DURABILITY PERFORMANCE OF LIGHTWEIGHT CONCRETE CONTAINING PALM OIL FUEL ASH AS MIXING INGREDIENT

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B.ENG (HONS.) CIVIL ENGINEERING

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ABSTRAK

Malaysia adalah antara pengeluar dan pengeksport terbesar hasil kelapa sawit di dunia. Sejak kebelakangan ini, Malaysia mengalami kekangan dalam melupuskan hasil kepala sawit yang tidak digunakan . Hasil kelapa sawit yang terhasil and dibiarkan itu menyebabkan masalah pencemaran alam sekitaran. Ianya juga menjadi antara sebab ketidakseimbangan ekologi sekirangan dibiarkan tanpa kata putus.Oleh sebab itu, hasil kepala sawit telah digunakan dalam menghasilkan konkrit ringan dengan kadar peratus yang berbeza. Konkrit tersebut diuji ketahanan dalam larutan asid dan sulfat.Semua konkrit tersebut telah direndam dalam air selama 28 hari sebelum dimasukkan kedalam bekas yang mengandungi laturan asid selama 1800 jam. Selain itu, konkrit tersebut telah dibiarkan dalam cecair sulfat selama 16 minggu untuk menguji kadar kehilangan berat dan untuk mnguji kemerosotan kekuatan konkrit. Hasil daripada kajian ini, 20 % kadar peratus POFA menunjukkan ketahanan yang cemerlang terhadap kedua- dua keadaaan.

ABSTRACT

Malaysia as the world's largest exporter of palm oil has been facing problem in disposing palm oil fuel ash, a by- product of palm oil mill since years ago. The abundant production of waste material from palm oil plantation which disposed at landfill will cause environmental degradation and it is harmful to the ecosystem or ecological imbalance if there is no proper action taken to reduce it. This research investigates the durability of lightweight concrete containing various percentage of POFA replacement when subjected to acidic and sulphate environment. All the specimens were subjected to water curing for 28 days before immersed in the hydrochloric solution having pH 2 for 1800 hours. The specimens also being subjected to sodium sulphate solution for 16 weeks. The strength deterioration was evaluated through mass changing of the specimens and compressive strength determinations. The finding shows that 20% of POFA replacement enhances the resistance of lightweight concrete towards acid attack and sulphate attack.

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LIST OF SYMBOLS

%	Percentage
mm	Millimetre
mm^2	Millimetre square
m^3	Cubic meter
µm	Micro meter
g	gram
kg	Kilogram
MPa	Mega Pascal
kN	Kilo newton
°C	Degree Celsius
°	Degree
A	Area
P	Maximum load carried by specimen during testing
fc	Compressive strength of concrete specimen
d	Depth

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
C-S-H	Calcium Silicate Hydrate
CaO	Carbon Oxide
HCI	Hydrochloric Acid
OPC	Ordinary Portland Cement
POFA	Palm Oil Fuel Ash

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete is one of the composite construction material that composed of a coarse granular material, the aggregate or filler that embedded with water and cement. Each of concrete possesses their own unique characteristic to meet the suit the needs of the construction industry. Concrete plays a key role in the construction field for making a various structure such as architectural structures, pavement, bridges, and others. It is also being used in oil production field to construct the massive off-shore platforms for drilling and production activities. Continues research and development of concrete have contributed to the production of various types of concrete over years to provide more alternative construction materials. Therefore, one of the concrete that popularly increases drastically in recent year is lightweight concrete. Lightweight concrete is the predominant materials being used in the construction field and it is known as aerated concrete in European countries due to its versatilities and lightness, which has brought a new image of application of Malaysia building Technology.

Lightweight is mainly depending on the concrete density. This is because using of lightweight concrete in construction field which possess low-density property that contributes towards the reduction of building and resulting in more economical structural design (Narayanan and Ramamurthy, 2008) .It is react as reducing of the dead load may consequently the decreasing of size of bearing load capacity. Lightweight concrete can be classified into low density natural aggregate concrete, synthetic aggregate concrete, and cellular or aerated concrete and high performance lightweight concrete. The practical range of concrete density for lightweight concrete is between 320kg/m^3 and 1850 kg/m^3 (Neville, 2006). Besides, lightweight concrete is good in thermal insulation properties and fire resistance, where it has a lower thermal conductivity which is a very important aspect in the construction field.

Malaysia is well known for palm oil industries and is one of the largest palm oil producers and exporter in the world **(**Mannan, 2008). In 2006, Malaysia had produced 17.7 millions tons of palm oil on 4.5 million hectares of land, (Muthusamy *et al.*, 2015). Because of that, these industries generate a lot of abundant waste product annually during palm oil processing and these waste products are simply disposed of without commercial return of (Mannan and Ganapathy, 2002). The larger amount of waste product from palm oil industry is not being reused and dumped in the landfill. In this scenario, it is predicted that larger amount of palm oil waste would be discarded as environmental pollution waste in the future. Therefore, oil palm waste had been chosen in research as new concrete material in order to convert environmental pollution problem into beneficial for the development of human civilization in the future.

1.2 Problem Statement

The cement industry is one of the well-known industries in Malaysia. The cement industry produces carbon dioxide which can cause greenhouse gas effect. Almost 4- 5 % of worldwide of a total of carbon dioxide gas is released during the production of cement. The released of carbon dioxide gas during the production of cement cause a lot of environmental problem to a human being and other habitants.

With around 40 % of total world supply in the years of 2008 to 2010, Malaysia is known as the second largest palm oil producer in the world (Altwair *et al.*, 2012). The abundant production of waste material from palm oil plantation will cause environmental degradation and it is harmful to the ecosystem or ecological imbalance if there is no proper action taken to reduce it. This waste product is normally disposed of through incineration whereby it is hard to dispose of easily. It is light which easy to be blown by the wind and spread to another place thus causing air pollution. The disposal of palm oil waste causes a negative effect on the health and comfort of the community (Tay and Show, 1995). More than 5 % of palm oil fuel ash (POFA) is left behind after the operation (Jamo, 2015). Due to the deficiency in nutrients as the fertilizers plus the underutilization of POFA, it is then disposed as waste in landfill

(Islam *et al*., 2014).Because of this, the government has to assign more hectares of land for huge waste disposal, which leads to further financial losses incurring from necessary transportation and maintenances. While, the high demand for cement and coarse aggregate in concrete, it causes this non-renewable resources depleting in the future generation.

1.3 Objectives of Study

The main objectives of this study were to study the durability of lightweight concrete containing palm oil fuel ash as mixing ingredients. The objectives of this research were as follow:

i. To investigate the effect of POFA content on compressive strength of lightweight concrete for 28 and 90 days.

ii. To investigate the acid performance of lightweight concrete containing POFA.

iii. To investigate the performance of lightweight concrete containing POFA when exposed to sulphate environment.

1.4 Scope of Study

This study concentrates on the performance of lightweight concrete containing palm oil fuel ash in terms of compressive strength, acid resistance and sulphate resistance. In the first stage of laboratory work, a mix proportion for lightweight concrete of grade 30 was developed using trial and mix method. Then, three series of concrete mix with finely ground POFA as part of mixing ingredient was composed of an unconventional mix comprises 0 %, 20% and 40 % of the total weight of cement. This mixes were prepared in form cubes and water cured for 28 days.

The acid resistance of lightweight concrete with POFA is evaluated by measuring the mass loss and strength reduction of the samples after immersed in hydrochloric solution. The durability of lightweight concrete containing POFA against sulphate attack was evaluated by placing the cubes in sodium sulphate solution. The mass change and strength deterioration was determined during the experimental work.

1.5 Significance of Study

The performance of lightweight concrete containing palm oil fuel ash in terms of acid resistance and sulphate resistance is known. By integrating palm oil fuel ash as mixing ingredient in concrete to encourage, the quantity of POFA disposed can be reduced. The dependency on cement for concrete production can be reduced as well. Integrating POFA waste in concrete is able to save the use of land for waste dumping.

1.6 Layout of Thesis

This report is consisting of 5 chapters. Chapter 1 discussed the introduction of palm oil fuel ash (POFA) and lightweight concrete and problem statement of research. The objectives of the study were identified in this chapter together with the scope of the study and the significance of the research. In chapter 2, the review of palm oil fuel ash (POFA) as the light concrete study according to available previous journal and thesis that contributed to information that needs in this research. In chapter 3, the laboratory work of study discussed in the methodology part. The materials preparation, method to get the mix proportion and mixing procedure were discussed in this chapter. Besides that, the testing used in testing the specimens were also discussed in this chapter.

Chapter 4 mainly presented and analysed about the laboratory results of lightweight concrete incorporated with POFA in term of compressive strength of the concrete on the effect of water content cement ratio, sand content and cement content. Chapter 5 concludes the whole study. Few conclusion and were drawn with respective objectives listed based on the results obtained from this study. Besides that, there are few recommendations was suggested in this chapter for future studies of the current research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete is a material that part form the basis of our modern society. It is a composite material that often used in construction for various purposes. Scarcely any aspect of our daily lives does not depend directly or indirectly on concrete. It is also well known for being the most versatile man-made building materials to be used for its enormous advantages in terms of durability and strength of concrete. Concrete is embedded in a hard matrix of materials such as cement or binder that fills the space between the aggregates particles and glues between them. Concrete is generally graded according to its compressive strength. There are various grades of concrete as being stated in IS: 456 -2000 and IS: 1343-1980. Based on this grading system in concrete, the suitability to be used will be determined (Narayanan and Ramamurthy, 2000). For an example, the concrete grade M5 and M7.5 are suitable for lean concrete bases, simple foundations or temporary reinforced constructions. Therefore, the techniques used to produce good concrete depends on the quality of raw materials used likes cement, aggregates and water, mixing rate and compacting way.

In this modern world, the addition of waste materials in concrete has rapidly increased due to the development of construction industry. This is linear to the effort in reducing the consumption of energy sources in the world. Therefore, it is seen that integrating palm oil fuel ash as mixing ingredients would reduce the utilization of natural resources in the concrete production. During recent decades, about thousands of tons of palm oil fuel ash are produced yearly by operation of 200 palm mills in Malaysia and most of these palm oil wastes is normally disposed of for landfill without any commercial returns (Awal, 1997). Palm oil fuel ash which contains siliceous compositions and is able to react as pozzolanic materials to produce a stronger and denser concrete when it is used as mixing ingredients in concrete (Adnan *et al.* ,2015). As Malaysia has focused on being the main hub for biotechnology industry region, it is estimated that millions of tons of waste produced annually and the government need to allocate landfills to dispose of the waste. The success of adding palm oil waste as mixing ingredients in concrete production would be able to reduce the amount of waste ending at the landfill.

2.2 Concrete

Concrete is a material produced when cement, aggregates / sand, coarse aggregate and water are mixed and blended in proportion mixture / ratio specified allowed to harden to form a structural member. While the ingredients are mixed, water and cement are unified through a chemical process called hydration and produce the cement paste. The cement paste acts as a binder/adhesive to the concrete components such as fine aggregates/sand and coarse aggregates. Mixture ratio must be in accordance with a predetermined determination to produce the essential strength. Concrete strength depends on the ratio of the mixture. Figure 2.1 shows the mixture ratio of concrete and concrete processes and table 2.1

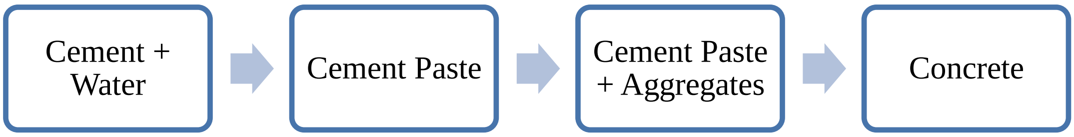

Figure 2.1: Concrete processes

Source**:** Polytechnic Module Series: Department of Technical Education Ministry of Education Malaysia (2002**)**

Table 2.1: Concrete mixture ratio

Mixture Ratio	**Uses**
1 : 5 :10	For site wall in the trenches
1:3:6	For concrete wall & others
1:2:4	For reinforcement concrete of column, beam & others
1: 1½ :3	For prestressed concrete, tanks & others

Source: Polytechnic Module Series: Department of Technical Education Ministry of Education Malaysia (2002)

The active ingredients in concrete are cement and water, while aggregates are inert materials. Aggregates gives no reaction during the hydration process but acts as a space filler and provide strength, durability and resistance in case of shrinkage. As the price of aggregates is cheaper from other materials so they can be used maximum possible intent. After hydration, the water content of water in the concrete becomes less and gradually dries. The concrete that has hardened and has a good design should have voids (air holes / voids) are about 1%, and cement paste (water / cement / aggregate mix of coarse and fine) of approximately 75%.

2.3 Properties of Concrete

Concrete making is not about of mixing ingredients to produce a plastic mass, but the good concrete has to satisfy the performance that required in the plastic or green state an also the hardened state. In the plastic state, the concrete should be workable and free from segregation and bleeding. Segregation is known as separation of coarse aggregate while bleeding is the separation of cement paste from the main mass. In its hardened state, concrete should be strong, durable and impermeable where it should have minimum dimension changes. This is important and taken as an index of its overall quality.

2.4 Advantages And Disadvantages of Concrete

The advantages of concrete as construction materials are, it is more economical in long term usage compare to other materials and it has equal coefficients of thermal expansion as steel reinforcement. Concrete possesses a high compressive strength while the corrosive and weathering effect of concrete is minimal. Besides, concrete is durable, fire resistance and need very little maintenance whereby the fresh mixed concrete can be easily be moulded and formed into any shape or size according to specifications. The formwork will be more economical and cut cost because it can be reused for the same work.

Besides, the disadvantages of concrete are it has low tensile strength and easily crack. This is due to temperature changes; concrete might undergo expansion and contractions. The fresh concrete shrinkage when drying and hardened concrete expands when it wetting. Provision for construction has to be provided to avoid cracks from happed due to drying of shrinkage and moisture movement in concrete. Concrete is partially impervious to moisture efflorescence might happened because concrete containing soluble salts and disintegrate due to alkali and sulphate attack.

2.5 Type of Concrete

There are many common type of concrete used in construction field such as normal concrete. Normal concrete is mixing of water, cement and aggregate where the setting time for normal concrete is about 30 -90 minutes depending upon moisture in atmosphere and fineness of cement. The strength values of normal concrete are about 10 MPa to 40 MPa. Besides, the high strength concrete is concrete mixing that has greater compressive strength and it is made by lowered the water cement ratio to 0.35 and below.

Air entrained concrete is one of the new revolution in concrete technology field whereby it is vulnerable to freezing and thawing action. It is prepared by adding the air entraining admixture. Air admixtures are used for the purpose of making entrained air in concrete. There are two phenomenon's regarding freezing and thawing action on concrete. First, when water inside concrete mass freezes, it expands 9-10 % due to this increase in the size it exerts pressure on its surrounding and thus creates a tensile force. Next is osmotic pressure where there are two parts which are frozen and unfrozen. Normal concrete cannot sustain 3-4 cycles of freezing and thawing as air entrained concrete which can sustain 100 cycles.

2.6 Mixing Ingredients of Concrete

2.6.1 Cement

Cement is defined as materials that have adhesive and cohesive properties which enable it to bond material fragments into a compact whole. In construction, the term cement is a material that enables the bonding of materials that creates concrete mixture which consists of coarse and fine aggregates, water and also cements itself. The functions of cements are:

a) To bind the sand and coarse aggregate together.

b) To fill the voids in between sand and coarse aggregate particles

The common colour of cement is usually grey. There was also white cement it is more expensive than the grey one. Generally, when cement is mixed with water, sand and gravel, it forms concrete. Meanwhile, if cement is mixed with water and sand, it will forms cement plaster. On the other hand, when cement is mixed with water, lime and sand, it will forms mortar. There are two types of cements, known as hydraulic cement and high alumina cement.

2.6.2 Water

All water used to mix concrete must be clean. In most cases, potable (drinking) water is required for the mixing of concrete. Water used to mix concrete must also be free of harmful amounts of oils, acids, alkalis, salt, organic materials and all elements that can be damaging to concrete or reinforcement used within the concrete (Zarina *et al.,* 2013). The quality of the water is important because impurities in it may affect with the setting of the cement, the strength of the concrete or cause staining of its surface and may also lead to corrosion of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be measured. Clear distinction must be made between the effects of mixing water and the attack on hardened concrete by aggressive waters because some of the latter type may be harmless or even useful when used in mixing (Neville and Brooks, 2008)

2.6.3 Aggregates

Aggregates are used to describe the gravels, crushed stones & other materials which are mixed with cement and water to make concrete. Aggregates make up about 75% of the volume of concrete, so their properties have a large impact on the properties of the concrete (Alexander and Mindess, 2005) .Aggregates are granular materials, most regularly natural gravels and sands or crushed stone, although sometimes synthetic materials such as slags or expanded clays or shale's are used.

The role of aggregates is to provide much better dimensional stability and wear resistance, and without aggregates, large castings of neat cement paste would basically self-destruct upon drying. All aggregates should be clean, which is, free of impurities such as salt, clay, dirt or foreign matter (Edward, 2008). Aggregates are generally divided into two size ranges, coarse aggregate, which is the fraction of material retained on a No. 4 (4.75mm) sieve, and fine aggregate, which the fraction is passing the No. 4 sieve but retained on a No. 100 (0.15mm) sieve.

2.6.4 Coarse Aggregates

Choosing the best coarse aggregate is important to guarantee the concrete mixture reach the desired strength. The form must be nearly rounded and the surface must be rough to produce the strongest concrete. To avoid such kind of space, the aggregate shape is a main factor and if aggregate voids are minimized, the amount of cement paste required to fill those void also minimized maintain workability and strength. It is tough to actually live the form of irregular body like concrete mixture that square measure derived from rocks. Not solely have the characteristics of the parent rock however conjointly the kind of device employed in crushing influence the shape of aggregates.

Research shows that, there is a relationship between the voids of aggregates and shape, texture and grading of aggregate. In rounded, cuboidal and well hierarchic particles exhibits lower void content than flaky, elongated and angular aggregates. Roundness and angularity square measure the vital characteristic of aggregates. Roundness is defined of particle and it should be measure in terms of convexity wherever angularity indicates the sharpness of the sides and corners. Nonetheless, flaky and elongated particles can produce harsh mixture and serious effect in workability. An excess of poorly sharped particle could decrease the strength of concrete through the increase of water demand. Additionally, flat particles can be oriented in such way that they could impair the strength and durability of the concrete. In concrete pavements, flat particles can be oriented in such a way that they could impair the strength and the durability of concrete. In concrete pavements, flat particles near the surface inhibit excessive water from entering mortar above particle, thus contributing to the deterioration of the surface. So from that, it is clear that crushing type of aggregate definitely had effects on properties of concrete because of the crushing type of aggregate that can change and control the shape factor directly (Muhit *et al.*,2013)

2.6.5 Fine Aggregates

Fine aggregate is a material that passes through a 4.75mm BS 410 Test Sieve. Sand is mostly thought about to possess a lower size limit of about 0.07mm, material between 0.06mm and 0.002mm is classified as silt and smaller particles are called clay. Sand may be described as:

a) Natural sand – fine aggregate resulting from natural disintegration of rocks

b) Crushed stone sand or crushing gravel sand – fine aggregate produced by crushing the hard rocks or natural gravel

The purposes of the fine aggregate are basically to fill the voids in the coarse aggregate and to act as a workability agent in concrete mixture. If the fine aggregate is round shaped, the workability will be increased as reflected by use of less cement

2.7 Factor Affecting Concrete Strength

a) Quality of the raw materials used.

There are basically three types of raw materials that been used, which consists of cement, aggregates and also water. The cement that been used must according the appropriate standards and stored correctly, which is in dry conditions. The aggregates also must be chosen correctly. The features of the aggregates, the sizes and its shape, texture and strength, determines the strength of concrete. The presence of silt and clay may reduce the strength of concrete. Meanwhile, clean water must be used for the mixture of concrete.

b) Water- cement ratio

Water used to produce concrete mix that is both plastic and easy to work with. If water is used more than had supposed, strength and density of concrete will decrease. If the water used is too low, it is difficult to be mixed and concrete hydration process is not perfectly done. The relationship between the ratio of water and cement in the concrete mix is known as the water-cement ratio. The water-cement ratio refers to the mixing water and cement used for the mixing ratio. Generally, the lower the water-cement ratio, it will increase the concrete strength and workability will become lesser

c) Coarse- fine aggregate ratio

For coarse and fine aggregate ratio, when the proportion of fines and coarse aggregate is increased, the overall aggregate surface area will also increase, thus the water demand also increasing. Assume that the water demand is increased, the water-cement ratio will increase thus the compressive strength of it will decreasing

d) Coarse aggregate- cement ratio

Fine and coarse aggregates shall consist of various sizes to produce a minimum void. The use of cement should be sufficient to fill the void in the sand and cement sand sufficient to cover the void in the coarse aggregate. However, it would produce a rough concrete. Therefore, more cement and sand is required to produce a mixture which has high workability

e) Age of concrete.

The concrete will not reach it effective strength in early days, for instance 3 or 7 days. For most practical applications on site, the majority of the strength of concrete will only be achieved by 28 days.

f) Compaction of concrete

It is important to ensure that there is no trapped air in concrete mixture. Any trapped air due to inadequate compaction will result to reduction of strength. Generally, if there was 10% trapped air in the concrete, the strength will decrease up to 30 to 40%.

g) Temperature

The rate of hydration reaction is temperature dependent. If the temperature increases the reaction conjointly will increase. This implies that the concrete kept at higher temperature can gain strength more quickly than the same concrete kept at a lower temperature. However, the ultimate strength of the concrete kept at the higher temperature are going to be lower. This can be as a result of the physical type of the hardened cement paste is less well-structured and more porous when hydration proceeds at quicker rate. This is a very important purpose to remember because temperature contains a similar but more pronounced damaging result on permeability of the concrete

h) Relative humidity

If the concrete is allowed to dry out, the association reaction can stop. The hydration reaction cannot proceed without moisture.

i) Curing

The harmful effects of storage of concrete during a dry atmosphere are reduced if the concrete is satisfactorily cured to prevent excessive moisture loss.

2.8 Durability of Concrete

Durability of concrete may be defined as the ability of the concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. It is normally refers to the duration or life span of trouble –free performance of the concrete. Besides, durability of concrete also depends on following factor cement content, compaction, curing and permeability and internal causes like physical of concrete and chemical properties. There are some certain condition that concrete will remain durable if the cement paste structure is dense and low permeability, made with graded aggregate that are strong and inert and the ingredients in the mix contain minimum impurities such as alkalis, chlorides, sulphates and silt.

The acid attack resistance is measured in term of the loss of weight of specimen under the attack of acid solution. A lower weight loss indicates higher acid resistance. The factor determining the acid attack is the permeability in concrete which depends on the porosity, size of pores, continuity of the pores and its distribution. The acid resistance improves with the increase in cement content for mixes having same water cement ratio due to improvement of the hydrated paste quality. The increase in water cement ratio for mixes with the same cement adds to the porosity of the paste structure thereby reducing its acid resistance.

2.9 Lightweight Concrete

2.9.1 Lightweight Aggregate Concrete

Lightweight aggregate concrete can be defined as a type of concrete which includes an expanding agent that increases the volume of the mixture and gives the same strength with normal concrete. Structural lightweight aggregate concrete is vital and gives solution for weight and durability problem in the construction industry. The lightweight concrete has its own advantages of high strength, good tensile strength, low coefficient of thermal expansion and sound insulation characteristic due to air voids in lightweight concrete (Mouli, 2008). For the same crushing strength, the density of concrete made with such an aggregate can be as much as 35 percent lower than normal weight concrete.

The advantages of lightweight aggregate concrete are reduction of overall weight results in saving structural frames, footing and piles. It is rapid and relatively simple construction where it is economical in terms of transportation as well as reduction in manpower. While the disadvantages of lightweight aggregate concrete are the mixtures are very sensitive to water content and it is difficult to place and finish because of the porosity and angularity if it is in aggregate. The mixing time for lightweight aggregate concrete is longer than the conventional concrete Table 2.2 shows the types of aggregate and dry density.

Table 2.2: Types of aggregate and dry density

Aggregate Type	Trade Name	Dry Density (kg /m³)
Furnace clinker	-	720- 1040
Processed fly ash / pfa	Lytag	770 – 960
Foamed blast furnace slag	-	670 - 920

Source: (Neville, 2010)

2.9.2 Properties of Lightweight Aggregate Concrete

Lightweight aggregate concrete is made with both coarse and fine lightweight aggregates, with higher –strength concrete that will be replacing all or part of the fine fraction with normal weight sand. By this kind of replacement will make the increment the unit weight of the concrete by as much as 320 kg/m³ (Alexanderson, 1979). It the other words, it is one type of lightweight materials. consisting of Portland cement paste or cement are trapped in mortar or cement filter matrix, with a homogeneous void or pore structure created by air voids, which are trapped in mortar or cement paste by a suitable chemical agent (Ramamurthy, 2009). It can be divided into two groups which are mechanical properties and others. For mechanical properties, compressive strength can be included. Compressive strength is the most important mechanical properties of every concrete including lightweight concrete as it is playing a very important responsibility in construction in order to sustain the load and transfer the whole load from the top until the ground of a building. The compressive strength decreases exponentially with a reduction in density of lightweight concrete (Kearsley, 1996) Furthermore, in general, there are also some factors will affect the strength of aerated concrete other than concrete's density, such as specimen shape and six, method of pore formation, direction of loading, curing age, water content, characteristic of ingredients used and the method of curing are reported to influence the strength of lightweight concrete (Valore, 1954).

In addition, another factor such as the cement-sand and water-cement ratios, curing regime, type and particle size distribution of sand also can affect strength of lightweight concrete (Hamidah *et al.*,2005). On the other hand, compressive strength is inversely proportional to the void diameter, especially with a dry concrete between 500 and 1000kg/m^3. The composition of the paste determines the compressive strength in densities higher than 1000 kg/m^3 because the air void is far apart to have an effect on the compressive strength. On the other hand, the compressive strength of lightweight concrete is not affected by small changes in water content ratio. Meanwhile, the increase in water content within the consistency and stability limit provide an increase in strength of concrete. The compressive strength of lightweight concrete for various mixture composition and densities was summarized and reported in the literature (Ramamurty and Nambiar, 2009)

2.9.3 Application of Lightweight Aggregate Concrete

Lightweight concrete can be used for a wide range of applications as insulation, infill and lightweight foundation. It is used in securing old-mine workings, shafts tunnel and other underground voids. Furthermore, it can be used to fill redundant sewers, pipelines fuel- tanks, culverts, and subway. Lightweight is also used in rodent exclusion infill beneath railway station platforms, infill spandrel arches under bridges and viaducts, roof screeds and floor insulation, soil stabilization and replacement, harbour retaining wall backfill, airport aircraft arrestor bed , annulus fill of pipelines, tunnel-linear backfill, road foundations and many more. Figure 2.2 and figure 2.3 shows the structure that built up using lightweight aggregate concrete

Figure 2.2: Bridge that built using lightweight aggregate concrete

Source: www.esci.org

Figure 2.3: Building that using lightweight aggregate concrete

Source: www.esci.org

2.10 Palm Oil Industry In Malaysia

Malaysia is one of the world's leading producers and exporter of palm oil and palm oil products. The oil palm was first introduced in Malaysia in 1870 as an ornamental plan. There is more than two hundred palm oil mill plant operating in the country (Mannan *et al.*, 2002). Oil palm waste is a one of type waste material that produces from palm oil industries. Factor affecting palm oil development including demographic , market price fluctuation that influence economy, cultural that changed consumption pattern that encouraging economic investment and technological. Figure 2.4 and 2.5 shows the production of palm oil in year 1961-2009 and in year 2015 and 2016.

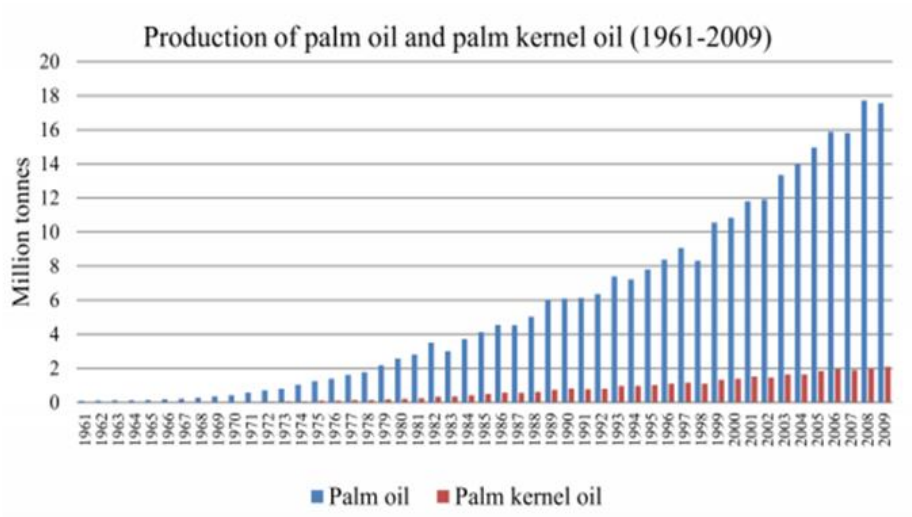

Figure 2.4 : Production of palm oil and palm kernel oil

Source : Data from FAOSTAT 2011-04-29

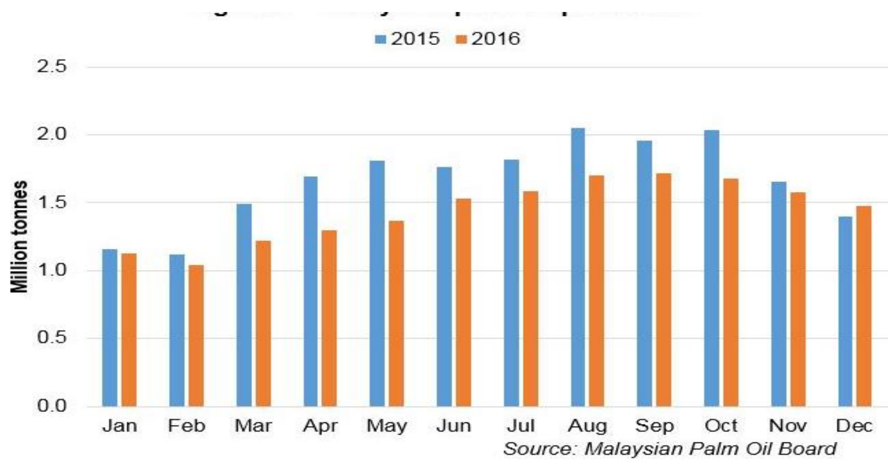

Figure 2.5 : Production of palm oil in 2015 and 2016

Source: Malaysia Palm oil board ,(2014)

2.10.1 Characteristic of POFA

POFA is a pozzolanic material as indicated by both physical properties and chemical analysis (Awal and Hussin, 1997). This characteristic is crucial in determining the suitability of using POFA as mixing ingredients in concrete. The physical properties of POFA are greatly influenced by the burning condition, particularly burning temperature (Abdullah *et al.*, 2006). In particular, the rate of hydration, pozzolanic reaction and development of POFA concrete microscopy, it is found that underground POFA particles are mostly large, spherical and porous. In contrast, the ground POFA generally consist of smaller crushed particles with irregular and angular shape similar to the Portland cement (Chindaprasirt *et al.*, 2007). This shows that the ground POFA is coarser than OPC but the ground POFA becomes finer than OPC.

Usually, the particles size of POFA can be reduced by the grinding process in ball mills or Los Angeles abrasion machine using mild steel bar instead of steel ball (Abdullah *et al.*, 2006). The grinding process reduces not only the particles size but also the porosity of the POFA (Kiattikomol *et al*., 2001). After grinding, POFA can be less porous with smaller particles (Paya *et al*, 1996). The general physical properties of raw and ground POFA are presented in Table 2.3.

Table 2.3: Physical characteristics as received and the blended ground POFA

Physical Properties	**Raw POFA**	**Ground POFA**
Appearance before ignition	Dark spongy	Greyish, powdery
Appearance after ignition	Porous, greyish	Brownish
Texture	Hard ,gritty, light cellular	Powdery
Shape	Irregular	Round

Source: Oyeleke *et al*, (2011)

2.10.2 Properties of POFA

POFA is pozzolanic materials as indicated by both physical properties and chemical analysis. This characteristic is crucial in determining the suitability of POFA as mixing ingredients. The physical properties of POFA area unit greatly influenced by the burning condition, particularly burning temperature. The rate of hydration, pozzolanic reaction and development of palm oil waste concrete microscopy, it is found that underground palm oil waste particles are mostly larger, spherical and porous in particular situation. While, the chemical composition of POFA are varying because of different manufacturers. However, silicon oxide continues to be the key chemical composition in POFA. Chemical composition of ordinary Portland cement and POFA are shown in table 2.4

Table 2.4 : Chemical composition of ordinary Portland cement

Chemical Composition	**OPC**	**POFA**
Silicon dioxide (SiO_2)	20.10	57.71
Aluminum Oxide (Al_2O_3)	4.90	4.56
Ferric oxide (Fe_2O_3)	2.50	3.30
Calcium Oxide (CaO)	62.00	6.55
Magnesium oxide (MgO)	3.10	4.23
Sulphur oxide (Na_2O)	2.30	0.25
Sodium oxide (Na_2O)	0.20	0.50
Potassium oxide (K_2O)	0.40	8.27
Titanium Oxide (TiO_2)	0.20	-
Phosphorus Oxide (P_2O_2)	<0.90	-

All values are in percentage

Source : Tangchirapat, (2006)

2.10.3 Application of POFA in Concrete

There are many uses of POFA in concrete production especially towards improving the properties of concrete. According to (Tay and Show, 1995), they had revealed that the compressive strength of concrete decreases as the POFA content increases. In contrary, other researcher have found that the concrete made with POFA exhibit a higher compressive strength than OPC concrete (Tonnayopas *et al.,* 2006)

Another researcher, (Chindaprasirt *et al.*, 2006) POFA can be applied as the new pozzolanic materials in concrete with an acceptable strength. They added that the optimum cement replacement by POFA is 20% which if it is beyond this ratio, the compressive strength is reduced and also tends to give higher permeability of concrete. Nevertheless, it was suggested to use finer POFA in order to achieve better strength of POFA concrete, the reduction in the strength of concrete is expected as it has lower particles surface area that affects the pozzolanic activity in the POFA concrete.

(Awal and Hussin, 1996) highlighted that adding POFA enable concrete to increase the resistance towards sulphate and acid attack. The expansion of concrete due to sulphate attack decreased with the increased content of underground POFA (Jaturapitakkul *et al.*, 2007). However, high strength concrete containing ground POFA showed a better resistance to sulphate attack than normal POFA concrete (Tangchirapat *et al*., 2009) which thereby indicates that the POFA fineness influences the sulphate resistance of concrete. However, literatures discussing on the performance of concrete containing POFA as partial sand replacement is very limited. The fineness of POFA influenced the strength of concrete, the finer the POFA will lead to the strength development of concrete. The strength of concrete influenced by the fineness of POFA.. The same replacement that the coarser one due to the higher total surface area of POFA particle that increases the pozzolanic activity and hence increases the concrete strength (Awal, 1998). This is due to the higher total surface of POFA particle that increases the pozzolanic activity and hence increases the concrete strength.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presented about the materials used and the test methods that was followed throughout the study. At the beginning of this chapter, details of raw materials such as cement, course and fine aggregates, sand, palm oil waste, superplasticizer presented. Then, the next section discussed on the sample preparation needed to achieve the objectives of this research. The final part of this chapter discussed about the test procedure that had been followed to evaluate the concrete performance.

3.2 Methodology Flow

Figure 3.1 shows the methodology flow chart of the research process from the beginning of the research until the presentation of the result of the research.

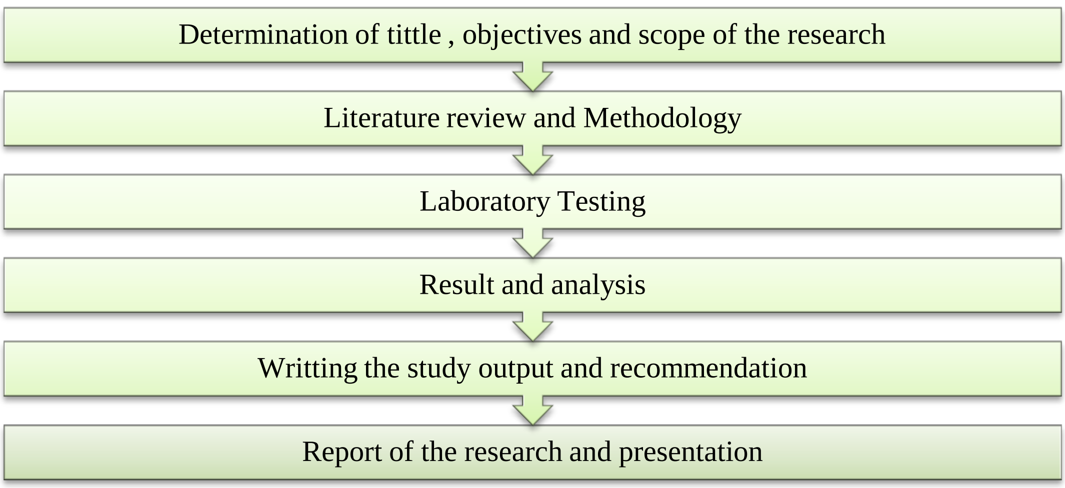

Figure 3.1 : Methodology flow chart

3.3 Experimental Work

The methodology process throughout the study based on the flowchart shown in figure 3.2. The points discovered in this chapter including the materials preparation , mix design, testing procedures and the standard specification used for this research.

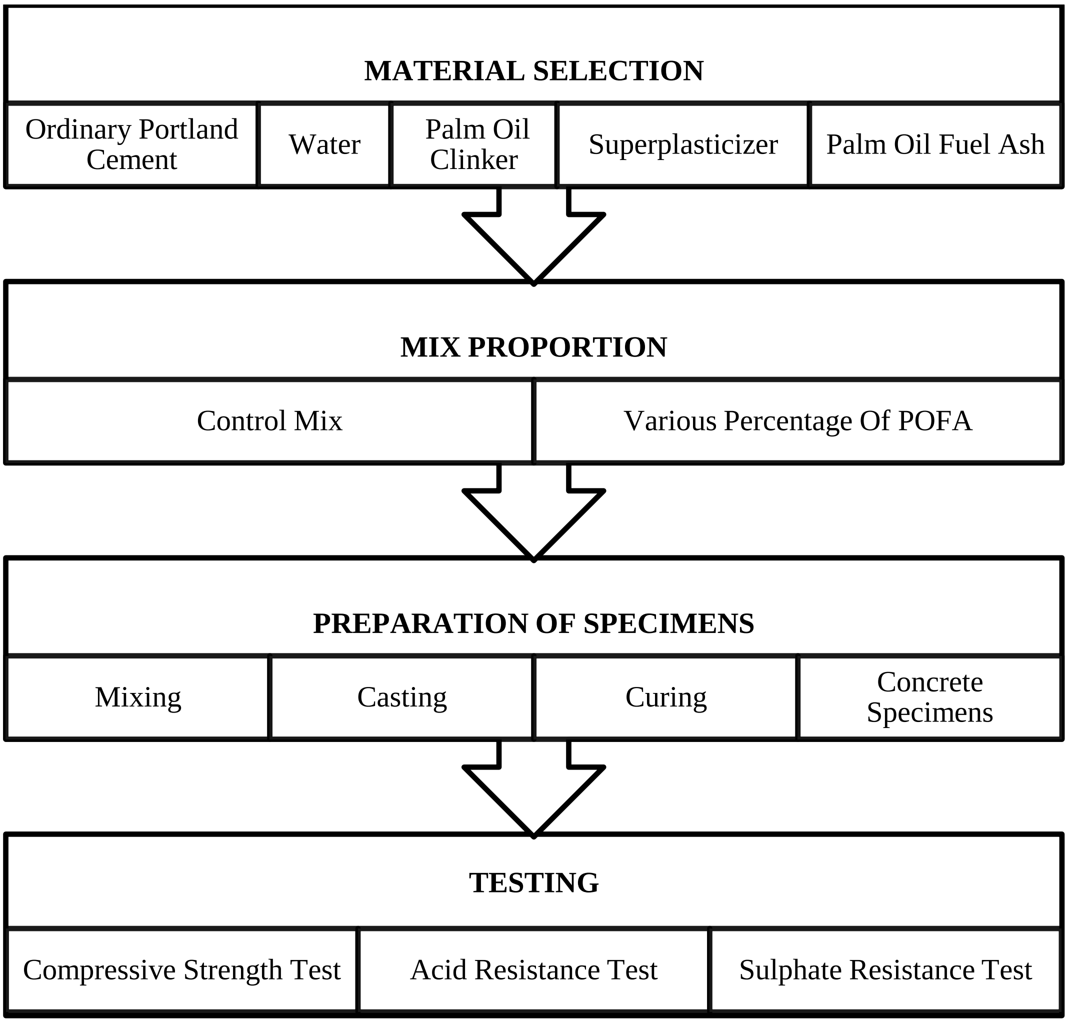

Figure 3.2: Experimental work

3.4 Concrete Specimen Mixing Ingredients

In this research, four raw materials were used to produce lightweight concrete. The materials involved are Ordinary Portland Cement (OPC), palm oil clinker, water and palm oil fuel ash and superplasticizer as mixing ingredients in concrete.

3.4.1 Cement

Type of cement that most widely recognized is Ordinary Portland Cement (OPC) whereby it utilized regularly as a part of the concrete production in Malaysia. It is produced by YTL Cement Sdn. Bhd under the brand name of "Orang Kuat" was used throughout the research. According to ASTM C150 (2005) , the Ordinary Portland Cement used in this research is complied with Type 1 cement

3.4.2 Water

Water is the vital sources in the concrete production. The cement needs sufficient water to create calcium silicate hydrate gel (C –S – H gel) during hydration process. During the concrete mixing design, the volume of water was calculated and the quality of water had controlled to ensure the quality of concrete. This due to the affection the strength of the concrete and may cause the corrosion of the steel reinforcement. In this study, the tap water was used in concrete mixing. Tap water was used must not contained any impurities as it may affect or harmful to durability of concrete.

3.4.3 Fine Aggregates

Fine aggregates were used as mixing ingredients in concrete. The use of fine aggregate is to fill the voids in concrete and act as workability agent. It was dried in oven before it is used to prepare concrete mix.

Figure 3.3 : Fine Aggregate

3.4.4 Palm Oil Fuel Ash

In this study, POFA was obtained from nearby oil palm mill in Pahang. These materials had processed as the mixing ingredient in cement. After brought back from mill, this waste was dried in oven at the temperature 105 C for 24 hours to remove the moisture and frying purpose. To get the required size, it was sieve using 300μm sieve. The process of palm oil waste preparation was presented in form of flowchart as in figure 3.4. Figure 3.5 and 3.6 shows POFA before and after sieving process.

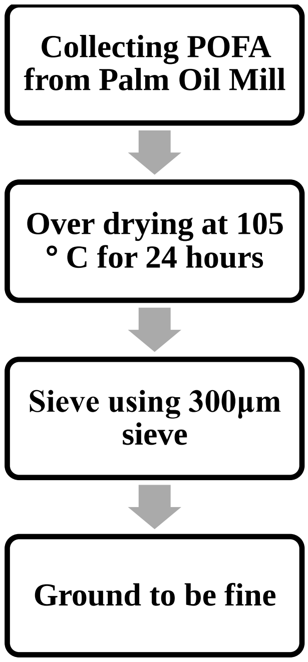

Figure 3.4: Palm oil fuel ash preparation process

Figure 3.5: Palm oil fuel ash

Figure 3.6: POFA after sieving process

3.4.5 Palm Oil Clinker

In this study, POC was obtained from nearby oil palm mill in Pahang. This material had processed as the mixing ingredient in aggregate. After bringing back from mill, this waste is dried in oven at the temperature 105 C for 24 hours to remove the moisture.

3.4.6 Super plasticizer

In this study, super plasticizer was used as it is known as high range water reducers. It had reacted as dispersant in order to avoid particle segregation in concrete cube. Super plasticizer used to give special properties to fresh or hardened the concrete and also to increase the workability, durability and strength characteristics of the concrete mixture.

3.5 Mix Proportions And Trial Mix

In this research, trial and error process used in term of percentage of POFA to obtain the optimum mix proportion of the lightweight concrete. In this research, during trial mixing, three type mix proportion are casted. The optimum percentages of POFA used are 0 %, 20 %, and 40 %. The water to cement ratio for each type of mix proportion was tried from the range of 0.4 with uniform increment for each mix. Density for every mix was controlled to get optimum mix proportions.

3.6 Preparation of Specimens

The quantity, weight and blending of raw materials before forming operation of concrete was calculated. The concrete batching was carried out by using the methods of weighting and pouring ingredients into the mixer. The ingredients were calculated for each batch of concrete to form equal quality concrete mix. It was important to mix the concrete using weight to gain better accuracy. According to concrete design mix calculation, the materials used were weighted. Next, the materials were mixed well using concrete mixer until it is uniformly distributed to ensure that cement paste is mixed well. Palm oil clinker was added follow by fine aggregates, water superplasticizer, cement and palm oil fuel ash to obtain the uniform concrete mix base on the standard BS 1881: Part 108. The concrete cubes were covered with the wet gunny after casting to avoid evaporation and change of temperature. The specimens were left in laboratory for 24 hours and the specimens were cured after being removed from the molds.

A fresh concrete was poured into mold of desired shape and allowed to solidify for the casting process. The concrete cube of (100 x 100 x 100 mm) was casted by filling each mold with three layers of concrete where each layers compacted uniformly at least 25 times using a rod. After casting, the specimens were covered by wet gunnysack to reduce evaporation for the first 24 hours before remoulding. In this research, the specimens were cured in the water tank at the temperature of 26-29 °C. The period of curing is 28, and 90 days. Figure 3.7 and 3.8 shows the casting process and curing process.

Figure 3.7: Casting process

Figure 3.8: Curing process

3.7 Procedure of Testing

3.7.1 Compressive Strength Test

Major testing to estimate the concrete strength was compressive strength. The compressive strength of all cubes of (100mm x 100mmx 100mm) was measure under the following procedures. A total of nine concrete were tested. All the specimens were subjected to water curing until the testing date. The specimens were tested at the age of 28 and 90 days. Before the sample was places inside the compressive strength test machine, the weight of the sample were recorded and the testing machine bearing surfaces was wiped in order to ensure it was clean. The sample was placed at the centre of the lower plate and the load was applied to the specimen. The maximum concrete strength was directly taken from the machine or calculated using equation 3.1 (ASTM C39).

$$\text{Compressive strength , fca} = P/A \qquad \text{Eq (3.1)}$$

Where :

P = maximum load indicated by the testing machine ,N

A = cross sectional area of specimen (mm^2)

Figure 3.9: Compressive strength machine

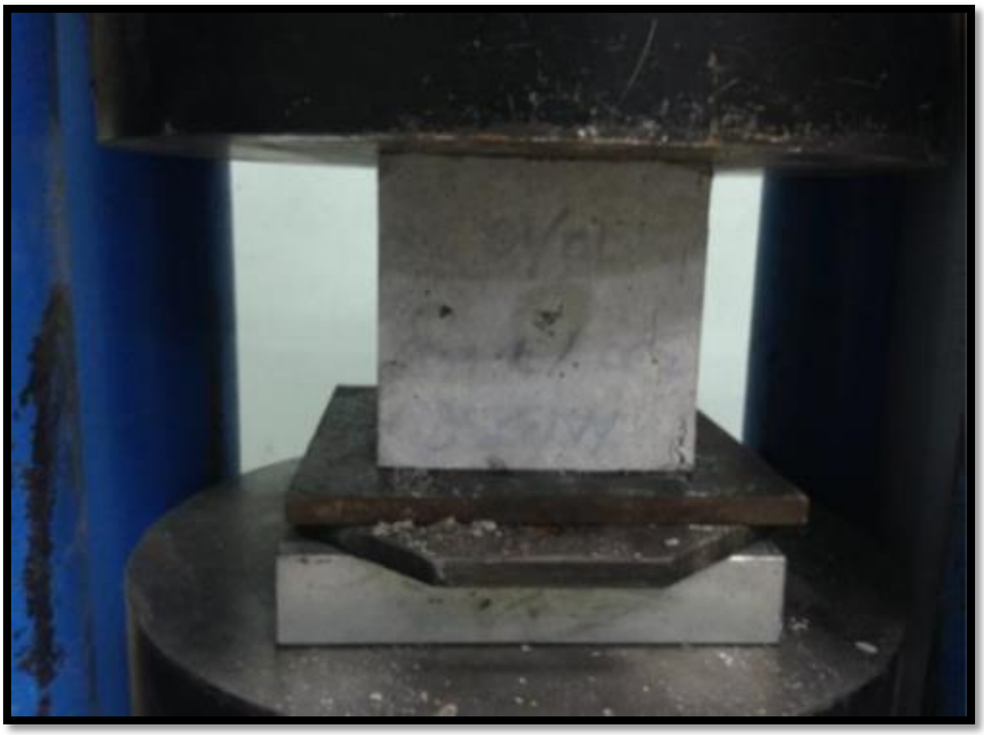

Figure 3.10: Testing in progress

3.7.2 Acid Resistance Test

Acid resistance test was determined that are measurement two parameters which were mass loss, and strength deterioration done by (Mailar, *et al.*, 2016). This test was conducted by preparing concrete cubes of 100 x 100 x 100 mm size containing various percentages of POFA. All the concrete cubes were cured for 28 days using water curing before immersing it in acid solution.. After 28 days, the mass of all concretes were measured. Then, six specimens from each mixes were immersed in 5% Hydrochloric acid (HCl) solutions for 1800 hours. At every 100 hour, the weight of the specimen was measured and any changes in terms of specimen shape and deterioration was observed until the period of 1800 hours. The pH of the hydrochloric acid solution was regularly monitored and adjusted to keep it constant that was of about 2 similar. The mass loss was determined by using Eq. 3.2 (Mailar, *et al*., 2016)

$$M_{Lt} = \frac{M_t - M_i}{M_i} \times 100 \qquad \text{Eq(3.2)}$$

Where

M_{Lt}	=	cumulative weight reduction
M_t	=	weight at time, t (kg)
M_i	=	initial weight before exposure to acid (kg)

At the end of testing period, at 1800 hour, all the concretes were tested for strength loss using compressive strength machine. The average value of six specimens was taken and reported. Strength deterioration was determined using Eq. 3.3 (Mailar, *et al*., 2016).

$$\text{Strength Deterioration (\%)} = \frac{fcw - fca}{fcw} \times 100 \qquad \text{Eq(3.3)}$$

Where

f_{cw} = average strength of concrete cubes cured in water

f_{ca} = average compressive strength of cubes immersed in acid solutions

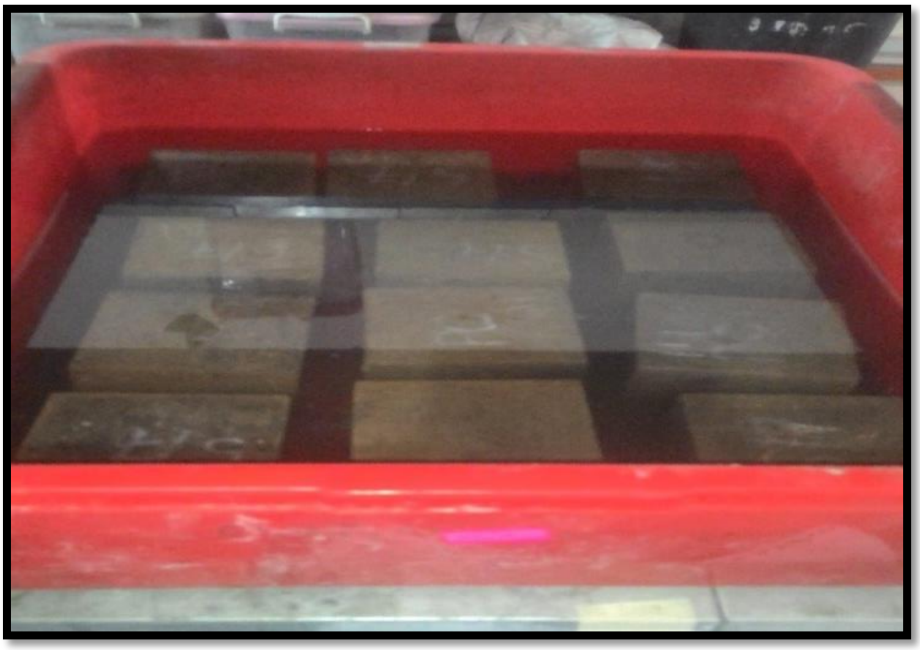

Figure 3.11: Acid resistance test

Figure 3.13: Weighting of concrete cube

3.7.3 Sulphate Resistance Test

The sulphate solution was prepared according to ASTM C1012 (2004). The degree of sulphate attack was evaluated by measuring strength reduction and mass change similar to the experimental approach applied by (Najjar *et al.*, 2017). Hundred and twenty 100 x 100 x 100 mm concrete cubes which consist of control specimen and POC lightweight aggregate cubes containing 0%, 20%, and 40% POFA were prepared and cured for 28 days using water curing. Six specimens from each mix were immersed in 5% sodium sulphate (Na_2SO_4) solution for 16 weeks.. Mass measurement and visual assessment of the concretes were conducted every week until the age of 16 weeks. The mass loss was determined by using Eq. 3.4 (Najjar *et al*, 2017)**.**

$$\text{Mass loss (\%)} = \frac{m_1 - m_2}{m_1} \text{x } 100 \qquad \text{Eq(3.4)}$$

m_1 = mass of specimens before immersion

m_2 = mass of specimens after immersion

The compressive strength test was conducted at the end of testing date in order to determine the strength reduction when the lightweight aggregate concrete was immersed in sulphate solution. The compressive strength reduction (R_c) was calculated using the following Eq. 3.5**(**Boudali *et al*, 2016**)**.

$$R_c \text{ (\%)} = \frac{f_c - f_e}{f_c}\, x\ 100 \qquad \text{Eq(3.5)}$$

Where

f_c = average compressive strength of concrete cubes cured in water

f_e = average compressive strength of concrete cubes cured in Na_2SO_4

Figure 3.14 : Sulphate resistance test

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the experimental data were analysed for each sample of testing. The data were illustrated in tables and graphs for the observation and comparisons. The results displayed include compressive strength, mass change and strength deterioration. The early part of the chapter, presents result on compressive strength containing various POFA content. After that, the performance of concrete in acidic and sulphate environment is discussed by presenting data obtained from acid resistance test and sulphate resistance test.

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4.2 Compressive Strength

Cube test indicates the major compressive strength was carried out according to ASTM C- 39. The sample cubes with dimension of 100 mm x 100mm x 100mm were tested. The sample cubes were cured in water and tested for compressive strength at the curing age of 28 and 90 days. The compressive strength average was taken from the result of three average sample cubes. The effect of POFA as mixing ingredients on overage compressive strengths of the different POFA replacement sample cubes with curing period of 28 and 90 days in figure 4.1

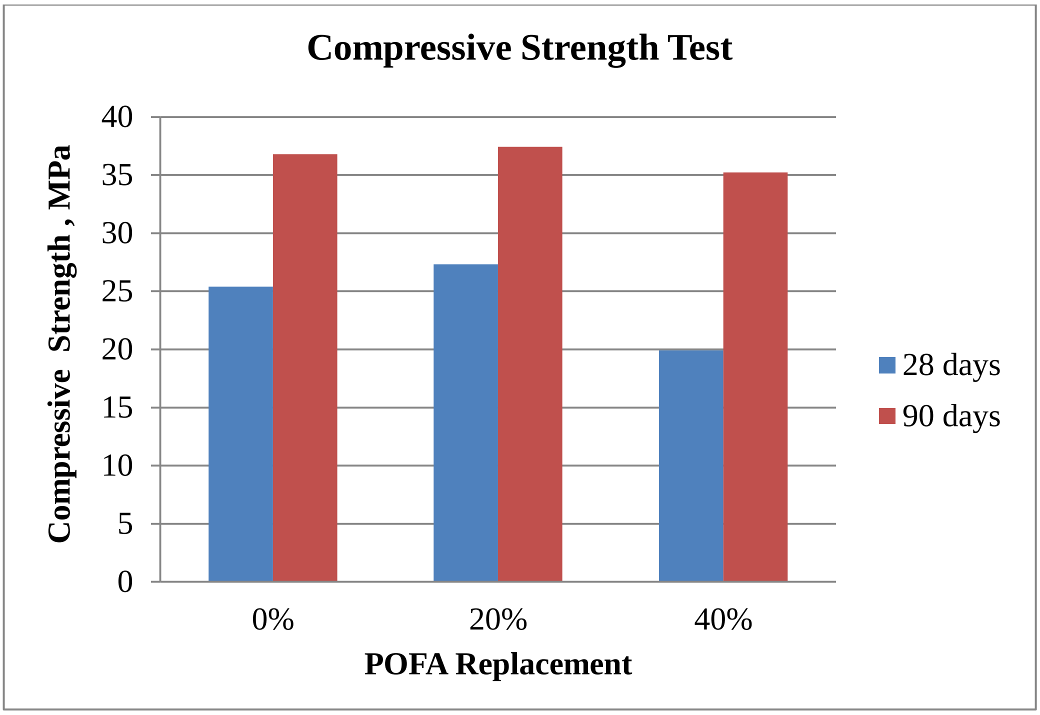

Figure 4.1: Compressive strength result

Figure 4.1 shows the variation of compressive strength with POFA replacement at the age of 28 and 90 days. The highest compressive strength was obtained by concrete containing of 20 % of POFA replacement. This is because of the filling effect of the fine POFA and also the pozzolanic reaction that improves the bond between the aggregates. The presence of pozzolanic ash promotes pozzolanic reaction that increases the amount of secondary C-S-H gel contributing towards the densification of concrete internal structure leading to strength enhancement. Meanwhile, the compressive strength of 40 % of POFA replacement specimen was the lowest at all curing age. It is observed that the concrete strength reduces as more POFA is added. This is due to the lesser amount of CSH gel produced. Then, the free hydrated lime is also not sufficient for complete pozzolanic reaction to take place. Similar observation has been reported by past researcher (Hussin *et al*, 2009).

4.3 Acid Resistance

Acid resistance test was done to determine the total mass loss and strength deterioration of the sample cubes. This test was conducted by preparing concrete cubes of 100mm x 100mm x 100 mm size that containing 0% , 20% and 40 % of POFA replacement. All the concrete cubes were cured for 28 days using water curing before immersing in Hydrochloric solution to measure total mass loss and strength deterioration as shown in figure 4.2 and 4.3

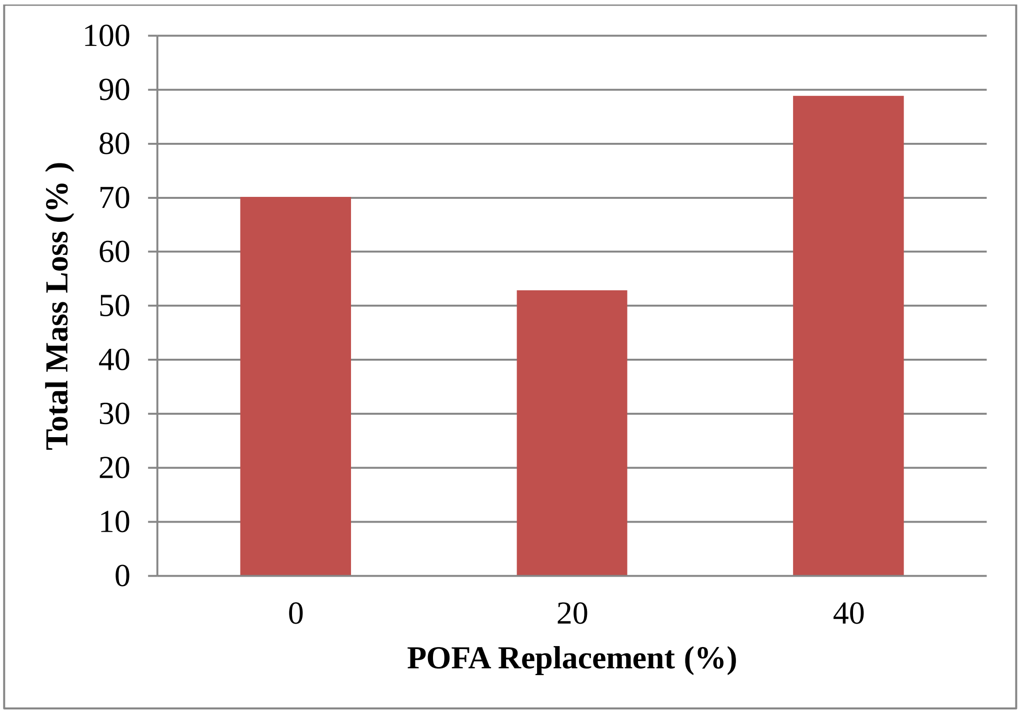

Figure 4.2 : Total mass loss of concrete cubes after immersed in Hydrochloric acid solution for 1800 hrs.

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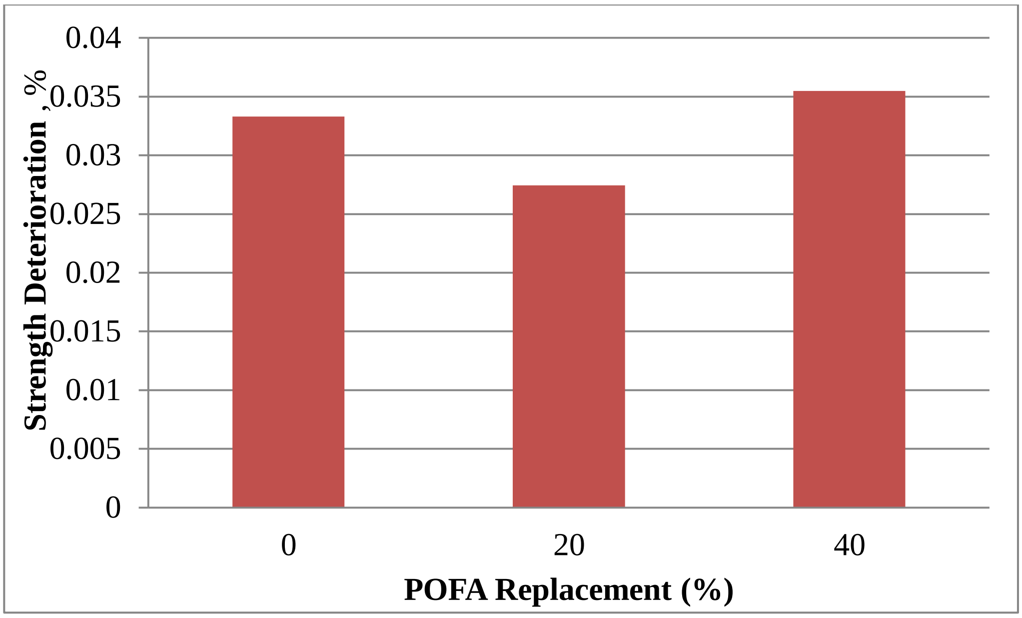

Figure 4.3: Strength deterioration of cubes after immersed in Hydrochloric acid solution for 1800 hrs.

Figure 4.2 and 4.3 shows the total mass loss and strengthdeterioration samples in HCI solution for 1800 hrs. It showed clearly that the sample with 20% POFA replacement indicated a relatively smallest total mass loss and lowest strength deterioration. The better resistance of POFA specimen is expected not only because of the fact that POFA is being identified as good pozzolanic materials. 40 % POFA replacement sample undergo higher mass loss due and higher strength deterioration to lower CaO content. This is also due to the lesser presence of CSH gel in concrete. Figure 4.4 illustrates the physical appearance of cubes after exposed to acid resistance test.

0 % POFA Replacement

20 % POFA Replacement

40 % POFA Replacement

Figure 4.4: Physical appearance of cubes after exposed to acid resistance test.

4.4 Sulphate Resistance Test

Sulphate resistance test was prepared according to ASTM C1012 (2004).. The sample size of 100mm x 100mm x 100mm was prepared and undergone water curing for 28 days. Then, the sample from each mix were immersed in sodium sulphate to determine the total mass and strength deterioration as shown in figure 4.5 and 4.6

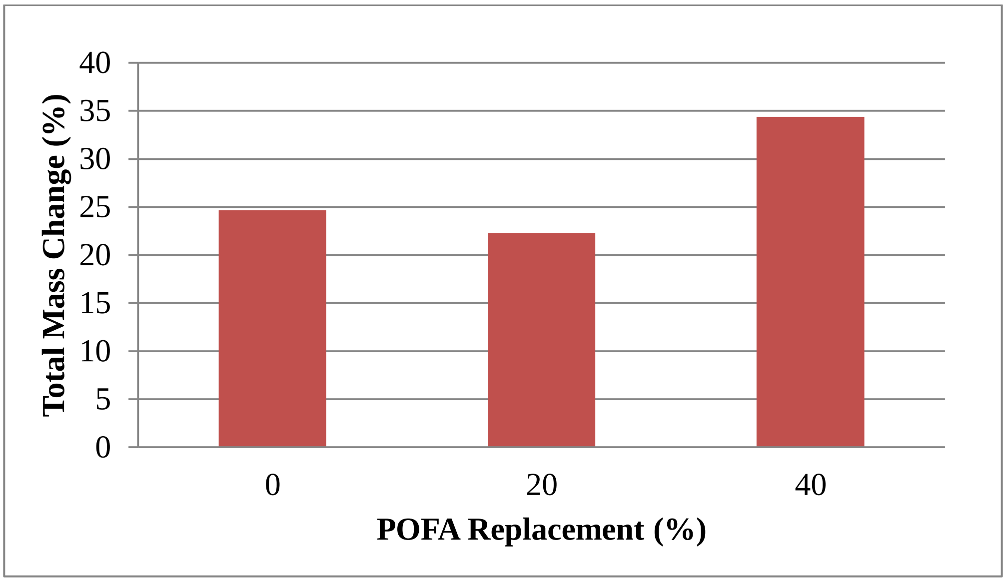

Figure 4.5: Total mass change of concrete after immersed in Na_2SO_4 solution for 16 weeks.

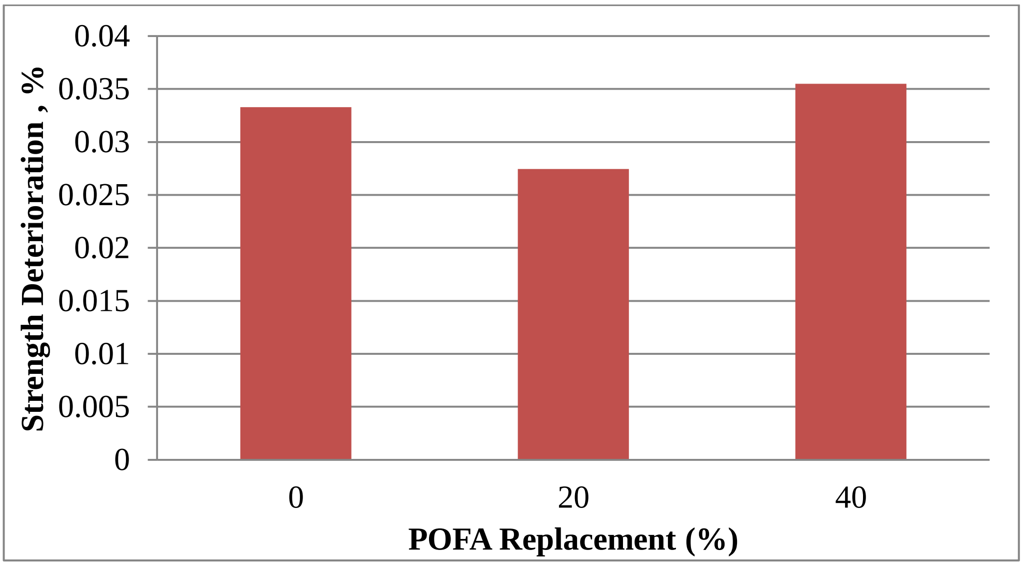

Figure 4.6 : Strength deterioration of cubes after immersed in Na_2SO_4 solution for 16 weeks.

The total mass change and strength deterioration of the specimens after immersed in sulphate solution was shown in figure 4.5 and 4.6. Generally, usage of palm oil fuel ash as mixing ingredients influence the sulphate resistance through variation in the total mass change. 20% of POFA replacement experience lowest mass change and minimum strength deterioration 40 % of POFA replacement sample experience huge mass change in sulphate solution. This is due to the concrete cracking resulting from internal pressure created by ettringite fills in the voids of concrete leaving the aggregate detached from the. In conclusion, cubes in sulphate resistance test experience less strength deterioration for 16 weeks Figure4.7 indicates the physical appearance of cubes at the end of testing period .

0% POFA replacement

20 % POFA replacement

40 % POFA replacement

Figure 4.7: Physical appearance of cubes at the end of testing period

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter includes the findings obtained in this research. This study is to determine performance of lightweight concrete containing POFA subjected to acid and sulphate resistance test. Recommendation for the future research works also included.

5.2 Conclusion

Based on the finding and analysis in Chapter 4, few conclusions are drawn as follows:

i. The 20 % of POFA replacement achieved the highest compressive strength for 28 and 90 days. This is because of the presence of pozzolanic ash promotes pozzolonic reaction that increases the amount of secondary C-S-H gel contributing towards the strength enhancement.
ii. The results indicated 20% of POFA replacement concrete had superior durability and more resistance to deterioration in hydrochloric solution.
iii. 20% POFA replacement concrete experienced lowest mass change and strength deterioration in sulphate resistance test.

5.3 Recommendations

This study is mainly focus on durability performance of concrete containing POFA as mixing ingredient. The following suggestion is made for further research by:

i. To further studies on the corrosion resistance of concrete containing POFA.
ii. To further studies on the chloride resistance containing POFA.
iii. To further studies on the fire resistance containing POFA.

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