DURABILITY PERFORMANCE OF LIGHTWEIGHT CONCRETE CONTAINING OIL PALM ASH SUBJECTED TO AIR CURING

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Thesis submitted in fulfillment of the requirements
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ABSTRACT

Cement manufacturing industry and solid waste disposal from palm oil industry in Malaysia had caused a bad impact towards the environment. The production of cement produces high amount of carbon dioxide emission while the disposal of palm oil waste such as oil palm ash (OPA) and palm oil boiler stone (POBS) are rather be disposed in landfills without profit return. This has made the palm oil waste as a source of material to partially replace the cement content in the concrete mix as to reduce the environmental pollution and amount of waste being disposed. Moreover, the use of POBS as course aggregate replacement in concrete can perpetuate the natural resources such as granite. Hence, a research to study the durability performance of lightweight concrete (LWC) containing oil palm ash as partial cement replacement that is subjected to air curing is made for 23 weeks. In fact, LWC containing OPA exhibits low water absorption as it is high in pozzolanic reaction. This study also emphasized the durability performance in terms of both acid and sulphate resistance towards LWC. Trial mix is made in the early stage of concrete mix design to select the best performing OPA lightweight concrete while taking account into durability and strength. As such, concrete Grade 60 with 20% of OPA as partial cement replacement is the best mix to sustain acid and sulphate attacks with a great durability and strength. All in all, this study proves that LWC containing OPA is potentially be applied in construction industry for structural application as it can minimize the cost of production while at the same time reduces the dead load of concrete structure.

ABSTRAK

Industri pembuatan simen dan pelupusan sisa pepejal daripada industri minyak sawit di Malaysia telah menyebabkan kesan yang tidak baik terhadap alam sekitar. Pengeluaran simen menghasilkan jumlah pelepasan karbon dioksida yang tinggi manakala pelupusan sisa minyak sawit seperti abu kelapa sawit dan batu dandang minyak sawit dilupuskan di tapak pelupusan tanpa pulangan keuntungan. Ini telah menjadikan sisa kelapa sawit sebagai sumber bahan bagi menggantikan kandungan simen dalam campuran konkrit untuk mengurangkan pencemaran alam sekitar dan jumlah sisa yang dilupuskan. Selain itu, penggunaan batu dandang minyak sawit penggantian padang agregat dalam konkrit boleh mengekalkan sumber-sumber semula jadi seperti granit. Oleh itu, penyelidikan untuk mengkaji prestasi ketahanan konkrit ringan yang mengandungi abu kelapa sawit sebagai separa penggantian simen yang tertakluk kepada pengawetan udara dibuat untuk 23 minggu. Malah, konkrit ringan mengandungi kandungan abu kelapa sawit dengan penyerapan air yang rendah kerana ia adalah tinggi dalam reaksi pozolanik. Kajian ini juga menekankan prestasi ketahanan dari segi kedua-dua asid dan rintangan sulfat terhadap konkrit ringan. Cubaan campuran dibuat dalam peringkat awal reka bentuk campuran konkrit untuk memilih yang terbaik bagi konkrit ringan yang mengandungi abu kelapa sawit semasa mengambil kira ketahanan dan kekuatan. Oleh itu, gred konkrit 60 dengan 20% abu kelapa sawit sebagai separa pengganti simen adalah gabungan terbaik untuk mengekalkan asid dan sulfat serangan dengan ketahanan yang hebat dan kekuatan yang tinggi. Kajian ini membuktikan bahawa konkrit ringan mengandungi abu kelapa sawit berpotensi digunakan dalam industri pembinaan untuk applikasi struktur kerana ia boleh mengurangkan kos pengeluaran dan pada masa yang sama dapat mengurangkan beban struktur konkrit.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

kg/m^3	kilogram per cubic metre
mm	millimetre
MPa	megapascal
%	percent
°C	degree Celsius
fc	compressive strength
N/mm^2	newton per square millimetre
m_1	mass of specimens before immersion
m_2	mass of specimens after immersion
μm	micrometre

LIST OF ABBREVIATIONS

LWC	Lightweight Concrete
LWAC	Lightweight Aggregate Concrete
LWA	Lightweight Aggregate
OPA	Oil Palm Ash
POBS	Palm Oil Boiler Stone
ASTM	American Society for Testing and Materials
C-S-H	Calcium silicate hydrate
BS-EN	British Standard
OPC	ordinary Portland cement
HCI	hydrochloric acid
$CaCO_3$	calcium carbonate
CaO	calcium oxide
OPS	Oil palm shell
SO_3	sulphur trioxide
SiO_2	silicon dioxide
$NaSO_4$	sodium sulphate
C_3A	tricalcium aluminate
CO_2	carbon dioxide

CHAPTER 1

INTRODUCTION

1.1 Background Study

Lightweight concrete (LWC) is widely used in the construction industry since it is lighter than the conventional concrete used for construction with a density lower than 2000kg/m^3. As such, the LCW can be found in the making of the component of buildings where it does not impose a great load such as the parapet wall and road liners. It is mostly used due to its porosity that provides a good water absorption for the internal curing to test on the strength and durability of it as to compared with the conventional concrete. There are basically three types of lightweight concrete that include Lightweight Aggregate Concrete, Aerated Concrete and No-Fines Concrete.

The reasons why the lightweight concrete is widely used are because it can reduce the dead load of the concrete structure while at the same time can produce a low cost of production in terms of the size reduction, less steel reinforcement work and low volume of concrete. LWC is also high in fire resistivity that can provide more efficient strength-to-weight ratio while improve the thermal property. In addition, LWC is designed to achieve the similar properties as the normal concrete such as the durability except for which LWC is made of both the lightweight course and fine aggregates. Knowing that the lightweight aggregates used are usually consist of expanded shale, slate or clay materials that had been fired in a rotary kiln in order to develop a porous structure.

Palm Oil Boiler Stone (POBS) is the waste product of the palm oil industry that is produced in the boiler when the husk fibre and shell of palm oil is burned to generate energy for the refineries (Mohd, 2012). In Malaysia, the palm oil is widely produced year by year since it gets high demand in the market. Palm oil boiler stone (POBS) is a waste by-product from the incineration process of oil palm shells and fibres. They are porous and lightweight in nature, which makes them suitable for use as a lightweight aggregate (LWA) (Kanadasan & Abdul Razak, Materials & Design (1980-2015), 2014).The number of palm oil waste increases as the number of palm oil production increases which then will affect the environment if the waste is not being disposed wisely. Furthermore, using the POC as the partial cement replacement can cause a higher water absorption for the LWC and the shrinkage with low modulus of elasticity. The characterization of such waste to identify its suitability as a cement replacement material, can ultimately lead to lower carbon footprint concrete (Karim & Hashim, 2017).The palm oil boiler stone is usually irregular in shape with a greyish colour and high in porosity. The utilization of waste by-products in concrete has garnered positive outcomes over the past few decades in terms of the cost savings and conservation of natural resources (Kanadasan & Sarker , 2015).

1.2 Problem Statement

As for this study, the palm oil waste is use in the lightweight concrete because palm oil is produced numerously in Malaysia and plus, the supply of the natural aggregate in the making of lightweight concrete that is cement is about to decrease since the demand is getting higher. The production of the cement is decreasing due to high demand and fast development in construction industry while knowing that the process of making a cement will takes time since it needs to burn and process in such a long time.

However, to eliminate the use of palm oil is very impossible since it is one of the main contributor to our country in terms of economy since Malaysia is the second biggest palm oil exporter in the world after Indonesia. But not to worry because the construction industry can use the palm oil waste as the ingredient or mix to make a concrete in order to minimize the disposing of the waste because the waste can lead to a harmful environment such as the air pollution and soil pollution since the palm oil waste is being dumped in the landfills. Other than that, people might also get exposed to the disease if keep consuming the water that flows through the waste disposal area and the landfills in Malaysia is increasing from time to time if the palm oil waste is not being disposed wisely. Making the POC as the partial cement replacement in the making of lightweight concrete is a little as much helping our country to minimize these problems in a long period of time because POC has a similar physical property as the conventional aggregate hence, the price of the LWC that had been mixed with the POC is cheaper than the conventional price. The concerns over paucity and supplies of raw materials have led researchers to identify alternative materials that could be incorporated as partial cement replacement in concrete production,

1.3 Objective of Research

The objectives of the study are:

i. To determine the compressive strength of the lightweight concrete containing Oil Palm Ash (OPA)
ii. To determine the acid resistance of the lightweight concrete containing Oil Palm Ash (OPA)
iii. To determine the water absorption and sulphate attack on the lightweight concrete containing Oil Palm Ash (OPA)

1.4 Scope of Research

This study is focused on the durability of the lightweight concrete containing palm oil fuel ash as partial cement replacement. The lightweight concrete is subjected to air curing for 28 days. This study is to test the compressive strength of the LWC whether it is stronger or not as to compare with the conventional LWC in the construction industry. There are 60 concrete cubes in total for this study.

In this study, the immersing solution that had been used to test the durability of the LWC is hydrochloric acid (HCI) and sodium sulphate (NaSO4) solution. In fact, hydrochloric acid is a strong acid that can be a corrosive acid towards concrete.

1.5 Layout of Thesis

In this writing, chapter one consists several items that are known as the introduction, problem statement, research objectives, scope of research, significance of the study and the layout of the thesis for each of the chapters. In fact, the introduction is the starter of the thesis that tells what the topic is about. Knowing that the problem statement describes the problem(s) that is going to be studied throughout the studies and it may contains a general problem written in the form of a statement by the specific questions. In addition, the objectives of the study must be tally with problem statement and it includes the specific and general objectives of the research. The scope of the research shows the explanation of the study that includes the limitation considered during the study such as the actual place and duration of the study as well as the other specific aspects. The significance of the study discusses the reasons in conducting the research while stating the contribution of the study to the society in a long period of time.

Next is about chapter two that consist of the literature review of the past research made by other researchers. It elaborates on the reaction between the acid and sulphate in order to test the compressive strength of the lightweight concrete. It also describes about how does the palm oil waste can be obtained from and what does it means by the water absorption of the lightweight concrete.

Chapter three is indicates the methodology of the study or the experiment details such as the step-by-step procedures that had been done to achieve the objectives of the study. The methodology starts with the procedure on how to prepare the materials for the mix of the LWC such as where to get the clinker, how to prepare the clinker before it is ready to be mixed as the partial cement replacement and how to prepare the solutions that is going to be used for immersing the concrete cubes after 28 days of the air curing.

Chapter four tells us the results of the study whether the objectives can be achieved or not. The weight of the LWC cubes before and after immersing the cubes into the hydrochloric acid and sulphate solution are being discussed. Other than that, the compressive strength of the LWC cubes had been tested and discussed. To shows some changes or result pattern for this study, the results obtained were analysed and presented in the form of graphical and tabulated illustrations. Finally, is the chapter five. It is about the conclusion of the study and includes with the recommendation for the future study to guide the next generation to perform the study much better in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter Two is about the literature review that includes the presentation of the past studies related to the topic chosen that are suitable to be used as the reference for this study in order to develop an understanding upon completion of this study on the durability of the oil palm ash lightweight concrete while testing the acid and sulphate attack on the lightweight concrete itself. There are many references that can be referred to as to strengthen the understanding on this topic. Recently, there are problems or issues that related to the cement production and the disposal of the oil palm ash which had made the usage of the OPA as the partial cement replacement as one the best way to reduce all those problems in order to produce a lightweight concrete. As such, the usage of waste product in the lightweight concrete production can be beneficial to both economy and the environment while reducing the waste production in our country. Besides, this study had discussed the effects of using the OPA as the cement partial replacement on the compressive strength, water absorption and the attacks from the acid and sulphate towards the lightweight concrete. Utilizing waste material in the construction industry is an effective way to protect the environment and minimize construction cost (Abutaha, Kanadasan, & Abdul Razak, 2016).

2.2 Lightweight Concrete (LWC)

2.2.1 Production of Lightweight Concrete

The rapid progress of development and urbanisation had resulted in a shortage of natural resources that are used as the conventional building construction materials such as cement. In addition, the process of producing these natural resources have gave pollutions to the water, air and soil which in return would pass out the impact to the earth livings. In order to meet the ever-increasing demand for the energy efficient building construction materials there is a need to adopt cost effective, environmentally appropriate technologies and upgrade traditional techniques with available local materials (Mangesh, Ralegaonkar, & Mandavgane, 2013).

Basically, there are two ways of producing the LWC. The first way is to mix between cement, water, sand, lightweight aggregate and admixture while the second way is to mix the cement, water, sand and admixture all together in the mix design process. The admixture mentioned is the special air entrained agent such as Sika Lightcrete by which the mix is batched for a designed volume the air entrained is measured to determine final volume of the concrete batched. The air entrained agent creates the tiny air bubbles in concrete.

2.2.2 Advantage of Lightweight Concrete

Lightweight concrete is a concrete with an air-dried unit weight that is not exceeding 1850kg/m^3. Basically, the lightweight concrete (LWC) can be categorized into three categories that includes the aerated concrete, lightweight aggregate and no fines concrete which had different properties. The good side of using the LWC in the construction industry is its low in density property that reduces the loads on the foundation while supporting the structures to two-third or less however, the engineering properties of LWC is highly depending on the material used in the mix design.

2.2.3 Application of Lightweight Concrete

The British Code of Practice BS8110 recommends a minimum characteristic strength of 15.0 N/mm^2 at 28 days. The applications of LWC is widely known in the making of load bearing and non-load bearing concrete blocks, precast wall panels as well as for the insulating purposes. In addition, lightweight concrete has been used since the 18th centuries by the Roman and now it is widely used as loose-fill insulation in masonry construction where it enhances fire ratings, reduces noise transmission and good termite resistant. Structure with lightweight concrete should assure adequate performance of member under heavy loading (Ahmmad, Bahri, & Jumaat , 2014). The accelerated development of the concrete industry has made possible the use of lightweight concrete for many purposes: floors, walls, columns, supports, shell roofs and boats. High strength lightweight concrete is used extensively in the precast concrete industry (Stamenkovic, 1970).

2.2.4 Properties of Lightweight Concrete

The most significant property of lightweight concrete is it reduces the weight at no sacrifice in strength. Lightweight Concrete provides the same compressive strength as normal weight aggregates with approximately the same cement content. The lower density and higher insulating capacity are the best obvious characteristics of lightweight aggregate concrete by which it distinguishes itself from ordinary normal weight concrete (Abdulzahra & Najim, 2015). It is found that the using of lightweight aggregate instead of normal aggregate contributed in production good characteristics of concrete such as compressive strength, tensile strength and modulus of rupture. However, the unit weight and water demand of these materials are less than the normal aggregate unit weight and water demand. Variations in the weight, density, absorption, and surface moisture of aggregates produce both independent and related effects on the properties of concrete. Some effects are the result of a direct relationship between one or more aggregate factors and a property of concrete, such as the influence of the weight and density of aggregates on the weight of concrete (Brink & Timms, A. G.).

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2.3 Palm Oil Boiler Stone (POBS)

2.3.1 Utilization of POBS in Construction Industry

Although the agro-industry in Malaysia has been the backbone of the country for a few decades, products from this industry generate a huge amount of waste that requires suitable disposal (Kanadasan J. , et al., 2015). The utilization of waste materials from the palm oil industry gives various benefits in construction industry. Palm oil boiler stone is a by-product that can be produced from the processed palm oil. Agricultural wastes have been used for animal feed, fertilizer and fuel for energy production, but little work has been carried out to develop utilization of these wastes in the production of building materials (Abang Abdullah & Satish, 1996). The use of agricultural wastes as aggregates in lightweight concrete can provides an alternative to conventional methods for the production of lightweight concrete (Abang Abdullah & Satish, 1996). A self-compacting concrete using POBS showed that almost 68% of the compressive strength can be achieved when POBS is replaced with natural aggregates (Kanadasan J. & Hashim Abdul Razak, Utilisation of By-Product Materials in Concrete, 2015). There are numerous studies have been conducted on the incorporation of waste agricultural by-products in the construction industry. Utilisation of POBS in concrete production not only solves the problem of disposal of this solid waste but also helps to conserve natural resources. (Abdullahi, Foo, & Bashar, 2014)

2.3.2 Production of POBS

Wastes are produced in large quantities from agro-based industries and the use of these waste materials in construction industry would contribute towards a cleaner environment (Mannan & Ganapathy, 2004). Palm oil boiler stone is a by-product of palm oil industry which normally being dumped abundantly as waste which caused to the undesirable effects to our environment sustainability (Noor, Sofian, & Hilton, 2007). To produce a cleaner and greener concrete two waste materials from the palm oil industry were used as coarse and fine aggregates (Bahri, Jumaat, & Rasel, 2015). The different stages in the processing of palm oil generate various types of waste by-products, which must be disposed of appropriately for a cleaner environment and to reduce pollution. In this study, palm oil boiler stone (POBS), one of the by-products of the palm oil mill, was utilized in the production of self-compacting concrete (SCC) (Journal of Cleaner Production).

2.3.3 Benefit of Using POBS

The use of industrial waste as construction material to build environmentally sustainable structures has several practical and economic advantages. Oil palm shell (OPS) is a solid waste material from the palm oil industry that has been successfully used to produce high strength durable lightweight concrete. However, this concrete is very sensitive to a poor curing environment. (Aslam, Lachemic, Jumaat, & Shafigh, 2016).

2.4 Acid and Sulphate Attack

2.4.1 Effects of the Attack towards LWC

Although partial replacement of ordinary Portland cement (OPC) by various latent hydraulic binders can lead to improved sulphate resistance, the mechanism by which these latent hydraulic binders act is not established (Lawrence, 1990). Civil engineers must cope with a unique combination of corrosion by acidity, salt, and reducing conditions, and with the difficulties of design and construction of earthworks, roads, and drainage systems in unripe materials (Dent, 1986). Cements have long been known to undergo deterioration in sulfate-rich service environments. (Esperanza & Thomas, 2012). Furthermore, sulfate attack is defined as deleterious action involving sulfate ions; if the reaction is physical, then, it is physical sulfate attack that takes place (Neville, 2004). Sulfate attack on concrete structures in service is not actually widespread and the amount of laboratory-based research seems to be disproportionately large. Sulfate attack on Portland cement concrete is often said to arise from each of two major sulfate reactions, the sulfate ions react with C_3A and its hydration products to form ettringite with an increase in volume that results in expansion and subsequent cracking of the concrete (Tian, Cement and Concrete Research, 2000). Sulfate attack on Portland cement concrete is often said to arise from each of two major sulfate reactions. The sulfate ions react with C_3A and its hydration products to form entringite with an increase in volume that results in expansion and subsequent cracking of the concrete (Tian, Cement and Concrete Research, 2000).

2.5 Air Curing Method

Curing methods differed with varying combinations of fog room and air curing.

2.5.1 Compressive Strength of Lightweight Concrete

For the production of such high-quality concretes there is a need for a better understanding of the mechanism by which strength is generated in such system (Ferhad, 2004). Therefore, it is recommended that both compressive strength and waster absorption tests must be performed for quality control of oil palm shell concretes (Shafigh & Maghfouri, IOP Conference Series: Materials Science and Engineering). It is found that lightweight and normal weight concretes are affected differently by mix design parameters (Gomes & Gomes, 2013). It was concluded that high strength and durable lightweight concrete satisfying requirements for arctic concrete structures could be obtained by using lightweight aggregate with low moisture content (Tazawa, Nobuta, & Nojiri). Compressive strength (f_c) under different curing conditions and the splitting tensile and flexural strengths were compared with those of the normal weight granite concrete (Shafigh, Jumaat, & Abd Hamid, Construction and building materials, 2012). Test results show that the compressive strength and modulus of elasticity decreases with increasing in perlite content. Water absorption and sorptivity coefficient, however, increase with the higher perlite contents. The test results indicate that the thermal conductivity is substantially improved with the use of perlite and a strong relationship between thermal conductivity and unit weight is obtained (Sengul & Ali Tasdem, 2011).

2.5.2 Effect of Air Curing towards Lightweight Concrete

Besides, curing process also helps to prevent and replenishes the loss of moisture from the concrete as well as to maintain a good temperature for hydration to occur in the period of time (Awaludin, 2015). In this study, the period of curing is observed to be 28 days. The early results of the investigation suggest that the compressive strength of this concrete is less sensitive to lack of initial curing. However, depth of water penetration, which is indicative of the concrete’s permeability and hence durability, has been found to be more sensitive to the duration of initial curing even for the specimens exposed to the high-humidity seaside ambient conditions.

2.6 Water Absorption

Water is an important raw material for mixing concrete. It gives an important role in cement hydration process which helps the production of C-S-H gel (Siong, 2015). Regardless of its significant role, the water is an agent of deterioration which permeates concrete. Knowing that water molecule is very small until it can penetrate easily inside the fine pores of the lightweight concrete. At ambient temperature, water tends to exist in liquid state in a porous material rather than vaporizing and leaving the material dry. Hence, high internal stress leads to the expansion inside the concrete (Siong, 2015). It has been demonstrated that the rate and the extent of the absorption of mixing water by the aggregate in concrete is dependent not only on its water absorption, but also on its moisture content, moisture state, the procedure of concrete preparation and the concrete composition (Domagala, 2015). The effect of mixing water absorption by the lightweight aggregate revealed in tests of fresh concrete as the reduction of water-cement ratio was also reflected in hardened state of concrete as the increase of its strength. Water absorption test is used to evaluate overall performance of concrete in terms of durability. The water absorption of lightweight concrete might be considerably higher than the conventional concrete due to higher rate of pores in concrete and lightweight aggregate (Maghfouri, Shafigh, & Ibrahim). In fact, the determination amount of water is important because with excessive of water it will cause the concrete with higher slump and cause a free-flowing concrete. Increasing the water/cement ratio was found to decrease the strength of lightweight aggregate concrete. The numbers of pores within the cement paste and in the aggregate/cement paste interfacial zone were found to increase (Lo, Cui, & Tang, 2007).

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the materials and testing procedures are elaborated in detail while the flowchart of the experimental work is also provided. To be specific, the beginning of this chapter explains on the detail of the materials used for this study. In addition, the contents of this methodology chapter continue with the lightweight concrete preparation process. The testing procedures that includes four tests namely as the compressive strength, water absorption, acid attack resistance and sulphate attack resistance test as to achieve the aim of this study.

3.2 Flowchart of Experimental Work

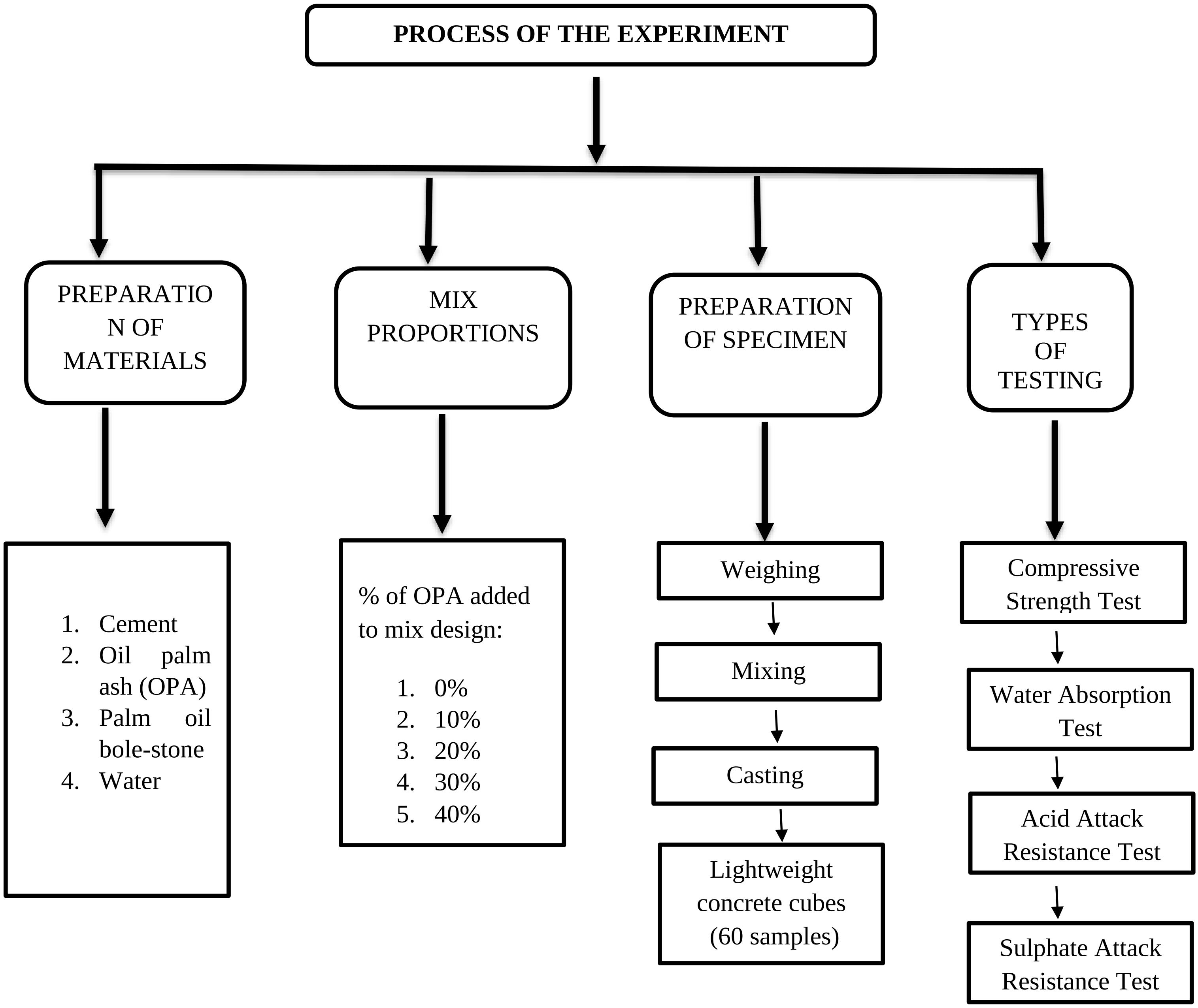

Figure 3.1: Flow Chart of the Experimental Work

3.3 Materials

The materials used in this research are Ordinary Portland Cement (OPC), Palm Oil bole-stone as coarse aggregates, Oil Palm Ash (OPA, fine aggregate and water.

3.3.1 Cement

Cement is widely used in construction industry no matter what type of cements are they since it is a binder that comes in a finely ground inorganic material. In fact, the cement will form a paste that will sets and hardens when mix with water due to the hydration reactions that occurs in a presence of water.

For this study, Ordinary Portland Cement (OPC) is used in the mix design to produce the lightweight concrete. The OPC type of cement used is the Orang Kuat manufactured by YTL Cement Marketing Sdn. Bhd.

Figure 3.2: YTL Orang Kuat OPC Cement

3.3.2 Palm Oil Boiler Stone

In this study, the palm oil bole-stone (POBS) is used as the coarse aggregate in the design mix for the production of the lightweight concrete. It is obtained from the palm oil mill located in Lepar, Pahang. At the palm oil mill, the palm oil bole-stone is collected and filled in the gunnies before transporting it to Universiti Malaysia Pahang. At the lab, the collected bole-stone is cleaned up first so that any dirt can be eliminated. Then, the bole-stone is dried in the oven at the temperature of 110ºC ± 5 for 24 hours. The oven drying process is to ensure that there is no moisture content in the bole-stone after washing them with the tap water. After the removal of the bole-stones from the oven, it need to be crushed into small pieces since the bole-stones were collected in a large portion of sizes. The next step after crushing them into smaller sizes is to sieve them where only certain size of POBS were used in the concrete mixing work.

Figure 3.3: Collecting POBS at the palm oil mill

Figure 3.4: POBS Cleaning process

Figure 3.5: Cleaned POBS

Figure 3.6: Collecting the cleaned POBS

Figure 3.7: Siever

Figure 3.8: Sieved POBS

3.3.3 Oil Palm Ash (OPA)

In this study, POFA is used for different percent of 0%, 10%, 20%, 30% and 40% as partial cement replacement to test the durability of the lightweight concrete when mixing with the different mix design. The OPA is obtained from the palm oil factory. After collecting the OPA, it needs to be oven dried at the temperature of 110ºC ± 5 for 24 hours then, sieved it by passing it through 600µm sieve, 300µm sieve and pan. After sieved, it must be ground by the grinding machine until the size of the POFA is fine to achieve the required fineness based on the ASTM C 618-05a referred while increase it pozzolanicity. OPA is ground for 30000 cycles to get the fine size.

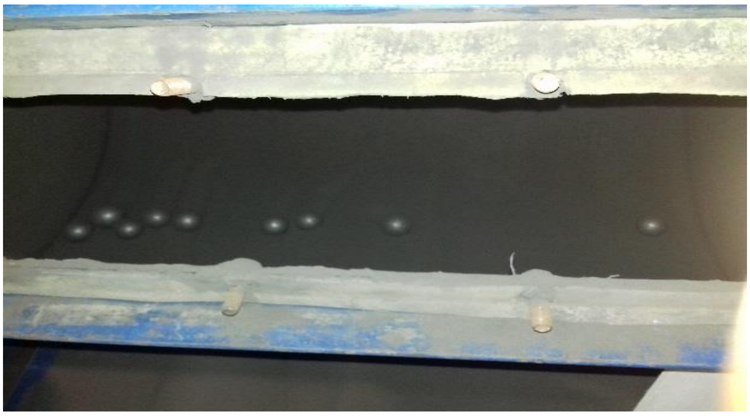

Figure 3.9: Grinding process of OPA in grinder

Figure 3.10: Grinding machine used to grind the oil palm ash

3.3.4 Water

Water is an essential element in the production of lightweight concrete because with the presence of water, the hydration process will take place. The standard to be used for mixing the water in concrete is EN 1008-2002(E) where it includes the specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete. There are several types of water that can be used for concrete mix process such as tap water and distilled water. The tap water is suitable for the concrete mix.

Figure 3.11: Water

3.3.5 Sand

Sand acts as the fine aggregate in this study. The sand of size below 4.75 mm was used as fine aggregate.

Figure 3.12: Sand used for concrete mix

3.4 Mix Proportion

The mix proportions to produce the palm oil clinker lightweight concrete is discussed as shown in Table 3.0. In this study, there are 6 samples of lightweight concrete cube that consist of different percentages of 0%, 10%, 20%, 30% and 40% of POFA mix.

Table 3.1: Mix proportion for lightweight concrete production

Materials	Density (kg/m^3)				
	POC LWAC	POC LWAC with 10% OPA	POC LWAC with 20% OPA	POC LWAC with 30% OPA	POC LWAC with 40% OPA
OPA	0	48	96	144	192

POBS	565	565	565	565	565
Water	216	216	216	216	216
Sand	750	750	750	750	750
Superplasticizer	4.8	4.8	4.8	4.8	4.8
OPC	480	432	384	336	288

3.5 Lightweight Concrete Preparation Process

The compressive strength, water absorption, acid and sulphate resistance attack were conducted on 100 mm cube specimens. After casting, these specimens were kept in the moulds for 24 h at a room temperature of 28 ± 2 ^{o}C. These specimens were then air cured for 28 days.

3.6 Testing Procedure

3.6.1 Compressive Strength Test

The aim of the test is to determine the compressive strength of the lightweight concrete when mix with the palm oil clinker, a waste from an agriculture to be the partial cement replacement in lightweight concrete production. The standard referred for this test is BSEN 12390-3..

The compression test was conducted soon as the removal of the samples from the curing tank at the age of 28 days air curing following the procedures in BSEN 12390-3. In order to minimize the error and inaccuracy during testing, the samples were cured according to the standard referred. In addition, the compressive strength of each samples was calculated by using the formula of the maximum load carried by the tested samples divided with the average cross-sectional area of the samples.

The compressive strength, C can be calculated as:

$$\mathbf{C=\frac{\mathit{P}}{\mathit{A}}}$$

where, P= maximum load that carried by the samples

C= compressive strength of the samples

A= cross-sectional area of the samples

Figure 3.13: Compressive strength machine

Figure 3.14: Compressed concrete cube

3.6.2 Water Absorption Test

The water absorption testing on the lightweight concrete is made by referring to the BS 1881-122. Firstly, the samples are cured for 28 days before placing the samples into the oven for drying purpose. The oven drying shall takes place for 72±2 hours at the temperature of 105 ^{o}C. After that, the samples need to be removed from the oven to cool it down for at least 24±0.5 hours before the weighing process can be done. Then, the samples are being immersed in the water for 30±0.5 minutes. Soon as the samples reach the immersing time in the water tank, the samples are taken out from the tank and dry immediately to be weighed again. Meaning that, there are twice weighing happens by which the first weighing is for before and the second weighing is for the after immersing the cubes into the water.

3.6.3 Acid Attack Resistance

Acid attack resistance test is conducted in order to study the effect of the acid on lightweight concrete. The acid used in this study is the hydrochloric acid which is categorises as the strong acid. In addition, concrete that is made of the Ordinary Portland cement (OPC) is highly alkaline with pH values that is normally above 12.5 and not easily attacked by the acidic solution due to its alkalinity. If pH level drops down lower than the stability limit of the cement hydration, then the hydrates will lose its calcium and decomposes to amorphous hydrogel or known as the insoluble salt that remain in the corroded layer of the concrete.

The solution of hydrochloric acid is mix with distilled water for which 244grams of Hydrochloric acid (HCl) solution is added into 20kg of distilled water. This solution is diluted inside the fume due to acidity property that is dangerous to be smell for. For instance, the weight of the cubes is drop due to the acid attack because acid will corrode the cubes slowly day by day. $Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$. This is the reaction of the HCl that causes the leaching of $Ca(OH)_2$ from the set cement. Knowing that the HCl attack is a typical acidic corrosion which can be characterized by the formation of layer structure.

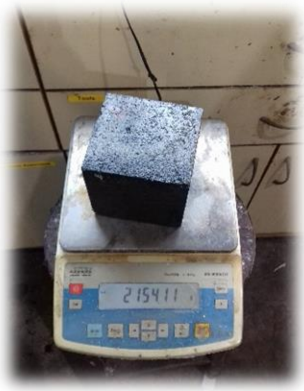

Figure 3.15: Weigh for mass loss

3.6.4 Sulphate Attack Resistance

Sulphate attack can be divided into two conditions that namely as the external and internal attack. The external attack is due to the soil that contains sulphate or the penetration of sulphate in the solution that might come from certain sources such as the seawater, moisture and oxidation that will subsequently causing crack and loss of concrete strength while the internal attack is occurs during the mixing of the concrete mix.

The solution of the sulphate is prepared by mixing the sodium sulphate with the distilled water. 1kg of sodium sulphate: 20 litres of distilled water. Sulphate reacts with cement will produce the gypsum gel that starts to fit into the voids inside the cubes. Basically, the early graph will show that the weight of the samples rises due to the sulphate fills into the cubes then the weight will drop since the cubes can no longer stand the sulphate attack which then will cause the cubes to crack and lose the weight.

Figure 3.16: Taking out the samples from the sulphate solution before weighing.

Figure 3.17: Weigh for mass change

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter is to briefly discuss about the outcome due to different percentage of OPA as partial cement replacement in lightweight concrete towards acid resistance, sulphate resistance and water absorption. Thus, all of the results obtained from the experimental work are presented in the form of graphs.

4.2 Acid Attack

In order to identify on how much the acid had attacked the strength of LWC containing OPA as partial cement replacement, the visual observation is one of the effective ways as to ensure the presence of acid attack. This observation is considered as the early precaution step from time to time in controlling the acid attack acted on the samples. Hence, there are no changes in physical appearance shown because the concrete strength in this experiment is high.

4.2.1 Mass Loss

From Figure 4.1, it is clearly shows that the increasing loss in mass for the samples happened when the time of immersion is longer. Based on the graph, it can be noted that the total of mass loss for each of the samples fall between range 0.80% to 2.5% along 1800 hours of immersion age. Concrete is made as alkaline in nature but somehow, it is susceptible towards the attack of acid due to its porous characteristic. Acid such as hydrochloric acid is categorized as an aggressive element as the calcium salt is soluble and precipitate through the pores on the concrete. The event of acid attack is due to the reaction of both calcium hydroxide from the cement paste and acid during the mix design process which then produces a kind of highly soluble calcium salt as its by-product. In conjunction with that, the soluble salt is easily leaches thus, affecting the mass loss towards the samples with no changes in the internal stress that might be seen as micro cracking of concrete structure. However, since the concrete has been added by the OPA as the natural source of admixture that acts as the partial cement replacement, the acid attacks can be minimized since the pozzolan itself that acts as a filler would fill the voids making the acid solution to unfit into the voids thus, reducing the acid attack prior to a longer period. The good finish and the minimum empty voids on the concrete surface led to a reduced penetration of acid solution into the interior of concrete and enhanced its resistance to the acid attack (S., Kumar, & Arel , 2017). In fact, the weakest product in cement hydration which is $Ca(OH)_2$ is highly susceptible to acid attack but not in concrete that contains OPA as the partial cement replacement. In addition, the produced $Ca(OH)_2$ in the hydration process might be utilized by silica in POFA to convert into C-S-H gel making the concrete becomes denser while the bond between the mix elements inside the concrete becomes stronger thus, increasing its durability performance towards the acid attack. All in all, OPA with an optimum amount added is the only mechanism that can provides a good resistivity towards acid attack. It is because the extra amount of OPA replacement in the concrete mix will leads to dryness on fresh concrete which then affecting the hardness. The uncounted pores will form if the mix is too dry leading to how hard the concrete mix for compaction by which it is then contributes to the easiness of the acid penetration.

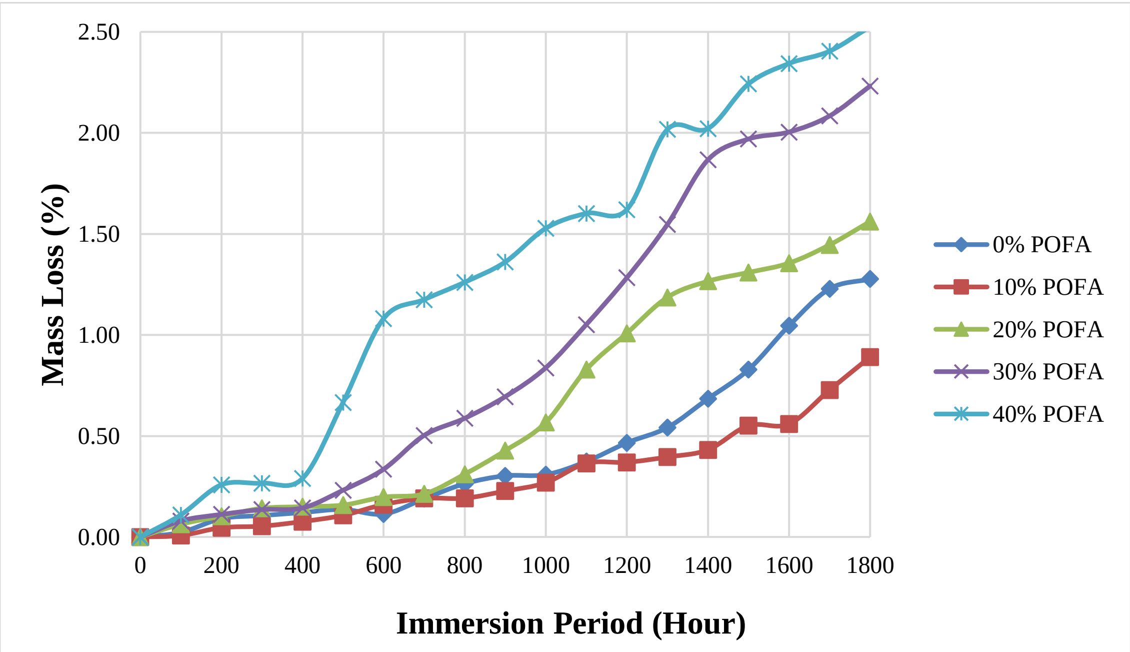

Figure 4.1: Mass loss percentage of POC LWAC with POFA specimens immersed in HCl solution for 1800 hours subjected air curing

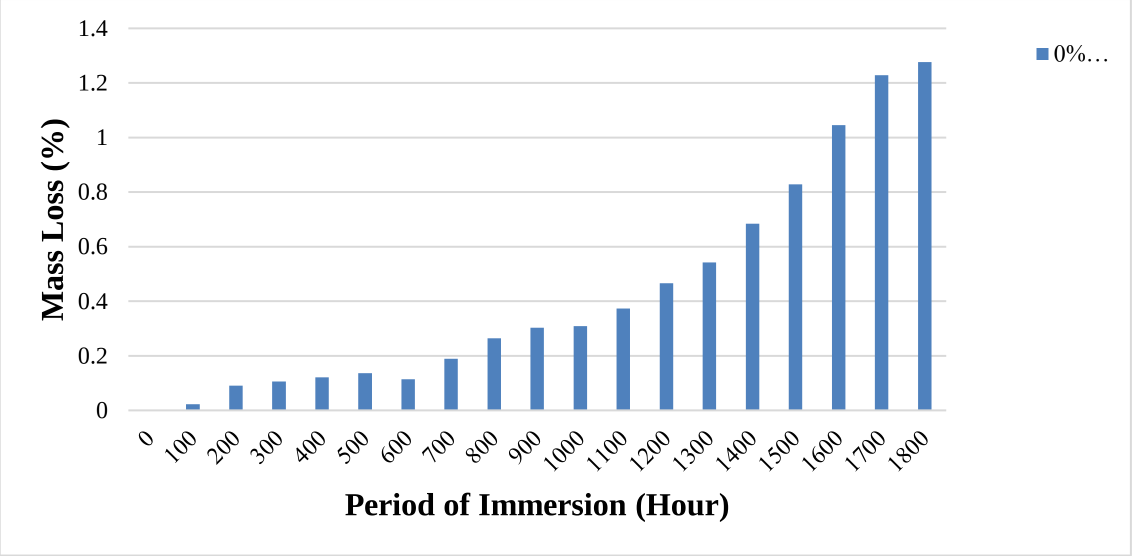

Figure 4.12: Mass loss percentage of POC LWAC with 0 % POFA specimens immersed in HCl solution for 1800 hours subjected air curing

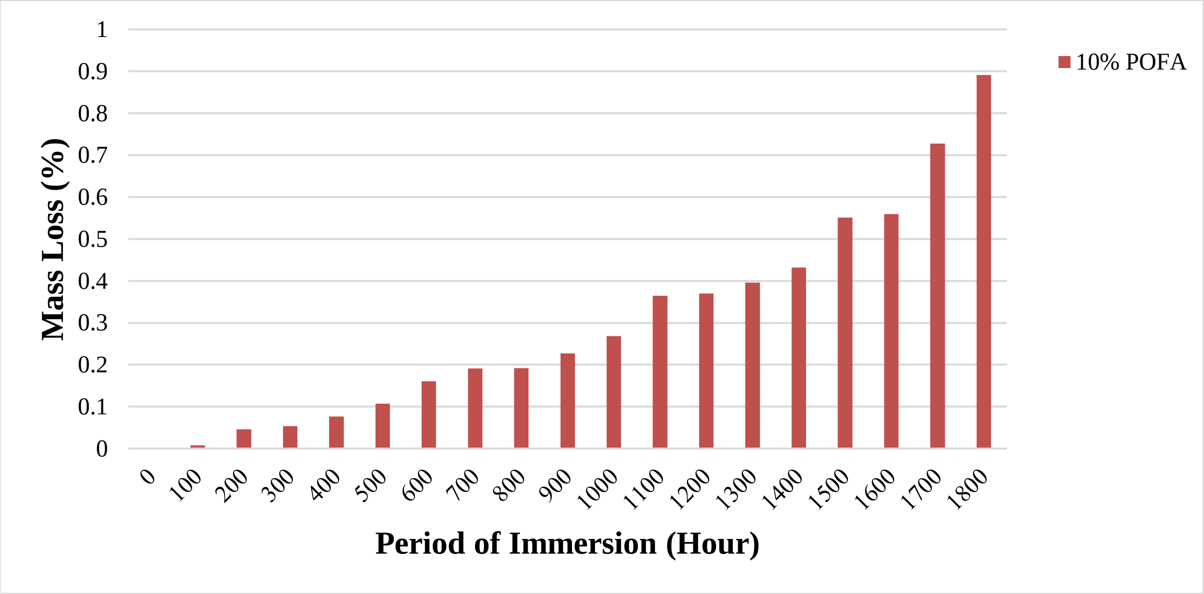

Figure 4.13: Mass loss percentage of POC LWAC with 10 % POFA specimens immersed in HCl solution for 1800 hours subjected air curing

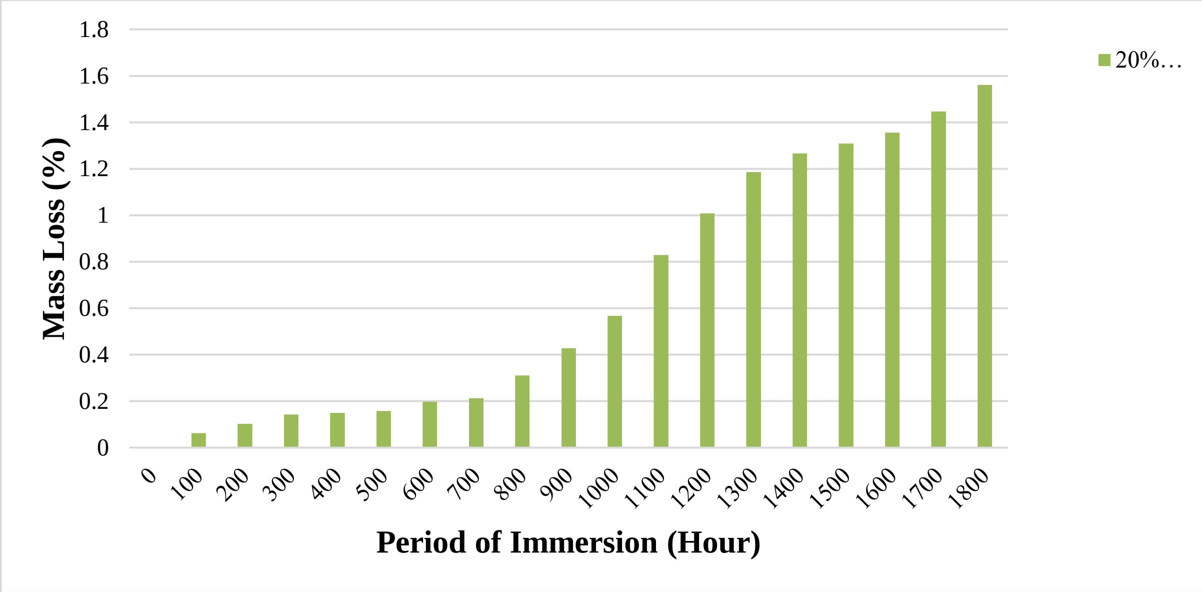

Figure 4.14: Mass loss percentage of POC LWAC with 20 % POFA specimens immersed in HCl solution for 1800 hours subjected air curing

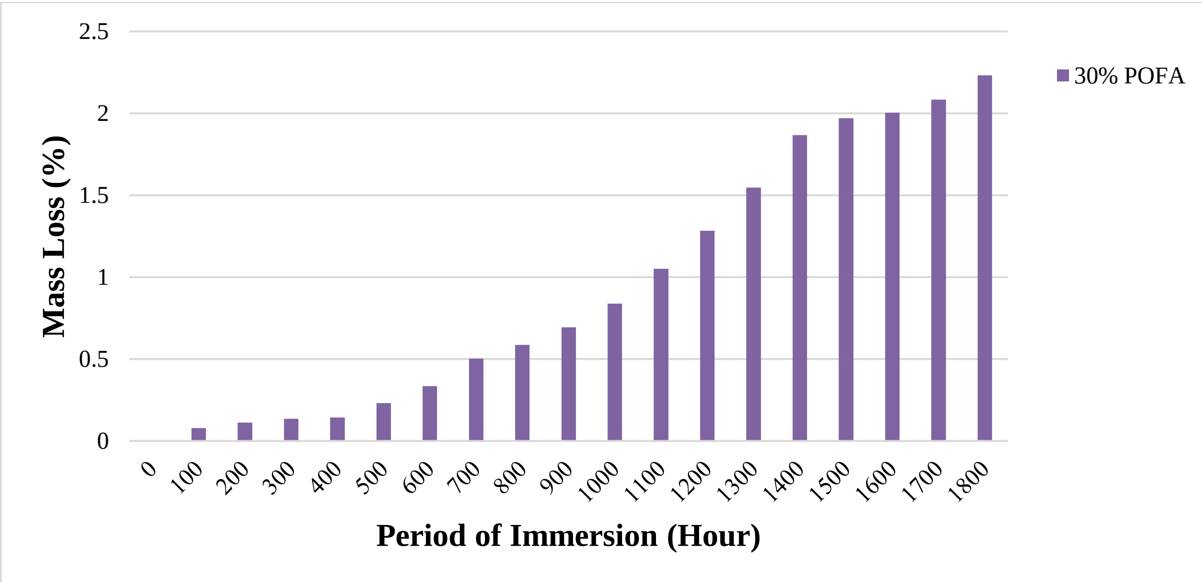

Figure 4.15: Mass loss percentage of POC LWAC with 30 % POFA specimens immersed in HCl solution for 1800 hours subjected air curing

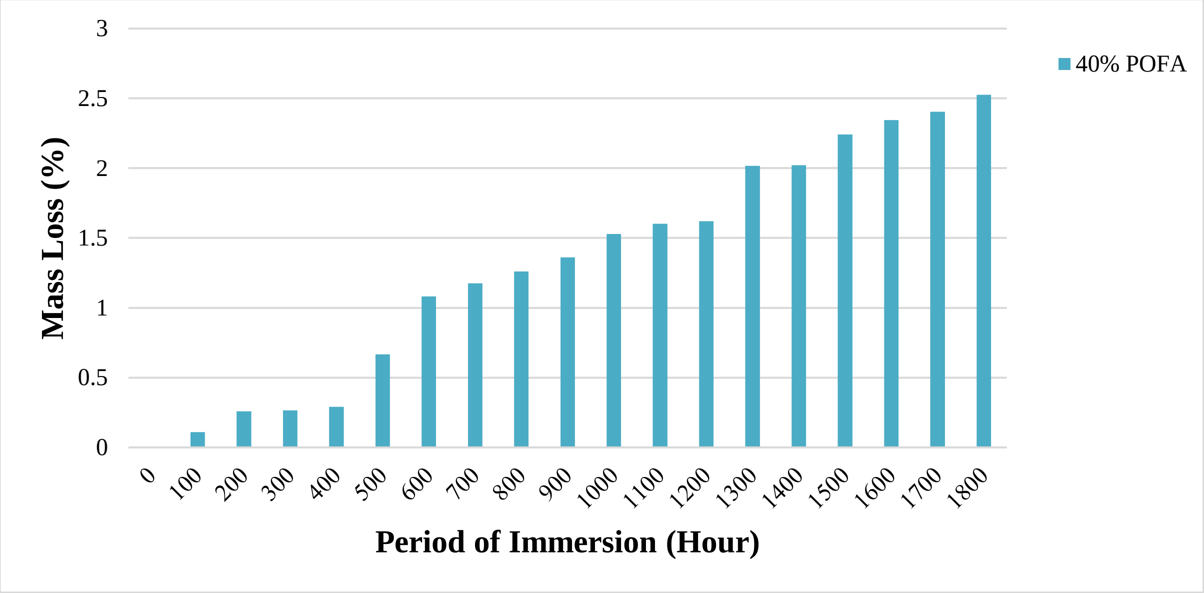

Figure 4.16: Mass loss percentage of POC LWAC with 40 % POFA specimens immersed in HCl solution for 1800 hours subjected air curing

Mass loss is the indication of acid attack in concrete. The addition of more OPA content as partial cement replacement is not a good way to increase the compressive strength of LWA because of the characteristic of OPA that is being seen porous as to compare to cement. As such, the only perfect proportion for addition of OPA in concrete mix as partial cement replacement suits only the optimum amount since it is quite hard to compact the mix because it dries immediately. This will then forming more pores with larger size that only can leads the concrete deterioration. From Figure 4.6, it is shown that the percent of mass loss is the highest at 1800 hours for 40% of OPA as partial cement replacement while Figure 4.2 proved the least percent of mass loss for 0% of OPA as partial cement replacement. It also shows that the percent of mass loss happened to be the least at the age of 0 until 400 hours of acid immersion while the percent mass loss increases gradually from the age of 400 until 1800 hours immersion. This is because the addition of more OPA in the mix reduces the amount of cement content that contains high content of Calcium Oxide that is utilised in hydration process producing Calcium Hydroxide that susceptible to acid attack. The amount of cement content is lower when more OPA is added thus, reducing the amount of CaO used in hydration process by which it is then limiting the pozzolanic reaction and the formation of C-S-H gel due to low in $Ca(OH)_2$ production. This has resulting in the less dense of internal concrete structure making the strength to be lowered affecting the durability itself. In addition, acid attack is most likely to attack the concrete with high content of OPA. It is because the acid attacks the hydrated lime which then producing the calcium salt that dissolves in water in a massive amount. It is noted that the 10% of OPA replacement is the optimum percent as it helps the concrete to achieve the highest compressive strength and good in acid resistance.

4.3 Sulphate Attack

Based on the observation made, the sulphate solution changed its color due the existence of sedimentation from the attack of sulphate on concrete. This observation is considered as the early precaution step from time to time in controlling the sulphate attack acted on the samples.

Sulphate attack is commonly due to the reaction of sulphate ion reacts with hydration of cement. There are two processes related to which sulphate attack can occurs that include the densification of transition zone on the conversion of lime forming during hydration process and also the refinement of concrete pores. The exposure of concrete structure towards the sulphate solution is most likely to enhance concrete deterioration because the sulphate solution will immersed into the pores of concrete if the concrete is not bind with pozzolans. However, adding pozzolan into the concrete mix will definitely minimize the intrusion of sulphate solution inside the concrete structure as in total since the pozzolan itself will acts as a filler to fill into the pores. One of the main causes of deterioration in concrete structures is the distress of concretes due to its exposure to harmful chemicals that may be found in natures, such as in contaminated ground waters, industrial effluents and sea waters (Dakshina Murthy & Rameseshu, 2007).

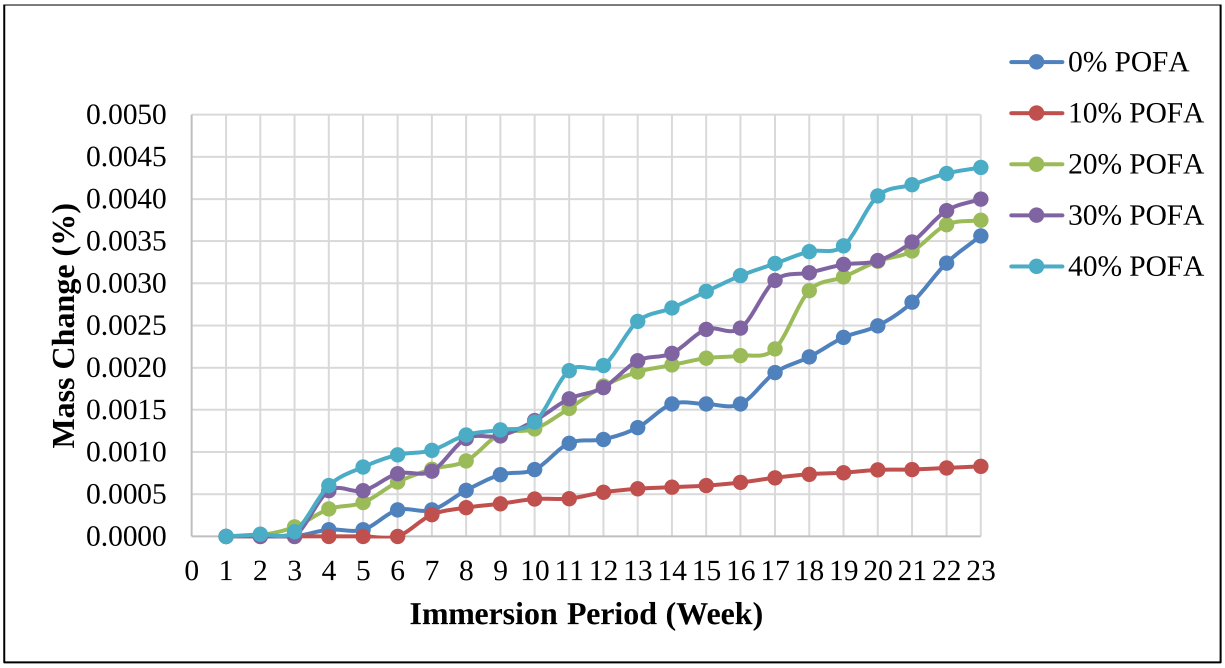

Figure 4.2: Percentage for mass change of POC LWAC with POFA specimens immersed in sulphate solution for 23 weeks subjected air curing

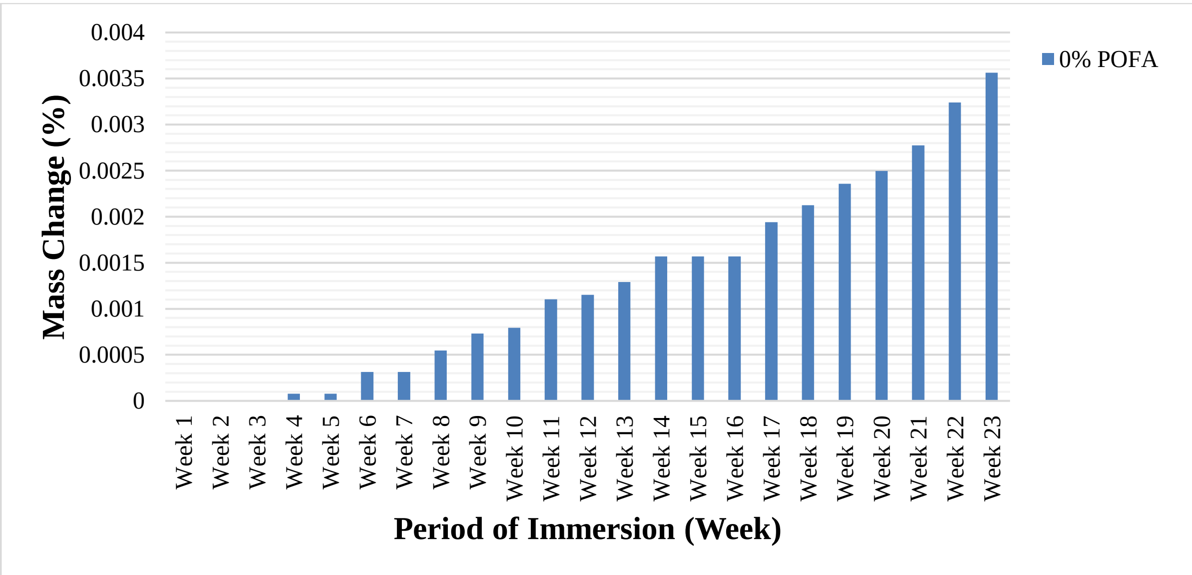

Figure 4.21: Percentage for mass change of POC LWAC with 0% POFA specimens immersed in sulphate solution for 23 weeks subjected air curing

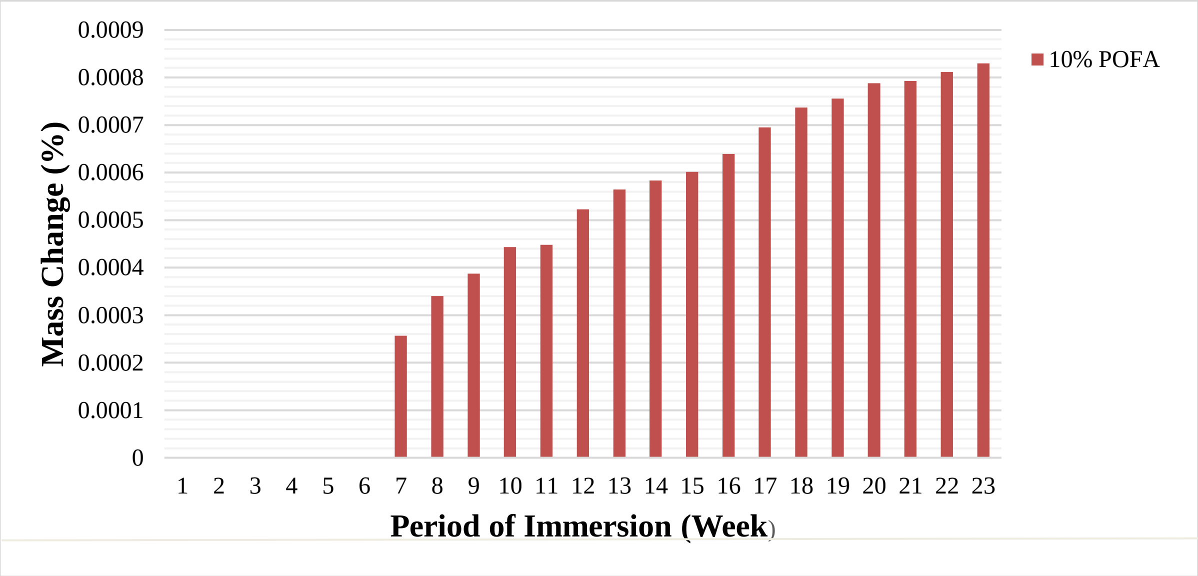

Figure 4.22: Percentage for mass change of POC LWAC with 10% POFA specimens immersed in sulphate solution for 23 weeks subjected air curing

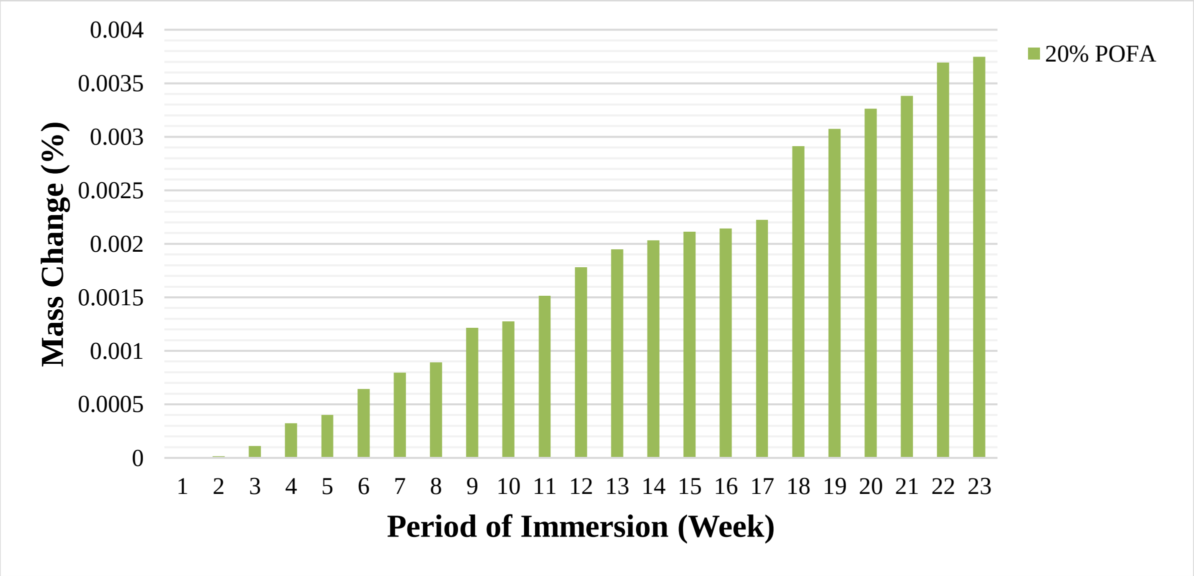

Figure 4.23: Percentage for mass change of POC LWAC with 20% POFA specimens immersed in sulphate solution for 23 weeks subjected air curing

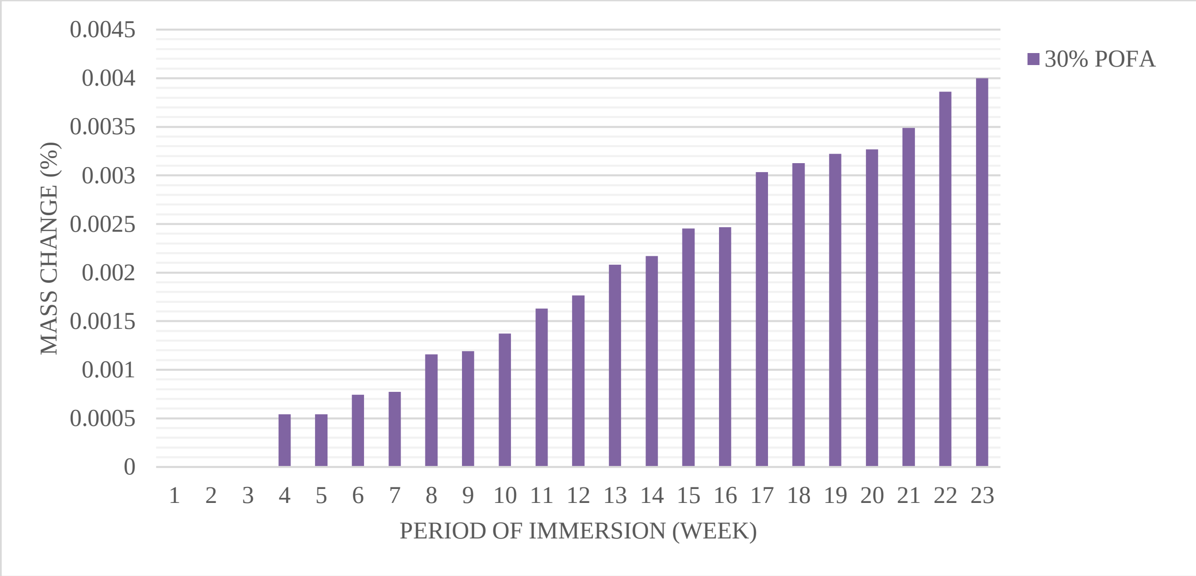

Figure 4.24: Percentage for mass change of POC LWAC with 30% POFA specimens immersed in sulphate solution for 23 weeks subjected air curing

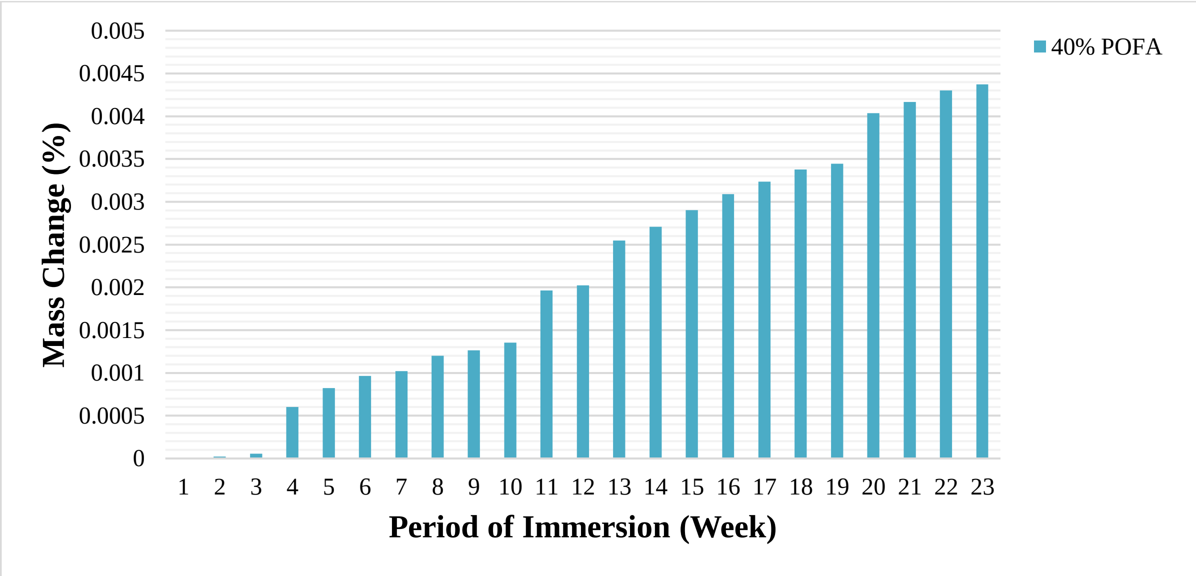

Figure 4.25: Percentage for mass change of POC LWAC with 40% POFA specimens immersed in sulphate solution for 23 weeks subjected air curing

From Figure 4.7, it is clearly shows that the increasing change in mass for the samples happened when the time of immersion is longer. Based on the graph in Figure 4.7, it can be noted that the total of mass change for each of the samples fall between range 0.00083 to 0.00437 along 23 weeks of immersion age. Change in mass of concrete illustrates that the sulphate has attack the concrete during the immersion in sulphate solution. Sulphate attack is known to be discussed as the reaction between hydration of cement and sulphate ions. At Week 4, concrete with 20%, 30% and 40% of OPA replacement started to change its mass at 0.00032, 0.00054 and 0.00060. Meanwhile, 10% of OPA replacement changes in Week 7 at 0.00026 and 0% of OPA replacement in concrete significantly changes during Week 6. This had shown that the highest change in mass is 0.00437% when 40% of OPA is partially replaced the cement content while the lowest is 0.00083% change in mass for 10% of OPA replacement. Thus, 10% of OPA replacement in concrete mix is the optimum cement partial replacement in concrete mix because OPA absorbs water very well. The higher percentage of OPA used in concrete mix would only makes the workability lower due to high water content. Moreover, POBS is porous in structure which allows water to fill into the pores making the concrete weaker. Sulphate that attacks on LWC containing OPA is characterized by sulphate ions and cement hydration process by which it causes the expansion, spalling and cracking while at the same time affecting the change in mass. This for sure will interrupt the strength of the concrete itself.

4.4 Water Absorption

Based on Figure 2, the water absorption for control POC LWAC, POC LWAC with 10%, 20%, 30% and 40% POFA is were 0.78%, 0.74 %, 0.79%, 1.09 and 1.12 % respectively. As for this experiment, the water absorption of samples laid within the range of 0.74 to 1.12% by which strengthen the evidence that concretes in any types of curing that not more than 10% are called high-quality concrete. However, if the amount of OPA content in the mixture of concrete mix is exceeding the optimum amount, it will automatically reduce the water absorption. The water absorption of POC LWAC with 10% POFA specimen was slightly falls between 0.03 to 0.38 % lower than other specimens while the highest water absorption reading falls on 40% of OPA replacement at 1.13%. This is because the upon hardening of fresh concrete, the small pores are emptied resulting a strengthened suction force that attracting the materials together thus, increasing higher rate of absorption and absorption in total. The absorption of water is influenced by the formation of C-S-H gel because it reduces the porosity of concrete making the concrete low in water absorption for LWC containing OPA.

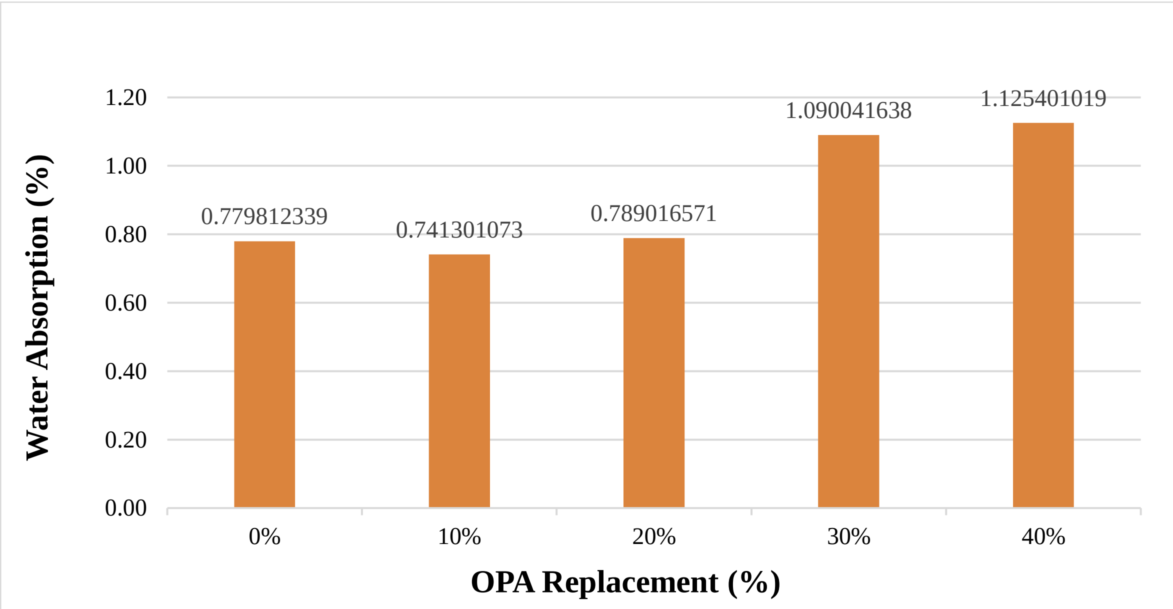

Figure 4.3: Water absorption of POC LWAC and POC LWAC with different percentage of OPA at 28 days of air curing

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter concludes the overall findings based on Chapter 4 based on the objectives stated in Chapter One. Apart from the conclusion, several suggestions are made for future investigations are also included in this chapter.

5.2 Conclusion

Rapid industrialization during the last 100 years brought remarkable changes to method of construction and in materials. Over 11 billion tons of concrete are being used annually making it as one of the most widely used construction materials. However, the developmental activities were accompanied by exploitation of natural resources in the production of concrete (Islam, et al., 2017). On top of that, the availability of POFA in LWC also consumes $Ca(OH)_2$ which is required for the formation ettringite thus, increasing the durability performance of lightweight aggregate concrete. All in all, this study had successfully shown that 10% of OPA as partial cement replacement in LWAC is durable to resist both acid and sulphate attacks and good for water absorption as it influenced by the C-S-H gel that fills into the pores reducing the porosity of concrete making lightweight concrete containing OPA as the partial cement replacement durable for 28 days of air curing.

5.3 Recommendation

The purpose of recommending the improvements and resolutions is to further expand this research becoming into the next level of succession. Firstly, what would happen to the durability performance of lightweight concrete towards water absorption if replaces OPA with other materials to partially replace the cement content. Next, what would integrate the mechanical properties of lightweight concrete in terms of creep and shrinkage instead of investigating the durability performance. Lastly, would it be much difference in terms of concrete compressive strength and moisture content if palm oil boiler stone is being replaced with other materials such as biomass power boiler and coal fired boiler.

This research provides the new information improving the previous information based on the durability performance of lightweight concrete subjected to air curing. Regarding to this study, BS design codes for both compressive strength and water absorption test with the help of references from researchers had been used as reference in order to achieve the objectives of the study.

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