EFFECT OF PALM OIL FUEL ASH (POFA) FOR FIBER REINFORCED CONCRETE TOWARDS CORROSION RESISTANCE

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SITI MASHITAH BINTI BAHRUN

Thesis submitted in fulfillment of the requirements
for the award of the
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DEDICATION

Praise be to Allah S.W.T the Lord of the World

Who says (interpretation of meaning)

"Give thanks to me and your parent. To me is final destination"

[Quraan,Luqman 31:14]

I dedicated this research to my family especially

Mr. Bahrun bin Abd Hamid and Mrs. Salmiah binti Md Ali

For keep encourage me and for opening my eyes to the world

And to my supervisor, Dr Fadzil bin Mat Yahaya,

All friends for their endless help, patience and encouragement.

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ABSTRAK

Simen Portland Biasa (OPC) diiktiraf sebagai bahan pembinaan utama di seluruh dunia. Malaysia dikenali sebagai pengeksport terbesar minyak sawit. Abu Bahan Api Kelapa Sawit (POFA) dianggap sebagai bahan buangan yang dihasilkan oleh pembakaran sisa daripada gentian, cengkerang dan tandan. Setiap tahun, kuantiti POFA meningkat disebabkan peningkatan tanaman pokok kelapa sawit di negara kita. Menurut penyelidikan, POFA adalah sisa bahan buangan dan mempunyai potensi untuk digunakan sebagai bahan binaan dengan menggantikan Simen Portland Biasa (OPC). Dalam kajian ini, kekuatan mampatan, 'accelerated corrosion resistance' dan kebolehkerjaan konkrit serat keluli yang mengandungi Kelapa Sawit Minyak Sawit (POFA) telah diuji. Simen Portland Biasa (OPC) sebahagiannya digantikan dengan POFA pada dos sebanyak 10%, 20% dan 30% berat simen yang digunakan dan spesimen kawalan adalah 100% OPC. Dari kajian ini, didapati bahawa penggantian POFA optimum adalah 20% berat simen. Kekuatan konkrit POFA telah mencapai kekuatan sasaran iaitu 30 N / mm2 berbanding OPC. Bagi ujian 'accelerated corrosion resistance', konkrit POFA menunjukkan prestasi yang lebih baik berbanding dengan konkrit OPC. Dari hasil yang diperoleh, jelas bahawa penggantian separa oleh POFA bermanfaat, terutamanya dalam pembinaan konkrit.

ABSTRACT

Ordinary Portland Cement (OPC) is well recognized as the major construction material throughout the world. Malaysia is known as the largest exporter of the palm oil. Palm Oil Fuel Ash (POFA) is considered as a waste material produced by burning of fibers, shells and empty fruit brunches. Annually, the quantity of POFA is increased due to the increase of the plantation of palm oil trees in our country. According to the research, the agro waste, such POFA is the pozzolanic material and have the potential to be utilized as construction material by replacing the Ordinary Portland Cement (OPC). In this study, the compressive strength, the durability of corrosion resistance and workability of steel fiber concrete containing Palm Oil Fuel Ash (POFA) were tested. The Ordinary Portland Cement (OPC) was partially replaced with POFA at the dosage of 10%, 20% and 30% by weight of cement used and the control specimen is 100% OPC. From this study, it was found that, the optimum POFA replacement is 20% of cement weight. The strength of POFA concrete has achieved the targeted strength which is 30 N/mm2 compared to OPC. As for the accelerated corrosion test, POFA concrete shows better performance compare to OPC concrete. From the results obtained, it is clear that the partial replacement of cement by POFA beneficial, especially in the construction of concrete.

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LIST OF SYMBOLS

%	Percentage
μm	Micrometer
mm^2	Milimeter square
m^3	Meter cube
g	Gram
°C	Degree Celsius

LIST OF ABBREVIATIONS

BS	British standard
UMP	University Malaysia Pahang
FKASA	Fakulti Kejuruteraan Awam dan Sumber Alam
ASTM	American Society for Testing and Materials
POFA	Palm Oil Fuel Ash
OPC	Ordinary Portland cement
PC	Portland cement
CO_2	Carbon dioxide
SiO_2	Silicon oxide
Al_2O_3	Aluminium oxide
Fe_2O_3	Iron oxide
CaO	Calcium hydroxide
MgO	Magnesium oxide
K_2O	Potassium oxide
Na_2O	Natrium oxide
SO_3	Sulphur trioxide
w/c	Water cement
mm	Milimeter
min	Minute
hr	Hour

CHAPTER 1

INTRODUCTION

1.1 Background

Steel fibre reinforced concrete (SFRC) is increasingly being used in the construction of prefabricated segmental linings for bored tunnels, since it entails simplified production processes and higher-quality standards (Marcos-meson et al., 2017). SFRC is a composite material, combining a cementitious matrix and a discontinuous reinforcement, consisting of steel fibres uniformly distributed in the matrix. The use of steel fibres as partial or total replacement of conventional reinforcement bars has become a popular solution for the construction of prefabricated segmental linings for bored tunnels, due to its overall superior durability and good performance in compression.

However, international standards and guidelines are not consistent regarding the consideration of steel fibres for the structural verification of SFRC elements exposed to corrosive environments, hampering the development of civil infrastructure built of SFRC. Concrete reinforced with fibres (which are usually steel, glass or “plastic” fibres) is less expensive than hand-tied rebar, while still increasing the tensile strength many times.

It is an undeniable fact that concrete is the most widely used man-made construction material in the world today, and will remain so for decades to come. The popularity of concrete is largely due to the abundance of raw material, low manufacturing and maintenance cost, excellence in compression, and corrosion aspects, durability to weathering and fire hazards, versatility in forming various shapes and its unlimited structural applications in combination with steel reinforcement (Parande et al., 2008). In Malaysia, Ordinary Portland Cement was known as common or general-purpose cement, it is commonly used for general construction especially when making precast, and precast-pre stressed concrete that is not to be in contact with soils or ground water. However, the production of cement gives the bad impact towards environment and people. The cement production process is classified as the second biggest source that is responsible for 6.97% of CO2 emission in the world (Bamaga, Hussin, & Ismail, 2013). Additionally, carbon dioxide was created by the combustion of fossil fuels or plant matter, among other chemical processes. Carbon dioxide is one of several greenhouse gases that can cause global warming by trapping the Sun's radiant energy in our atmosphere. This process is called the greenhouse effect.

The reduction of cement content in concrete can be achieved by utilization of supplementary cementitious materials (Sooraj, 2013). The palm oil industry in Malaysia, over the last few decades, has grown in size to become an important agricultural-based industry, where the country today is the world's largest producer and exporter of palm oil (Al-mulali et al., 2015). The agro waste such POFA can be used as POFA itself possessing pozzolanic behavior which can be used as cement replacement in concrete (Raut & Gomez, 2016). Besides, many researchers have studied the use of palm oil fuel ash in concrete (Kroehong, Sinsiri, & Jaturapitakkul, 2011).

1.2 Problem statement

Nowadays, there are a lot of problems in buildings due to cracking. Cracking can be because of various factors such as because of creep, drying shrinkage, thermal movement, uneven settlement and many more. Nevertheless, what can be highlight for this research study is cracking which is happened because of corrosion that happen in steel bar reinforcement. Corrosion decreases the cross-sectional area and the strength of reinforcement. With the increase of corrosion time under aggressive environments, the increased volume of corrosion products may cause concrete cover cracking (Ma et al., 2017). Corrosion in steel happens because of the present of water and oxygen. The oxygen and water exist trough the pore that have at the concrete. When the corrosion happens, the corrosion at the steel bar will push the concrete. Because of this, the surface of the concrete will slowly crack. When corrosion is getting worst, the corroded bar will expose. This is how the corrosion in steel bar start causing the crack.

In other hand, construction and development project required usage of high amount of concrete. One of the main products required in manufacturing concrete is cement. Cement production is consuming significant amount of natural resources, with the increase of the cement will lead to the increasing of the carbon dioxide on earth. Ordinary Portland Cement (OPC) is one of the famous type used in construction. The primary component in produce cement is limestone. The heating of limestone will release carbon dioxide (CO_2) directly. The production of cement will release greenhouse gas emissions directly and indirectly.

Malaysia is a major contributor of palm oil. In 2007, approximately 3 million tons of POFA were produced in Malaysia alone and this production rate is likely to rise due to the increased size of the palm oil tree plantations around the country (Mohammadhosseini et al., 2017). Most of the POFA was disposed of as waste. The waste that been disposed in landfill will create problems to the environment.

Therefore, research about the using of POFA as cement replacement and steel fibre reinforced concrete is necessary since POFA itself have the potential to recover the corrosion in steel reinforcement bar.

1.3 Research objectives

The main objectives of this study are:

i. To determine the effect of Palm Oil Fuel Ash (POFA) and steel fibre on workability.
ii. To determine the effect of Palm Oil Fuel Ash (POFA) and steel fibre towards concrete strength.
iii. To determine the effect of Palm Oil Fuel Ash (POFA) and steel fibre on corrosion resistance of steel reinforcement in concrete.

1.4 Scope of study

In this research, an attempt to use steel fibre reinforced concrete containing POFA as partial cement replacement. This study is to determine the workability, strength and corrosion resistance of the concrete by using different percentages of POFA in which are 10%, 20% and 30% during the tests. This study was conducted by using three tests, which are workability, compressive strength test and accelerated corrosion test. Four set of the specimens were used for each tests, which are PC concrete, 10%, 20% and 30% of POFA concrete.

For compressive strength test, the concrete was poured into 150x150x150 mm of mould and cured for 7, 14 and 28 days before be tested in order to determine the compressive strength of the PC concrete and POFA concrete. As for accelerated corrosion test, the concrete will be poured in cylinder which is 80mm in diameter and 150 mm in height. This specimen was cured for 28 days and later the specimen was placed in a container containing 5% of NaCl. Lastly, the excess of the concrete were used in order to carry out the workability test, which is by doing the slump test. The entire test involved in this study was conducted at Faculty of Civil Engineering and Earth Resources (FKASA) Laboratory, University Malaysia Pahang (UMP).

1.5 Research significance

Since Malaysia is known as the major contributor of waste management, so this study is important in order to reduce the amount of waste and at the same time will help in reducing the cost of construction. This study will benefit for structural building and everyone since the objective of this study is to reduce corrosion in steel reinforcement and by using POFA as partial cement replacement will later help in decrease waste in this country. By considering the condition of this country, which the target is to give people a better and cleaner environment. This study will help in facing environmental problems which mainly caused a pollution to surrounding and helps reduce the failure occur in structural buildings.

Apart from that, the usefulness of this study in society is, they will get better understanding about the effectiveness of POFA as replacement material that will give the positive result to the environment. Besides, this study can help a little bit by giving an idea to the next researcher to conduct a research on how benefit this POFA can be in concrete production.

This study is important since it will benefit to the surrounding including the society and the environment as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review is vital since it is the chapter where will discussed about the relevant materials which related to the project. The topic that will be discuss in this chapter is the application and characteristic of POFA waste were discussed which based on previous study. Besides, characteristic of concrete, cement, aggregate, water and fibre reinforced concrete were discussed. In this chapter, will discuss detail about the material used and laboratory test that involved for this study.

2.2 Concrete

Concrete has been stated as a material that commonly made from the mixture of aggregate, sand, cement and water. Concrete also has been characterized as a brittle material, with low tensile strength and energy absorption capacity (Mehta, 2014). Even though concrete is not as strong as steel, but it is still the most widely used in engineering material. This because, unlike wood and ordinary steel where concrete possesses excellent resistance to water. The ability of ideal material for building structures to control, store and transport water. The widespread of concrete also is because of the ease with which structural concrete elements can be formed into a variety of shapes and sizes. This because freshly made concrete was a plastic consistency, which enables the material to flow into prefabricated formwork. After a number of hours when the concrete has solidified and hardened to a strong mass, the formwork can be removed for reuse (Mehta, 2014). Another reason why concrete is the most popular material used in engineering is because concrete it is usually cheapest and most readily available material on the job.

2.2.1 Properties of concrete

The concrete has its own properties and these properties are important for construction to know the condition of the concrete when it is in wet condition. This is also to recognize whether the concrete rusts rot and it also not effected by the termites or other insects and also to know if the concrete can be moulded into any shape according to the mould.

2.3 Cement

Cement is called as a binder because it has hardening properties and can bind other material at the same place. In the general sense of the word, it can be described as a material with adhesive and cohesive properties that make it capable of bonding mineral fragments into a compact whole. The cements of interest in the making of concrete have the property of setting and hardening under water by virtue of a chemical reaction with it and been called as hydraulic cement. In other words, hydraulic cements are a cement that not only harden by reacting with water but also form a water-resistant product. There are several types of cement used in construction. Some of it are:

- Portland Cement (PC)
- Sulphate Resisting Portland Cement (SRPC)
- Rapid Hardening Portland Cement (RHPC)

2.3.1 Portland cement

Portland cement is a hydraulic cement produced by pulverizing clinkers consisting essentially of crystalline hydraulic calcium silicates, and a small amount of one or more forms of calcium sulphate and up to 5% limestone as an inter-ground addition. The name ‘Portland Cement’, given originally due to the resemblance of the colour and quality of the hardened cement to Portland stone. In Malaysia, Portland Cement is known as common or general-purpose cement and it is commonly used for general construction especially when making precast and precast-pre stressed concrete that is not to be in contact with soils or ground water.

2.3.2 Manufacturing process

The process of manufacture of cement consists essentially of grinding the raw materials, mixing them intimately in certain proportions and burning in a large rotary kiln at a temperature of up to about 1450℃ when the material sinters and partially fuses into balls known as clinker (Mehta, 2014). The mixing and grinding of the raw materials can be done either in water or in a dry condition, hence the names ‘wet’ and ‘dry’ processes. The actual methods of manufacture depends also on their moisture content.

In the wet process of cement manufacture, the grinding and homogenization of the raw mix was carry out in the form of a slurry. The slurry is a liquid of creamy consistency, with a water content of between 35 and 50 percent, and only a small material about 2 percent larger than a 90 µm sieve size (Al-mulali et al., 2015). Anyhow, modern cement plants prefer dry process because it is more energy efficient than the wet process operation. The dry process kilns equipped with multistage suspension preheaters, which permit efficient heat exchange between hot gases and the raw-mix, require a fossil-fuel energy input on the order of 800 kcal/kg of clinker compared to we process which use about 1400 kcal/kg (Mehta, 2014).

The final operation in the portland cement manufacturing process consists of pulverizing the clinker to an average particle. This operation was carried out in ball mills, also called finish mills. Approximately 5 percent gypsum or calcium sulphate is usually inter-ground with clinker in order to control the early setting and hardening behaviour of the cement (Mehta, 2014).

2.3.3 Type of Portland cement

There are two major standards for the type of Portland Cement which are the American Society for Test Material 150 (ASTM C150, 2012) that were used primarily in United States (USA) and European (EN 197). In Malaysia, Portland Cement used must fulfil the ASTM. From the knowledge of relative rates of reactivity and products of hydration of the individual compounds, it is possible to design cements with special characteristics such as high early strength, low moderate heat of hydration, and high or moderate sulphate resistance (Mehta, 2014). According to the ASTM C 150/C 150M-12, Standard Specification for Portland Cement, here are the several types of Portland Cement:

Table 2.1 Types of Portland Cement

Type	Classification	Characteristics	Applications
1	General purpose	Fairly high C3S content for good early strength development	General construction (most buildings, bridge, pavements, precast units and etc.)
II	Moderate sulphate resistance	Low C3S content (<8%)	Structure exposed to soil or water containing sulphate ions
III	High early strength	Ground more finely, may have slightly more C3S	Rapid construction, cold weather concreting
IV	Low heat of hydration (slow reaction)	Low content C3S (<50%) and C3A	Massive structure such as dams, now rare
V	High sulphate resistance	Very low C3A content (<5%)	Structure exposed to high level of sulphate ions.
White	White colour	No C4AF, low MgO	Decorative (otherwise has properties similar to Type I)

Source: (Neville, 2011)

2.3.4 Chemical composition of Portland Cement

The chief chemical components of Ordinary Portland Cement (OPC) are calcium, silica, alumina and iron. Calcium is usually derives from limestone, marl or chalk. On the other hand, silica, alumina and iron come from the sands, clays and iron ores. Table 2.2 gives the oxide composition of a typical cement of the 1960s.

Portland cement is a hydraulic cement produced by pulverizing clinkers consisting essentially of crystalline hydraulic calcium silicates, and a small amount of one or more forms of calcium sulphate and up to 5% limestone as an inter-ground addition.

Table 2.2 Oxide and compound composition Portland cement of the 1960s

Oxide Content	Percentage (%)
CaO	63
SiO_2	20
Al_2O_3	6
Fe_2O_3	3
MgO	1 1/2
SO_3	2
K_2O	1
Na_2O	1
Loss on ignition	2

Source: (Neville, 2011)

2.4 Palm oil fuel ash (POFA)

Palm oil fuel ash (POFA) is a by-product from biomass thermal power plants where oil palm residues are burned (Kroehong et al., 2011). POFA form from incineration of palm oil solid waste such as empty bunches fibre and shell. POFA can be used as sources to generate electricity at certain oleo-chemical industry. Unmanageable of POFA will pollute the environment and cause serious damages to inhalation system either to human or animal.

Malaysia is a major contributor of palm oil. In 2007, approximately 3 million tons of POFA were produced in Malaysia alone and this production rate is likely to rise due to the increased size of the palm oil tree plantations around the country (Mohammadhosseini et al., 2017). Most of the POFA was disposed of as waste. The disposal and landfilling of industrial waste carpet fibre and POFA had detrimental effects on the environment due to their long disintegration period. They are generally causing traffic hazards besides potential of health hazards and environmental pollution problems (Skariah, Kumar, & Sahan, 2017).

One of the reasonable approaches for minimizing these adverse effects is the utilization of waste materials as useful resources in other industries, such as green building construction (Awal & Mohammadhosseini, 2016). Since the palm oil is one of major raw material used in produce bio-diesel, it likely that the production of POFA increases every year.

2.4.1 Properties of POFA

POFA can be used as constituents in concrete due to pozzolanic properties. Many researches have studied the use of POFA in normal concrete, high strength concrete and lightweight concrete (Awal & Shehu, 2013). POFA is one of the agro waste ashes whose chemical composition contains a large amount of silica and potentially used as cement replacement. Due to high silica oxide content in POFA which met the pozzolanic properties criteria, it is potentially utilized as cement replacement or a filler to produce strong and durable concrete (Munir, 2015).

The resulting palm oil fuel ash was then utilized to produce durable concrete by replacing the ordinary Portland cement at 0%, 10%, 20% and 30% by weight of cement. Table 2.3 showed the chemical composition of POFA compared with OPC.

Table 2.3 Chemical composition of POFA and OPC

Chemical composition	Percentage	
	POFA	OPC
Silicon Dioxide (SiO_2)	42.24	23.00
Aluminium Oxide (Al_2O_3)	4.48	4.00
Iron Oxide (Fe_2O_3)	6.09	3.50
Potassium Oxide (K_2O)	7.76	0.51
Magnesium Oxide (MgO)	4.02	1.23
Calcium Oxide (CaO)	5.63	64.0
Sodium Oxide (Na_2O)	0.10	0.25

In this study, POFA can be classified as class c by according to Table 2.4, which is the standard specification for pozzolan used in concrete. Based on the standard this material, which is POFA, shown to be pozzolanic material and can be used in this study.

Table 2.4 Chemical Requirements

Chemical requirements	Class		
	N	F	C
Silicon Dioxide(SiO_2) plus aluminum Oxide(Al_2O_3) plus Iron Oxide (Fe_2O_3)	70.0	70.0	50.0
Sulfur trioxide (SO_3), max %	4.0	5.0	5.0
Moisture content, max %	3.0	3.0	3.0
Loss on ignition, max %	10.0	6.0	6.0

Source: (ASTM C618 − 12a, 2014)

2.5 Water

Free water/cement ratio (water to cement ratio) is the main factor to determining the strength of the concrete. There are three roles of the water in the concrete work are:

i. Water spreading cement that every particle of aggregate covered tightly.

ii. Water makes the easy to work on concrete (easy to mix the concrete).

iii. Water is an agent of the chemical reaction in the cement to bind all the aggregate in mix concrete.

2.6 Aggregate

Aggregate was originally viewed as an inert material dispersed throughout the cement paste largely for economic reasons. Aggregate is cheaper than cement it is, therefore, economical to put into the mix as much of the former and as little of the latter as possible. Sand and fragments of stone aggregates are commonly used in the concrete mix. It is usually divided into two groups:

i. The fine aggregate or sand: Stone aggregates of a size not exceeding 5mm. It is available from the sand mine, quarry or river.

ii. Coarse aggregate: size between 5-50 mm and it is usually obtained from quarries.

iii. Stone-frosted content is 60-80% of the volume of concrete.

2.7 Workability

Workability is a property of freshly mixed concrete. Workability of concrete simply means the ability to work with the concrete. Besides, workability also is a property that directly affects strength, quality, appearance and even the cost of labor for placement and finishing operations. In order to determine the workability of the concrete, slump test was conducted. The slump test originated as a way for workers to judge how easy their day was going to be using freshly mixed concrete. Slump Test is carried out to measures the consistency of plastic concrete. This test was used extensively on site. There are three types of slump, which is true slump, shear slump and collapse slump. Figure 2.1 shows the type of slump while Table 2.5 shows the different ranges of slump values and how they might be used.

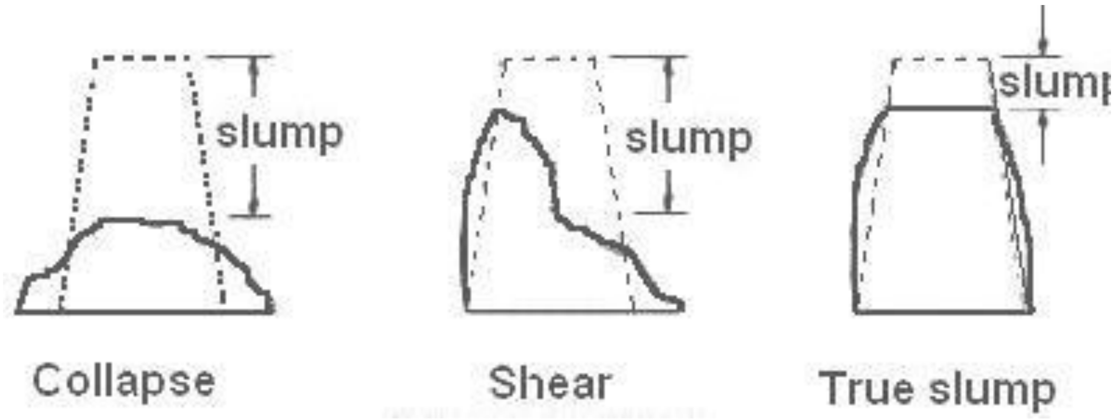

Figure 2-1 Types of slump

Source: https://en.wikipedia.org/wiki/Concrete_slump_test

Table 2.5 Differences of height of slump

Degree of Workability	Slump, in (mm)	Application
Very low	0-1 (0-25)	Very dry mixes used in paving machines with high-powered vibration
Low	1-2 (25-50)	Low-workability mixes used for foundations with light reinforcement; Pavements consolidated by hand-operated vibrators
Medium	2-4 (50-100)	Medium workability mixes; manually consolidated flat slabs. Normal reinforced concrete manually placed; heavily reinforced sections with mechanical vibration
High	4-7 (100-175)	High workability concrete for sections with congested reinforcement; May not respond well to vibration

Source: https://en.wikipedia.org/wiki/Concrete_slump_test

2.8 Compressive strength

The compressive strength test was conducted immediately after removal specimens from the curing tank. The standard use for this experiment are MS EN 12390-3:2012 and ASTM C109 / C109M. The main of the compressive strength test was to determine the compressive strength of hardened concrete specimen with reference to be standardized method.

The compressive strength was obtained from the compressive test. The ultimate compressive strength of a material was the value of uniaxial compressive stress reached when the material fails completely. Figure 2.2 shows the type of specimen failure.

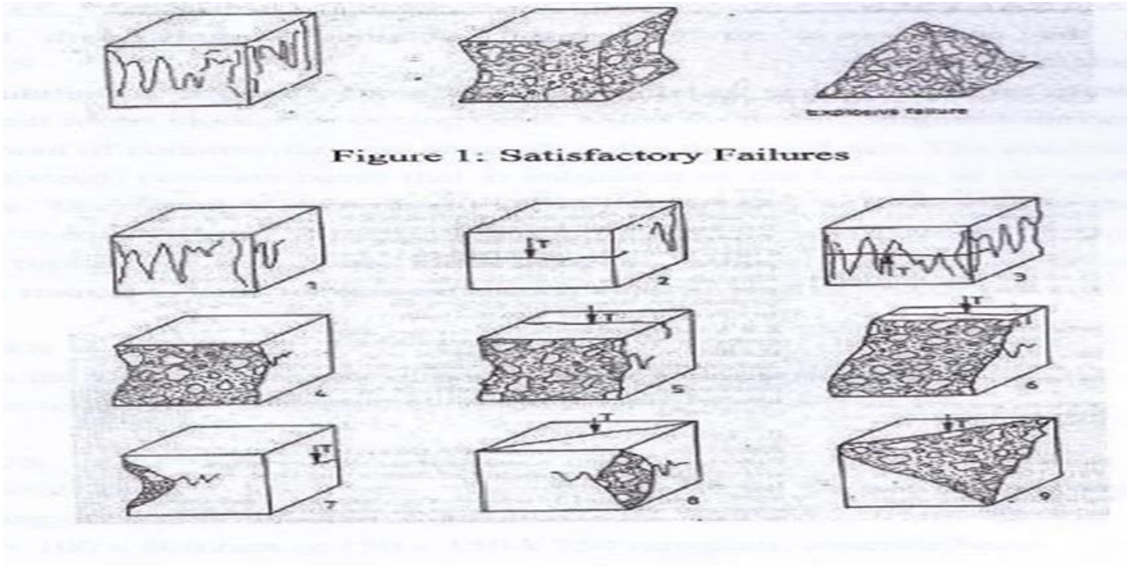

Figure 2-2 Type of Specimen Failure

Source: Civil Engineering Laboratory Manual, University Malaysia Pahang, 2011

2.9 Pozzolan reaction

Pozzolan are a broad class of siliceous or siliceous and aluminous materials which possess little or no cementitious value (silica) but react in the presence of water with calcium hydroxide at ordinary temperature, to form compounds possessing cementitious properties (Hussin et al., 2016). The reaction of cement are show in equation 1.1 and 1.2.

$$\text{Cement} + \text{Water} \longrightarrow CSH + Ca(OH)_2 \qquad \text{Eq. 1.1}$$

$$\text{Pozzolans} + Ca(OH)_2 \longrightarrow CSH \qquad \text{Eq. 1.2}$$

The reaction that happened in cement was hydration process of cement upon reacting with water. From this reaction, it will produce primary calcium-silicate-hydrate (C-S-H) gel bonding and calcium hydroxide ($Ca(OH)_2$). The $Ca(OH)_2$ were then react with pozzolans material to produce secondary CSH gel. CSH gel is the main component that contribute to the strength of the concrete. As for pozzolanic reaction, silica in pozzolans material were then react with the available $Ca(OH)_2$ that been produced from the hydration process. Factors that influence pozzolanic reaction were chemical composition, fineness and curing age. The finer the pozzolan material, the denser the concrete because all this pozzolan material will fill all the pores in the concrete and finally increases the strength of the concrete.

Pozzolanic cannot be independent. It will only react with the presence of $Ca(OH)_2$ and only can take place with water. In order to increase the strength of the concrete and better durability properties, total of CSH gel will be more. Basically, in concrete, $Ca(OH)_2$ need to reduce since $Ca(OH)_2$ will react when it meets with aggressive agents and lastly the concrete will crack and cause erosion. Thus, when pozzolans material has been added, this silica contain will consume all the $Ca(OH)_2$ and produce secondary CSH gel.

2.10 Accelerated corrosion resistance

It was known that the corrosion of reinforced steel is an important problem in the reinforced concrete structure. One of the most important issues in the corrosion of reinforced steel is the ingress of chloride ion into concrete (Horsakulthai, Phiuvanna, & Kaenbud, 2011). Accelerated corrosion test was conducted in order to determine how long POFA concrete can restrained the steel from crack. Corrosion in concrete structure was contributed from chloride-induced mechanism of deterioration mainly from absorption and diffusion of chloride ion. Chloride ion has ability to flow through absorption and diffusion might penetrate inside the concrete structure. Penetration of chloride ion gives an open space for reaction with steel embedded and cause high risk of corrosion.

Corrosion of steel embedded in concrete is an electro-chemical process. The corrosion process was stated to be similar to action, which takes place in a flash battery. The surface of the corroding steel functions as a mixed electrode that is a composite of anodes and cathodes electrically connected through the body of steel itself, upon which coupled anodic and cathodic reactions take place.

The factors affecting corrosion of steel in concrete may be classified into two major categories, which are internal factors and external factors. For external factors, it is such as seawater, moisture content and temperature. As for internal factors, it can happen because of impurities in aggregates and water cement ratio. Corrosion happens because of the present of water and oxygen. Corrosion also can speed up because of other element, which is salt. Salt that been used in this study which is sodium chloride (NaCl).

2.10.1 Anodic and cathodic reactions

For steel embedded in concrete, here are the possible reactions happened in the concrete.

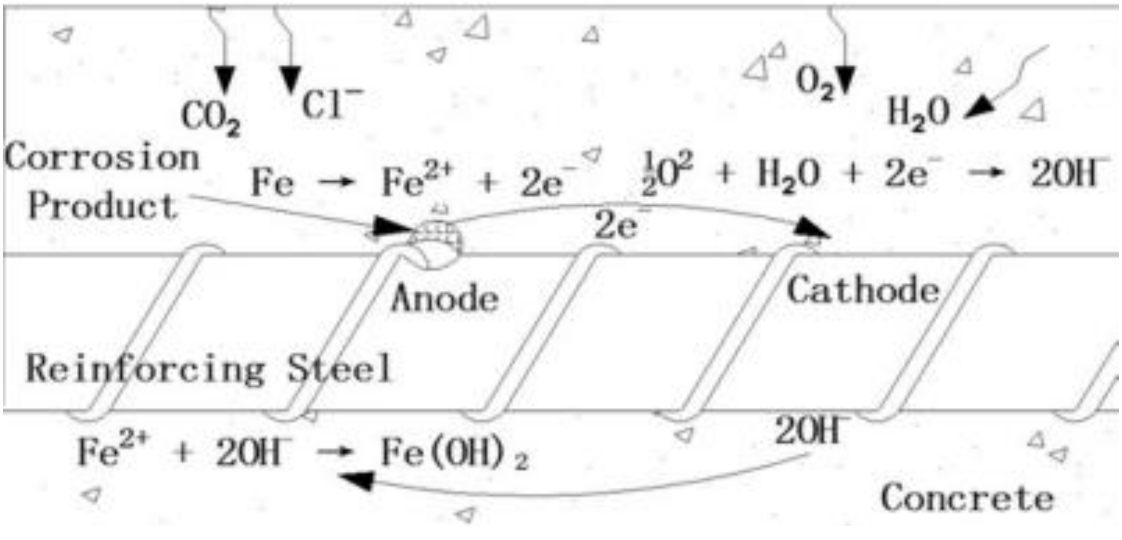

Figure 2-3 Reactions in concrete

Source: https://www.omicsonline.org/open-access/corrosion-of-reinforced-steel-in-concrete-and-its-control-an-overview

Reactions from anode and cathode later will produced Fe(OH). Fe(OH) is the corrosion product. This corrode later will go bigger and finally push away all the surrounding concrete and exposed the corroded bar. Next, surface cracking of the concrete will occur.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter clearly defines the research methods used to conduct the study. Besides, this chapter discusses in detail the research methodology that has been adopted in this study of concrete. The procedures about workability, compressive strength and study on corrosion were discussed detail in this chapter. Fibre reinforced concrete with variance of 10%, 20% and 30% of POFA and for this study the control specimen that is the fibre reinforced concrete without POFA were used as the variable in this test and go through the test. POFA in this test were used as cement replacement and which is the main focus to be tested in this study.

3.2 Experimental program

The process flow throughout this study towards workability and mechanical properties of concrete with POFA as cement replacement is as outline in Figure 3.1.

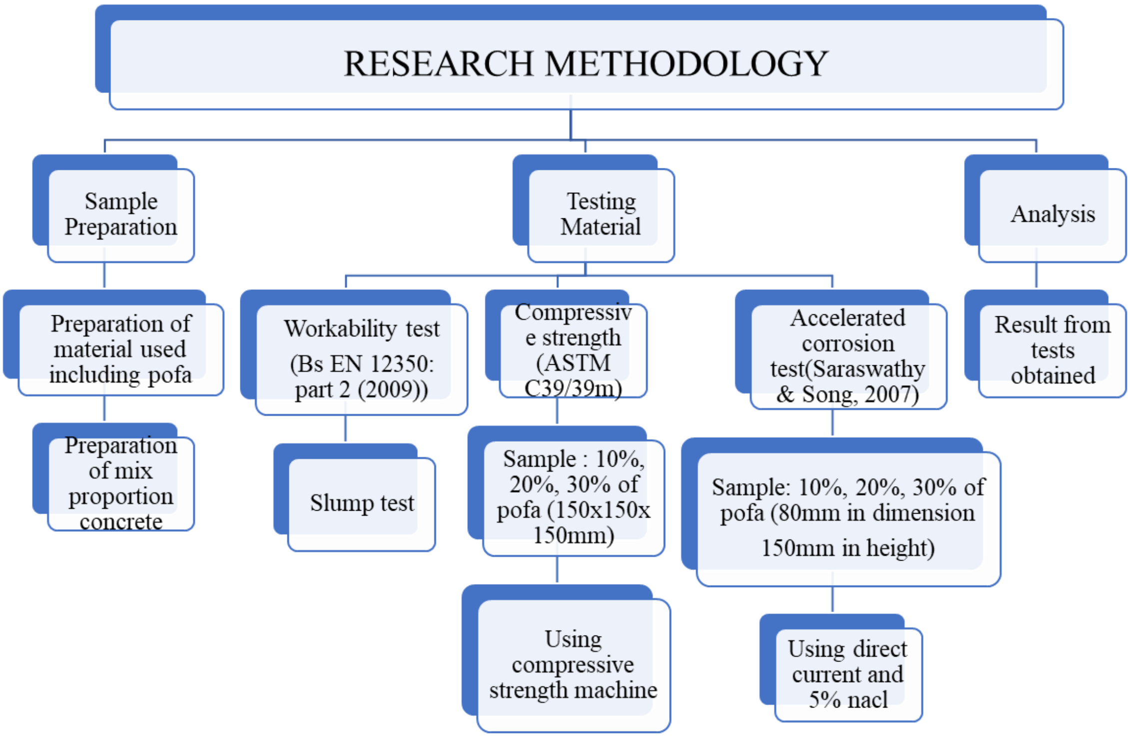

Figure 3-1 Experimental Process Flow

3.3 Sample preparation

3.3.1 Cement

For this study, Ordinary Portland Cement (OPC) that was being used type 1 Portland cement as in ASTM C 150-07.

Figure 3-2 Ordinary Portland Cement Type 1

3.3.2 Water

Water that has been used in this study is water that does not have any impurities that may affect the chemical reaction during the hydration process and pozzolanic reaction. In this study, the tap water were used.

3.3.3 Aggregate

There are two types of aggregate that has been used in this study.

3.3.3.1 Coarse aggregate

Coarse aggregate can be in form of gravel that consists of uncrushed, crushed or partially crushed mixed. It also can be in form of crushed rock or blended coarse aggregate. In this study, aggregate with maximum size of 20 mm were used. In this figure below showed the sieve analysis that been carried out in order to determine the distribution size of aggregate.

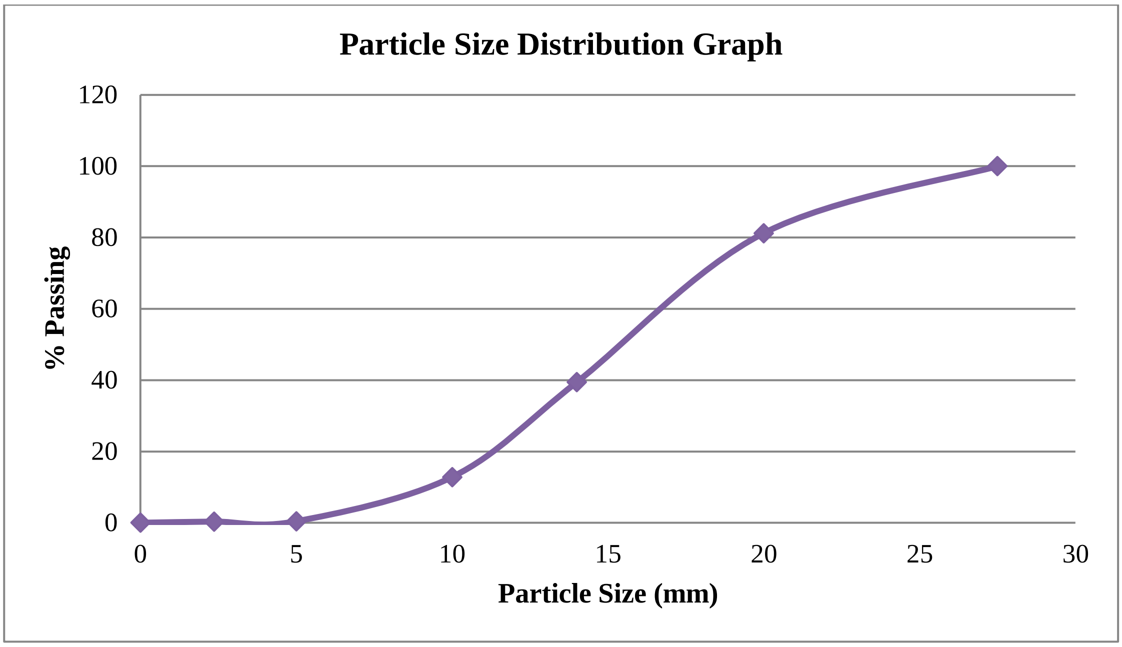

Figure 3-3 Sieve analysis result for course aggregate

3.3.3.2 Fine aggregate

Sand may be described as uncrushed, partially crushed, crushed gravel sand, crushed rock sand or blended sand. In this study, sand were used is sand which passing 600 µm sieve pan. In this figure below show the sieve analysis that has been carried out in order to determine the distribution size of fine aggregate.

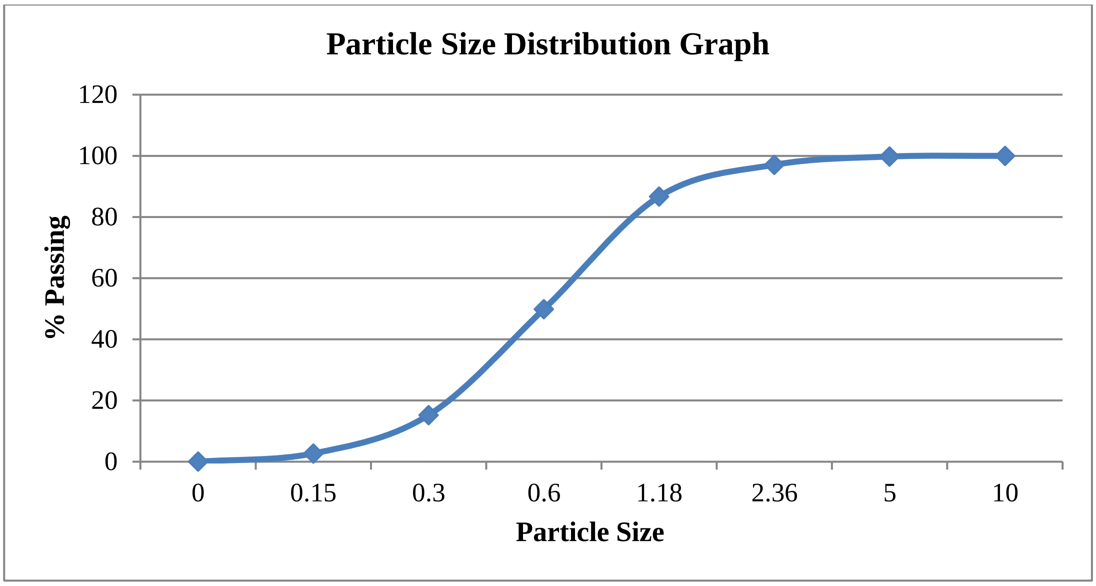

Figure 3-4 Sieve analysis result for fine aggregate

3.3.4 Palm oil fuel ash (POFA)

Palm Oil Fuel Ash (POFA) considered as a waste material produced by burning of fibres, shells and empty fruit brunches. In present study, POFA was obtained from Kilang Kepala sawit Lepar Hilir at Gambang, Kuantan.

3.3.4.1 Preparation of POFA

The POFA that obtained from the factory were dried into the oven within 24 hours and sieved with sieve size 63 μm. The amount of POFA used in depending on the weight of cement used in concrete mix. The percentage of POFA used were 10%, 20% and 30% of cement weight. Table 3.1 show the chemical properties between OPC and POFA.

Table 3.1 The chemical composition between POFA and OPC

Chemical composition	Percentage	
	POFA	OPC
Silicon Dioxide (SiO_2)	42.24	23.00
Aluminium Oxide (Al_2O_3)	4.48	4.00
Iron Oxide (Fe_2O_3)	6.09	3.50
Potassium Oxide (K_2O)	7.76	0.51
Magnesium Oxide (MgO)	4.02	1.23
Calcium Oxide (CaO)	5.63	64.0
Sodium Oxide (Na_2O)	0.10	0.25

Source: (Neville, 2011)

Based on the chemical composition of the POFA, this POFA is pozzolana materials class C because the amount of SiO_2, Al2O3 and Fe2O 3 is 52.81 % that recording standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete the minimum amount is 50% (C618 − 12a, 2014). Based on the standard this material, which is POFA, shown to be pozzolanic material and can be used in this study.

3.4 Preparation of Specimens

In order to perform the laboratory test, there are two types of specimen that were used. For compressive strength, the specimen that were used is 150 x150 x 150 mm cube that already have in the FKASA laboratory. Next for accelerated corrosion test, the specimen used is cylinder that 80mm in diameter and 150mm in height. This cylinder has been prepared using the PVC in the FKASA laboratory. As for slump test, the equipments can be obtained directly from lab. There are total of 32 specimens that will be cast.

3.5 Mix Proportion of Concrete

For this study, the design mix that used is specified characteristic strength, which is 30 N/mm^2 at 28 days. The mix proportion that has been calculated is for 1m3 of concrete. Table 3.2 shows the proportions of the design mix for the specimen.

Table 3.2 Proportion of design mix for 1m3

Materials (kg/m^3)	**0% POFA**	**10% POFA**	**20% POFA**	**30% POFA**
OPC	328	295	262	230
POFA	0	33	66	98
Steel fiber	7	7	7	7
Fine aggregates	785	785	785	785
Course aggregates	1177	1177	1177	1177
Water	190	190	190	190

3.6 Laboratory Testing

The mixing process was carried out by using concrete mixer as figure 3.5 below. After mixing process complete, sample being casted as per required in figure 3.6 and 3.7. The casting process also involving compaction of concrete mixture in order to get evenly distributed internal structure in term of size and composition.

Figure 3-5 Concrete mixer

Figure 3-6 Cube specimen

Figure 3-7 Cylindrical specimen

All the materials were mixed based on mix proportion that have been calculated. All the tests that involved in this study were followed by standard except for accelerated corrosion test which referred from the journal from science direct since there is no standard for that test yet. There are three tests involved in this study:

3.6.1 Workability

In order to determine the workability of the concrete, slump test was performed. It is to measure how hard and consistent a given sample of concrete is before curing. The concrete slump test is a one of the method of quality control.

A change in slump height would demonstrate an undesired change in the ratio of the concrete ingredients; the proportions of the ingredients were adjusted to keep a concrete batch consistent. This homogeneity improves the quality and structural integrity of the cured concrete. The procedure of doing slump test as MS 26-1-2:2009 is as below:

i. The mould and base plate were dampen and were placed on the horizontal base plate/surface and during filling; the mould was hold in firmly against the base plate/surface by standing on the two-foot pieces.

ii. The mould was filled in three layers, each approximately one-third of the height of the mould when compacted.

iii. Each layer was compacted with 25 strokes of the tamping rod.

iv. After the top layer has been compacted, the surface was strike off the concrete by sawing and rolling motion of the compacting rod.

v. The spilled concrete was removed from the base plate/surface.

vi. The mould was removed from the concrete by raising it carefully in a vertical direction.

vii. After the mould was removed, the slump height was taken by determining the difference between the height of the mould and that of the highest point of the slumped test specimen.

Figure 3-8 Slump test

3.6.2 Compressive strength test

Compressive strength is the primary physical property of concrete, and is the one most used in design. It is one of the fundamental properties used for quality control for concrete. Compressive strength may be defined as the measured maximum resistance of a concrete specimen to axial loading.

The concrete were poured into two sets of mould size 150 x 150 x 150 mm and were left harden within 24 hours. Then, the cube were cured for 7, 28 and 60 days before it can be used for testing.

Figure 3-9 The curing tank

After curing, the cube will undergo the compressive strength test. The cubes were dried before testing. In order to perform the compressive strength test, compression testing machine was used during the test. Figure 3.9 show the compression testing machine used during the compressive strength test. The cube was placed at the centre to the position of the cast. The load was applied at the constant rate of loading within the range 0,6 ± 0,2 MPa/s (N/mm2 s) until the compressive achieve 30% (MS EN 12390-3, 2012).

Figure 3-10 The compression testing machine

3.6.3 Accelerated corrosion test

Accelerated corrosion test is a testing, which indirectly gives information about the permeation characteristics of the concrete. Since there is no specific standard for this test, so in this study, this test will followed the previous researcher, which is Saraswathy & Song, 2007.

In this test, cylindrical specimen of size 80mm diameter and 150mm height were casted with centrally embedded steel and has been cured for 28 days. The cylindrical specimen has been placed in container which is stainless steel container and the specimen were immersed in 5% sodium chloride (NaCl) solution. NaCl will act as electrolyte as a medium for current/voltage to flow.

Embedded steel in concrete was anode with respect to an external stainless steel electrode serving as cathode by applying a constant positive potential of 12 V to the system from a direct current (DC) source. The day the crack is visible was recorded

Figure 3-11 Set-up for accelerated corrosion test

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this study, the POFA was used as partial cement replacement material in concrete in order to determine the corrosion resistance of the concrete. However, besides focusing on corrosion resistance, the strength of the concrete also need to take note. That is why compressive strength test was performed in this test. Before determine the strength, the workability will be tested first. In this chapter, the results that obtained was discussed based on research methodology. After obtaining the results, the determination made to conclude the optimum percentage amount of POFA can be replaced in concrete and also its suitability on construction application carries out and recommendation made.

4.2 Workability

The result of workability of concrete (slump test) for 0%, 10%, 20% and 30% replacement of POFA are shown in the Figure 4.1.

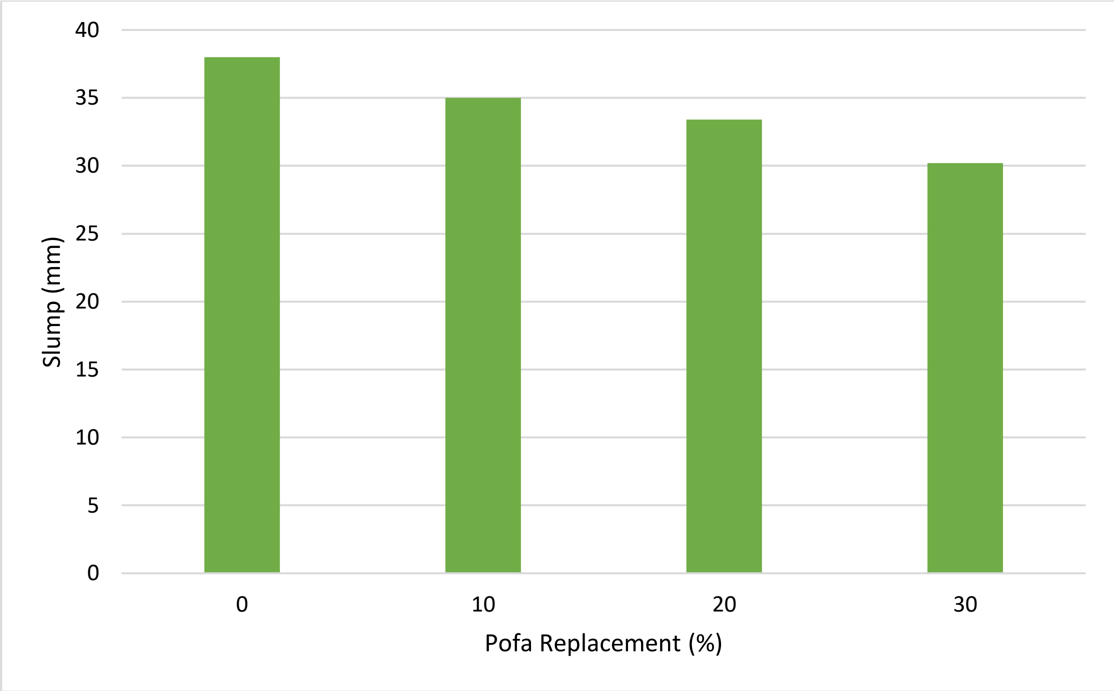

Figure 4-1 Slump test

From this figure, it shows that the height of slump was reducing as the percentage replacement with POFA increasing. The workability of fresh POFA concrete measured by the slump test reduces as the POFA content increases. This is because POFA absorbs more water to form a paste of standard consistency than cement.

Based on previous researcher, it can be seen that higher replacement of cement with POFA resulted in lower workability of the POFA concrete as compared to the concrete with OPC alone (Awal & Shehu, 2013).

4.3 Compressive strength

Figure 4.2 shows the graph of the compressive strength result with grade design 30 N/mm^2. The result shown is the compressive strength at 7, 28 and 60 days of concrete age with different percentage of POFA.

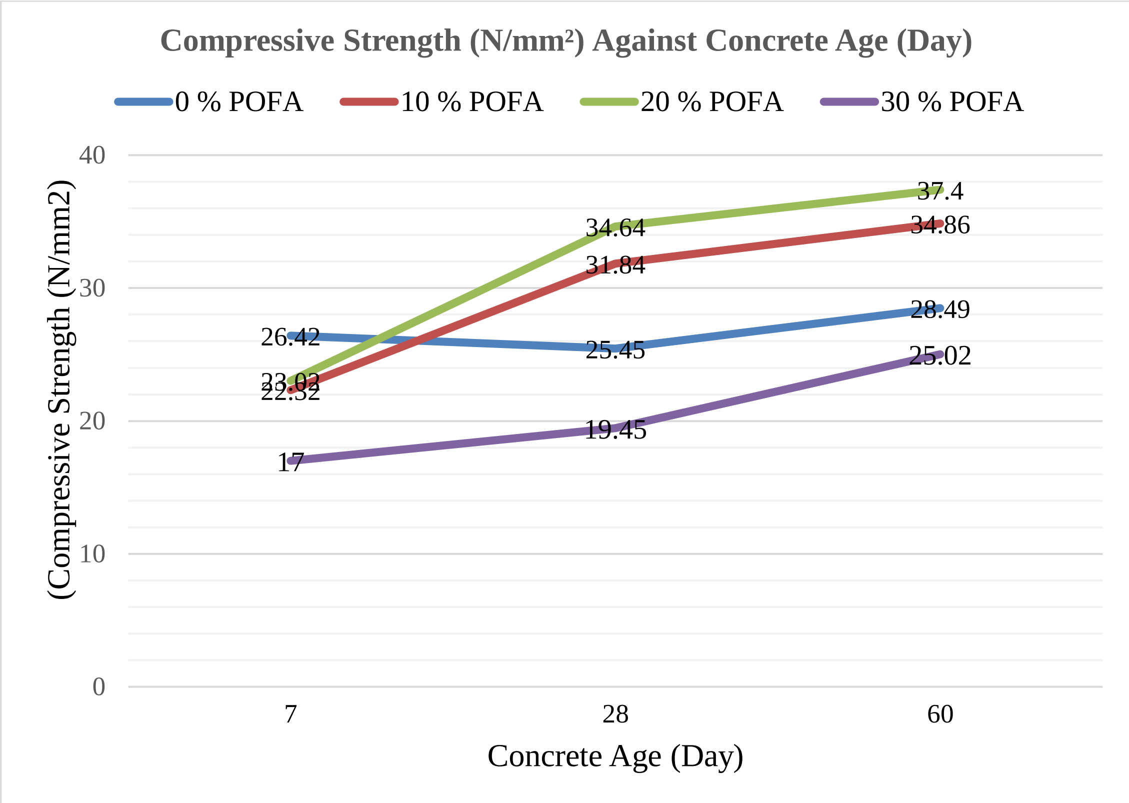

Figure 4-2 Compressive strength result

From the Figure 4.3, it shows that the compressive strength increases with the age of curing. From this graph, at the early age, which is at 7 days, the strength of POFA concrete shows lower strength gain than OPC concrete. This is because the pozzolanic reaction happen right after 28 days. That is why from the graph, the strength of concrete containing POFA only increases after 28 days. However, from this graph also, it shows that 30% of POFA decreases in the strength. The decreasing in the strength was due to the reduction in the cement amount and as a result of that calcium hydroxide ($Ca(OH)_2$) that has been produced from hydration process lower. When the $Ca(OH)_2$ is lower, it is was not sufficient to react with all available silica from pozzolan material. Lastly, the silica will not contribute to the strength development.

From the figure 4.3, the optimum percentage replacement of POFA was found to be at 20%. It is observed that the properties of can be maintained with POFA as partial replacement of cement at 20%. This is because due to the pozzolanic reaction, the amount of portlandlite, which in the crystal form decreases, thus enhances the homogeneity of the matrix. The homogeneity of concrete mix significantly reduces the porosity thus increases concrete density and strength.

Based on previous researcher who integrated 20% POFA as partial cement replacement material producing concrete exhibiting the highest compressive strength as compared to mixes with other replacement level (Yahaya & Muthusamy, 2015).

4.4 Accelerated corrosion test

Accelerated corrosion test was conducted in this study for specimen consisting of control sample POFA 0%, 10%, 20% and 30% content in concrete. The day of crack of the concrete are as table below:

Table 4.1 Result accelerated corrosion

Sample	Time to cracking (hr)
0% POFA	48
10% POFA	72
20% POFA	No cracking even after 144 h of exposure
30% POFA	No cracking even after 144 h of exposure

Table 4.1 shows the accelerated corrosion test result after 28 days curing. From this table, concrete containing 20% and 30% of POFA has no cracking even after 6 days (144 h) of exposure. This is because the replacement of POFA has made the concrete denser. When it is denser, the pores reduced and it is hard for the concrete to be attack from the outside, which oxygen and water cannot go through into the concrete. Besides, the replacement of POFA refined the pores and thereby the permeability and corrosion were reduced.

This finding was supported with the previous research, which state that there was no cracking observed in 15%, 20% 25% and 30% rice husk ash replaced concretes even after 144 h of exposure. Whereas in OPC concrete, the specimen was cracked even after 42 h of exposure in 5% NaCl solution. The concrete specimens containing 5% and 10% rice husk ash also failed within 72 and 74 h of exposure (Saraswathy & Song, 2007). Besides, it is generally accepted that incorporation of a pozzolan improves the resistance to chloride penetration and reduces chloride-induced corrosion initiation period of steel reinforcement (Chindaprasirt & Rukzon, 2008).

CHAPTER 5

CONCLUSION

5.1 Introduction

The objective of this study is to determine the workability on concrete. By using POFA as partial cement replacement, this study also is to determine the compressive strength of the concrete. Besides, the main problem of this study is to study about the corrosion resistance. The corrosion resistance towards concrete containing POFA and OPC concrete were tested in order to determine the corrosion resistance. The optimum percentage of POFA replacement for all the test results were combined and conclude to meet the objective of the study. Recommendation for better concrete mix and future study also were discussed in this chapter.

5.2 Conclusion

As a conclusion, the results from the tests shown that this POFA was suitable to use as partial cement replacement towards corrosion resistance and strength of the concrete. However, only small amount that can be used to replace the cement. Several conclusions can be drawn from the experimental test results. The conclusions are:

i. The workability of fresh POFA concrete measured by the slump test reduces as the POFA content increases.

ii. Based on 28 days compressive strength, it was demonstrate that the replacement amount of up to 30% OPC by POFA, mass for mass, had no adverse effect on the development strength. It also noticed that concrete containing POFA weaker at initial stage whilst equal or better at later ages.

iii. From the accelerated corrosion test, it can be conclude that concrete containing POFA improves the corrosion resistance properties.

As an overall conclusion, this thesis was fulfilling the entire objectives, which to determine the workability of concrete, the effect of POFA towards compressive strength and the corrosion resistance of concrete by using POFA a partial cement replacement. The replacing of 20% of POFA by weight of cement has shown the optimum partial due to the pozzolanic reaction.

5.3 Recommendation

In this research, it is strongly recommend the utilization of POFA as a partial cement replacement for concrete manufacturing technology as well as in civil engineering field especially for building and structure. Research on the others performance needed in order to develop these waste material products to be more applicable material in construction's company. There are some recommendations for future research suggested from the results obtained from the research:

i. To study the performance of fiber reinforced concrete containing POFA as partial cement replacement

ii. To study the effect of curing method towards fiber reinforced concrete containing POFA as partial cement replacement

iii. Use other type of cement instead of Ordinary Portland Cement in research and compared with other cement

iv. Study on the POFA as partial cement replacement with no grinding and compare with the result that grind the POFA

REFERENCES

Al-mulali, M. Z., Awang, H., Khalil, H. P. S. A., & Shaker, Z. (2015). Cement & Concrete Composites The incorporation of oil palm ash in concrete as a means of recycling : A review. *CEMENT AND CONCRETE COMPOSITES*, *55*, 129–138. https://doi.org/10.1016/j.cemconcomp.2014.09.007

Awal, A. S. M. A., & Mohammadhosseini, H. (2016). Green concrete production incorporating waste carpet fiber and palm oil fuel ash. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2016.06.162

Awal, A. S. M. A., & Shehu, I. A. (2013). Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. *Fuel*, *105*, 728–731. https://doi.org/10.1016/j.fuel.2012.10.020

Bamaga, S. O., Hussin, M. W., & Ismail, M. A. (2013). Palm Oil Fuel Ash: Promising supplementary cementing materials. *KSCE Journal of Civil Engineering*, *17*(7), 1708–1713. https://doi.org/10.1007/s12205-013-1241-9

C618 − 12a, A. (2014). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use, 1–5. https://doi.org/10.1520/C0618

Chindaprasirt, P., & Rukzon, S. (2008). Strength , porosity and corrosion resistance of ternary blend Portland cement , rice husk ash and fly ash mortar, *22*, 1601–1606. https://doi.org/10.1016/j.conbuildmat.2007.06.010

Horsakulthai, V., Phiuvanna, S., & Kaenbud, W. (2011). Investigation on the corrosion resistance of bagasse-rice husk-wood ash blended cement concrete by impressed voltage. *Construction and Building Materials*, *25*(1), 54–60. https://doi.org/10.1016/j.conbuildmat.2010.06.057

Kroehong, W., Sinsiri, T., & Jaturapitakkul, C. (2011). Procedia Engineering Effect of Palm Oil Fuel Ash Fineness on Packing Effect and Pozzolanic Reaction of Blended Cement Paste. https://doi.org/10.1016/j.proeng.2011.07.045

Kroehong, W., Sinsiri, T., Jaturapitakkul, C., & Chindaprasirt, P. (2011). Effect of palm oil fuel ash fineness on the microstructure of blended cement paste. *Construction and Building Materials*, *25*(11), 4095–4104. https://doi.org/10.1016/j.conbuildmat.2011.04.062

Ma, Y., Guo, Z., Wang, L., & Zhang, J. (2017). Experimental investigation of corrosion effect on bond behavior between reinforcing bar and concrete. *Construction and Building Materials*, *152*, 240–249. https://doi.org/10.1016/j.conbuildmat.2017.06.169

Marcos-meson, V., Michel, A., Solgaard, A., Fischer, G., Edvardsen, C., & Lund, T.

(2017). Cement and Concrete Research Corrosion resistance of steel fi bre reinforced concrete - A literature review. *Cement and Concrete Research*, (October 2016), 1–20. https://doi.org/10.1016/j.cemconres.2017.05.016

Mohammadhosseini, H., Yatim, J. M., Sam, A. R. M., & Awal, A. S. M. A. (2017). Durability performance of green concrete composites containing waste carpet fibers and palm oil fuel ash. *Journal of Cleaner Production*, *144*, 448–458. https://doi.org/10.1016/j.jclepro.2016.12.151

MS EN 12390-3. (2012). MALAYSIAN STANDARD.

Munir, A. (2015). Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material. *Procedia Engineering*, *125*, 739–746. https://doi.org/10.1016/j.proeng.2015.11.119

Parande, A. K., Babu, B. R., Karthik, M. A., K, D. K. K., & Palaniswamy, N. (2008). Study on strength and corrosion performance for steel embedded in metakaolin blended concrete / mortar, *22*, 127–134. https://doi.org/10.1016/j.conbuildmat.2006.10.003

Raut, A. N., & Gomez, C. P. (2016). Thermal and mechanical performance of oil palm fiber reinforced mortar utilizing palm oil fly ash as a complementary binder. *Construction and Building Materials*, *126*, 476–483. https://doi.org/10.1016/j.conbuildmat.2016.09.034

Saraswathy, V., & Song, H. (2007). Corrosion performance of rice husk ash blended concrete, *21*, 1779–1784. https://doi.org/10.1016/j.conbuildmat.2006.05.037

Skariah, B., Kumar, S., & Sahan, H. (2017). Sustainable concrete containing palm oil fuel ash as a supplementary cementitious material – A review. *Renewable and Sustainable Energy Reviews*, *80*(July 2016), 550–561. https://doi.org/10.1016/j.rser.2017.05.128

Sooraj, V. M. (2013). Effect of Palm Oil Fuel Ash (POFA) on Strength Properties of Concrete, *3*(6), 1–7.

Yahaya, F. M., & Muthusamy, K. (2015). Corrosion Resistance of High Strength Concrete Containing Palm Oil Fuel Ash as Partial Cement Replacement Corrosion Resistance of High Strength Concrete Containing Palm Oil Fuel Ash as Partial Cement Replacement, (June 2014). https://doi.org/10.19026/rjaset.7.857

APPENDIX I

AVERAGE OF COMPRESSIVE STRENGTH FOR EACH % OF POFA

PERCENTAGE OF POFA (%)	CONCRETE AGE (DAY)			
	0	**7**	**28**	**60**
0	0	26.42	25.45	28.49
10	0	22.32	31.84	34.86
20	0	23.02	34.64	37.4
30	0	17	19.45	25.02