete. Overall, this study is fully experimental in nature whereby the investigation is focused on the development of POFA and PFA as cementitious materials. Basically, the research is aimed to investigate the microstructures and durability towards chloride attack of concrete by incorporating the by-product materials. The study also involves selected mixes in order to investigate concrete resistance towards reinforcement corrosion to determine the effectiveness of these materials. The detail scope of work and the limitations of this study are as follows:

i. To inspect and characterize the properties of POFA and PFA chemically and physically due to the different production and sources.

ii. To find the optimal concrete mix by making the by-product materials namely POFA and PFA as a cement material replacement with the compressive strength of 40 MPa. Concrete mixes are prepared namely normal concrete cube (control specimen) and the others are PFA and POFA concrete. PFA and POFA concrete produced comprise the replacement of cement composition with different percentages specifically 10%, 20% and 30% of the total weight of cement. These percentages are adopted as proposed in the previous research by the diversity of POFA and PFA and do not give negative effects on concrete properties.

iii. To investigate the factors affecting compressive strength such as ash content and different curing regime which are looked into prior to studying the compressive strength. Four types of curing are conducted subjected to (i) air curing, (ii) wet and dry cycles, (iii) outdoor curing and (iv) water curing. There are 7, 28, 60, 90, 180 and 365 days of curing subjected to a compression test to determine the optimum percentage of PFA and POFA that can be applied to replace cement compositions without affecting concrete strength and increasing chloride resistance.

iv. To observe and determine the micro properties of concrete affected by POFA and PFA towards concrete porosity, microstructures and crystallization of materials that contribute to the performance of concrete towards chloride resistance.

v. To investigate the effectiveness of POFA and PFA on accelerated electrochemical tests towards corrosion resistance. These simulations are to investigate and observe the resistance provided by POFA and PFA to delay and prevent the corrosion of reinforcements. The simulation that is used is the accelerated method according to the existing standard and practice.

At the final stage, the suitability of POFA and PFA cement-based concrete mixes are tested for corrosion resistance. The performance of these materials has been investigated through the accelerated corrosion tests.

1.5 SIGNIFICANCE OF STUDY

The problem of corrosion of steel reinforcements in concrete is very important. The diffusion of chloride ions through concrete is a major cause of corrosion of reinforcing bars. The use of POFA as a material to prevent the corrosion of steel reinforcements has not been extensively investigated in scientific studies. POFA previously has been identified as a pozzolana and can only be used as a cement replacement in concrete to preserve the strength and enhance the durability against chemical attack. Durability of concrete is not only limited to the ability to maintain the strength or performance of concrete, but it is also important to prevent aggressive materials that can reduce the ability of other materials in it especially steel reinforcements that are commonly used in a concrete structure. Therefore, based on the need to produce concrete that can prevent the corrosion of steel reinforcements, it is necessary to see the POFA effectiveness in preventing or reducing the rate of corrosion of reinforcement steel used in reinforced concrete and it will be compared with PFA that has proven its effectiveness.

The pozzolanic action from POFA and PFA is being used as a ‘catalyst’ which is able to improve concrete properties by possessing cementitious properties and emitting the healing agent autogenously in the presence of moisture. In general, specimens consisting PFA and POFA as cement replacement materials exhibit lesser strength at an early age but compressive strength continues to increase as the curing age becomes higher. This is because pozzolana starts reacting somewhat belatedly with calcium hydroxide produced by clinker hydration and therefore it behaves like an inert diluting agent towards the Portland cement with which it has been mixed. Hence, by utilizing this observable fact, the corrosion resistance material can be produced with the right mechanism and method due to improvements in concrete properties.

The aim of this study is to support the utilizing of PFA and POFA in construction materials especially in concrete manufacturing. The optimum replacement of these by-products is still not being optimally utilized in the concrete industry especially in Malaysia. With a large production of POFA and PFA especially in power production and agricultural industries, these by-product materials could beneficially be used in the cement industry to ensure the sustainability and the use of a ‘green’ products which can solve some issues related to the environment. The results of this study explain the ability of POFA when used as a cement replacement and shows that it is able to slow down the corrosion in reinforcement steel by improving concrete properties with low pore volume compared to the normal concrete. Apart from that, it appears that POFA can bind chloride ions to reduce corrosion on steel reinforcements.

1.6 THESIS OUTLINE

The background of study, research problem, aims and objectives, scopes and significance of study have been discussed in the previous subchapters in Chapter 1. The following chapter (Chapter 2) will focus on the detail properties of the materials used and the effects of these materials towards concrete properties. The materials used in this study are from agro waste and power generation waste namely POFA and PFA which are largely produced in Malaysia. The properties of the raw materials are reviewed and discussed. The effects of these materials towards concrete properties mainly to its strength and corrosion resistance improvements are intensively reviewed. Besides that, the reinforcement corrosion mechanism and its cause are also discussed. The methodology used in this research is presented in Chapter 3. The method used to obtain an optimal mix proportion is discussed thoroughly. The description on the preparation of specimens is also included. This is then followed by the test procedure used in testing the samples.

The results and discussions of this study are divided into three parts. The first part is presented in Chapter 4 which concentrates on the effects of POFA and PFA towards concrete compressive strength with different curing regimes and on strength development. Optimal mix samples are selected based on the compressive strength test results of all the trial mixes which are discussed in detail in Chapter 4. Chapter 5 discusses the test results of concrete porosity and micro properties. This chapter mainly focuses on the effects of by-product materials towards the micro properties of concrete and its hydration products as a result of using POFA and PFA as cement replacement materials. SEM pictures are illustrated to show the porosity and hydration products from by-product materials used, which are related to the strength development and durability of concrete. Besides that, the quantity and mineralogy resulting from the blended cement are also discussed by the X-ray Diffraction (XRD) test in the chapter.

In Chapter 6, the results of concrete in resisting corrosion and its mechanism are discussed. The result from chloride ion penetrations and corrosion accelerated test are also presented. Finally, Chapter 7 presents a list of conclusions that can be drawn from this research. Recommendations are also given for future works in this area of study.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Concrete is the most widely used man-made construction material, obtained by mixing cement, water, aggregates and admixtures, which offers stability and flexibility in designing all building structures. There are many advantages of using concrete such as easy to construct, fire resisting, has high compressive strength and requires low maintenance. Unfortunately, concrete is not environmentally friendly materials, either to make, or to use, or to dispose of, or even it can be recycle. At the same time, concrete also has a disadvantage which is low strength in flexural and brittle materials and therefore reinforcement bars have been introduced to solve this weakness. However, the corrosion of reinforcement bars is one of the major problems with concrete structure and it is inevitable during its life span that can lead to structural integrity. It can be caused by internal and external factors such as being attacked by chloride ions from the environment and chloride from materials to produce concrete. Concrete with high porosity and permeability is also susceptible of harmful substances that easily penetrate and cause the corrosion of reinforcement bars.

Theoretically, bars embedded in concrete structures are protected both chemically and physically against environmental corrosion by the concrete cover. The high alkalinity of the pore solution ranging from pH 12.5 to 13.5 of the concrete cover provides a chemical protection by the formation of a protective oxide film or passive layer on the surface of the bars. The impermeability of the concrete cover is expected to provide a physical protection against the ingress of deleterious materials like chloride ions that are known to cause a breakdown of this passive layer when the $[Cl_2]/[OH_2]$

ratio at the surface of the bars reaches a threshold value of 0.3 (Diamond, 1986). The diffusivity of chloride through concrete therefore depends on the microstructure of the concrete cover.

The use of fly ash as a cement replacement material has become a common practice in the recent years. Fly ash is used in concrete for several economic and environmental reasons. Moreover, the fly ash particles react with calcium hydroxide, producing hydration products that strongly decrease concrete porosity and permeability by producing a dense microstructure (Kawamura and Torii, 1989) which is an improvement in the physical protection of any embedded bars. In addition to this, if there is chloride binding by the aluminate phase of the fly ash to form Friedel's salt, then the concentration of the free chloride ions in the pore water of concrete would be expected to decrease.

The growing Malaysian population along with the rapid development of the country has boosted the growth of the construction industry to meet the demands of end users. This scenario would lead to the consumption of more cementitious materials to be used in concrete productions. The rising cost of cement productions and environmental issues have resulted in the cement manufacturers and parties involvements in concrete production to find a solution that could allow the sustainability of concrete productions. It will provide an opportunity to researchers to explore and produce new materials in concrete productions. Therefore, by utilizing the previous research findings in the utilization of by-product materials, this study has developed a new cementitious material that can be used and improves concrete properties particularly in its strength and durability.

1.2 AIMS AND OBJECTIVES

The aim of this study is to develop concrete with high resistance towards chloride ions that could protect steel reinforcements from corrosion by using by-product materials namely palm oil fuel ash (POFA) and pulverized fuel ash (PFA). The specific objectives of the present study are as follows:

i. To determine the effects of POFA and PFA as a cement replacement on concrete compressive strength development.

ii. To determine the effects of POFA and PFA as a cement replacement on concrete porosity.

iii. To evaluate the performance of POFA and PFA as a cement replacement material towards chloride ion resistance of concrete and reinforcement corrosion.

iv. To determine the effects of POFA and PFA towards concrete hydration products namely C–S–H gel and $Ca(OH_2)$ which contribute to the concrete corrosion resistivity.

v. To find an optimal mix proportion of POFA and PFA as a cement replacement in concrete to resist the reinforcement corrosion without compromising the compressive strength.

1.3 PROBLEM STATEMENT

The common problem faced by reinforced concrete structures is the corrosion of steel reinforcements inside the concrete as time goes by and attacked by external corrosion agents. The severe tropical environment will accelerate the corrosion process that would lead to a shorter lifetime of a reinforced concrete structure. There are numerous examples of ‘spalling concrete’ found on reinforced concrete structures within marine and urban environments. Many concrete structures which have been exposed to aggressive environments, suffer from durability problems and fail to fulfill their design service life requirements. The problem is particularly serious in reinforced concrete structures where corrosion of the reinforcing steel can impair their safety and integrity. In a reinforced concrete structure, chloride ion penetration can be considered as a major cause of the corrosion of the reinforcing bars. Chlorides can penetrate through the concrete to reach the reinforcement bars and break down the passive oxide layer of the reinforcement bars to initiate corrosion. Due to this reason, concrete with

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The overall program of this study is to determine the effects of by-product materials which include PFA and POFA and is fully experimental in nature whereby the investigation is focused on the development of these materials as cementitious materials in a normal use. The aim of this study is to investigate the micro-properties and the durability aspect of concrete towards corrosion resistance by incorporating the by-product materials. The study involves simulations to the selected mixes in order to investigate corrosion resistance towards reinforcements in concrete and to determine the effectiveness of the materials.

The properties of a selected material must meet a certain satisfactory criteria before it can be used in a mix design. The production and test procedures in evaluating the concrete mixes, the proportion and preparation of the test specimens and the standards referred in conducting the tests are presented and discussed in the following subtopics. The basic materials for producing concrete in this study were cement, water, sand and coarse aggregates. POFA and PFA were used as cement replacements. Specimens were subjected to different exposure conditions starting from day one which involved air, water, outdoor and wet-dry curing in order to study the effects of curing type towards its strength. Therefore, this chapter explains the experimental program and the material properties for this study. All the formulation of mix proportion and method of testing are stated in this chapter in order to achieve the objectives of this study as discussed in Chapter 1. The methodology adopted in this study is fully based on an experimental investigation.

3.2 MATERIAL INCORPORATED IN PRODUCING SPECIMENS

The concrete consisted of five types of raw materials namely, cement, sand, coarse aggregate, water and by-product materials which were either palm oil fuel ash (POFA) or pulverized fuel ash (PFA). The concrete was designed with the grade 40 MPa in the compressive strength. Therefore, the materials used must be in good quality and must meet the minimum specifications as set in the reference standard.

3.3 COARSE AGGREGATE

Generally, aggregates are parts of the concrete that constitute the bulk of the finished product. They comprise about 60 to 80 % of the volume of the concrete and have to be graded so that the entire mass of concrete acts as a relatively solid, homogeneous, dense combination, with the smaller size particles acting as an inert filler of the voids that exist between the larger particles. The coarse aggregate is a saturated surface dry condition to ensure the water cement ratio is not affected. A few characteristics of aggregates that affect the workability and bond between concrete matrixes are shape, texture, gradation and moisture content. In this study, crushed aggregates from a quarry with the nominal size of 20 mm in accordance to BS 882 (1992) were used.

3.4 SAND

The sand used was from a river and it has fulfilled the BS 882 (1992) requirement. The condition of the sand was the same as the coarse aggregate which was in a saturated surface dry condition in order to ensure the water cement ratio was not affected during mixing proses.

3.5 CEMENT

The Portland cement (PC) produced by Pahang Cement was used in this study as the binder. This Portland cement was made to meet the specification requirement of

ASTM C 150 (ASTM C 150:2005). The opened cement was stored in an airtight container to protect the quality of the Portland cement. Opened cement that are left exposed to atmospheric humidity for a long time has a lower quality due to reactions between cement and the moisture in the air.

3.6 WATER

In order to produce a concrete mix, water plays a very important role. Supposedly, the water used should not contain any substance that might affect the hydration of cement and affect the durability of concrete. Generally, the common tap water was used throughout the study in mixing, curing and other purposes.

3.7 PALM OIL FUEL ASH (POFA)

Palm oil fuel ash is a by-product material obtained in the form of ash when burning palm oil husks or fibers and palm kernel shells as fuel in palm oil mill boilers. POFA which was used in this study was collected from a factory processing palm oil situated at Felda Lepar Hilir at the area of Gambang, Pahang Darul Makmur. The ash was found in the flue of the tower where all the fine ashes are trapped while escaping from the burning chamber of the boiler.

3.7.1 POFA Preparation

POFA is a by-product from the burning processes in thermal power plants, where palm nuts and empty bunches are burnt at the temperature of about 300-400^{o}C. In this study, POFA was used as a cement replacement in concrete to study its potential as a ‘catalyst’ to seal the pores in the concrete and bind chlorides.

POFA was produced from the mill at the foot of the flue tower and only grayish looking POFA was selected, sorted out and collected for the specimens production. The black POFA had to reduce or avoid due to the high unburned carbon content that can cause ineffective reaction when used as a cement replacement. The origin of palm oil fuel ash and stages involved in waste generation as shown in Figure 3.1 to Figure 3.3.