DURABILITY OF
LIGHTWEIGHT AGGREGATE CONCRETE
CONTAINING OIL PALM ASH (OPA)

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ABSTRAK

Di Malaysia, industri minyak sawit yang telah berkembang pesat sepanjang tahun telah menyebabkan penghasilan sisa dalam kuantit yang besar dan akan menjejaskan alam sekitar secara negatif. Penghasilan bahan binaan seperti simen dari sumber semulajadi telah menyebabkan banyak penghasilan gas-gas yang tidak perlu secara berlebihan ke udara boleh menyebabkan kesan rumah hijau terhadap alam sekitar. Debu Minyak Kelapa Sawit (OPA) merupakan salah satu jenis sisa industri minyak kelapa sawit – yang boleh didapati dengan mudah, akan digunakan dalam penyelidikan ini bagi membantu dalam mengatasi masalah pencemaran ini secara minor. Ketidaktentuan prestasi bagi kandungan konkrit ringan, penyiasatan dari segi ketahanan terhadap serangan asid dan sulfat dan penyerapan air akan dibuat. Lima siri 0%, 10%, 20%, 30% dan 40% kandungan konkrit ringan OPA dengan saiz campuran kiub yang sama (100X100) mm^2 akan disediakan. Spesimen dengan 0% kandungan OPA akan menjadi spesimen kawalan bagi siasatan ini. Spesimen konkrit ringan ini akan melalui temppoh pengawetan selama 28 hari iaitu selama 7 hari di dalam air dan selebihnya akan dibiarkan terdedah ke udara. Kehilangan berat spesimeen akan diperhatikan berkaitan bagi ujian rintangan asid dan sulfat. Kemerosotan kekuatan akan diperhatikan bagi ujian rintangan asid. Seterusnya, kadar penyerapan air akan diperhatikan bagi ujian penyerapan air. Hasil ketara yang diperolehi menyimpulkan bahawa dengan kandungan OPA yang semakin meningkat, berat spesimen semakin berkurang daripada berat asal dan kekuatan spesimen turut menjadi semakin merosot. Kadar penyerapan air juga semakin meningkat apabila kandungan OPA meningkat. Kesimpulannya, kesan negatif terhadap spesimen terjadi kerana kandungan OPA banyak, serta, melebihi kandungan optimum OPA yang sesuai menggantikan semen.

ABSTRACT

In Malaysia, the industry of palm oil has grown rapidly throughout the years causing an immense production of waste that will surely affect the environment negatively. The production of construction material from natural resources such as cement has produced an excessive amount of unnecessary gas into the air causing a blunt greenhouse effect on the environment. Oil Palm Ash (OPA) as one types of palm oil industrial wastes – can be easily obtained, were used in the research that in order to help in overcoming these problems. In regard of its uncertain performance as a content of lightweight concrete, an investigation in terms of durability against acid and sulphate attacks and water absorption were also made. Five series of 0%, 10%, 20%, 30% and 40% of OPA content lightweight concrete with the same mix proportioning of (100X100) mm^2 cube size were prepared. The specimen with 0% content of OPA was set as the control specimen of the investigation. These lightweight concrete specimens were then cured for 28 days – 7 days in water and the rest will be air cured. Losses of mass was observed in regard of acid and sulphate resistance test. Strength deterioration in regard of acid resistance test. While, in water absorption rate, the water absorption test were necessarily observed. The distinct result obtained concluded that with the increasing content of OPA, the specimens become susceptible to loss mass as compared to its original mass and deteriorate in strength. The water absorption rate observed also increase as OPA content increases. It is concluded that, all these negative effects on the specimens were only observed when the content of OPA is too much and exceeded the optimum content of OPA.

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LIST OF SYMBOLS

℃	Degree Celsius
%	Percent
µm	Micro-meter
C-S-H	Calcium Silicate Hydrate
$Ca(OH)_2$	Calcium Hydroxide
d	Day
ft	Feet
in	Inches
kg	Kilogram
kN	Loadings
lb	Pound
m	Metre
mm	Millimetre
Mpa	Strength (Mega-Pascal)
SG	Specific Gravity
$MgSO_4$	Magnesium Sulphate

LIST OF ABBREVIATIONS

OPA	Oil Palm Ash
POBS	Palm Oil Boiler Stone
LWC	Lightweight Concrete
LWAC	Lightweight Aggregate Concrete
SSD	Saturated Surface Dry
USA	The United State of America
YTL	Yeoh Teong Lay
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Concrete – commonly known as a major material in construction – is the mixture of cement, coarse and fine aggregates and with or without chemical-mineral additives. Being able to replace some of these materials could make significant changes to the environment and cost as well as the performance of the concrete themselves (Kanchidurai et al, 2017). Through a hydration process that binds the aggregates together the mortar – mixture of concrete ingredients, develops into becoming hard, durable and strong material. Depending on the content of the aggregate, the durability of the concrete would vary. The mixture of concrete with some lightweight coarse aggregate made up a lightweight aggregate concrete mixture. Typically, the density of lightweight concrete would be a lot less compared to the normal weight concrete. This is because, light weight structural concrete is an enhanced version of concrete, with emphasis on decrease in density of concrete, hence, when structural concerns require a minimum to the dead load, light weight concrete is used (Rasheed & Prakash, 2015). So, practically, the primary use of lightweight concrete is to reduce the dead load of a concrete structure.

Malaysia as one of the developing country in term of oil palm industry, have generate bunches of palm oil wastes. The most common wastes from palm oil mill is Oil Palm Ash (OPA) and Palm Oil Boiler Stone (POBS) are by-products of oil mills arising from the use of palm oil shell and palm oil bunches which are used to power oil mill plants for electricity generation (Awal and Hussin, 1997; Hussin et al., 2010). Each year, more than 100,000 tons of OPA is produced and is increasing annually, while the utilization of it is minimal. Thus, most of these oil palm waste will be disposed of in landfills, causing environmental and other problems (Jaturapitakkul et al., 2007). Its abundant in amount made it an easier option for material replacement as it is easily available. Besides, there is also a research conducted to have shown that these palm oil wastes can be used as material in the manufacture of concrete (Teo, et al., 2006). Based on World Business Council for Sustainable Development in the year of 2006, the cement industry produces about 2.6 billion tonnes of cement annually. The most important use of cement is in the production of concrete, twice the amount of which is used than the total of all other building materials, to construct our homes, schools, hospitals, sewage systems, pavements and more. Concrete is the most used man-made material in the world, a fact not widely known. Concrete has a cement content of between 10-15%. The excessive use of natural resources could be reduced significantly through this integration.

Considering the amount of OPA arising from palm oil mills in Malaysia, Thailand, Indonesia and other palm oil producing nations and the desire to address environmental problem posed by this waste, there is a need to examine further on the application of OPA at higher volume particularly in concrete operations. As such there have been lots of previous researchers that have reported various studies that shows OPA is as suitable to be use in the mixture of concrete (Chindaprasirt et al., 2008; Wongkeo et al., 2014; Deboucha et al., 2015). OPA has a lot of time been introduced as a pozzolanic material in concrete and there have been a lot of studies that focussed on OPA in the study of its mechanical properties in concrete such as compressive strength and modulus of elasticity of concrete. Some studies have considered the durability of these mix of concrete against sulphate attack and corrosion resistance of high-strength concrete (Chindaprasirt, et al., 2011). With the increasing needs to substitute the construction into an eco-friendlier environment, a proper study about any integrations toward that objectives should be made. So, it seems more than appropriate and beneficial to conduct a further study on the durability performance of lightweight concrete containing OPA.

1.2 Problem Statement

In construction industry, the act of building a shelter from scrap involve a lot of uses of machines, natural resources and cost. So, there have been a concern about how to improve construction practices to minimise their detrimental effects on the natural environment (Cole, 1999).Construction contributes to air pollution at all levels. It creates air pollution at a local scale through emissions of dust, fibre, particles and toxic gases from site activities and building materials production processes. It contributes to regional pollution through emissions of nitrogen and sulphur oxides in building materials production (Spence et al., 1995). Being the major user of the world's non-renewable energy sources and minerals, the construction industry has contributed a lot in causing pollution on the earth. Apart from that, an improving palm oil industry is also among the largest industry to contribute waste. Such as in Malaysia, its excessive production of waste from the palm oil industry has affected the sustainability of the country. Too much waste contributes to landfills and a higher possibility of causing a lot more pollution to the environment. This is because, the incineration of palm oil ingredients could release abundantly unnecessary smoke or gas to the atmosphere that will pollute the air. Therefore, the integration of palm oil industry by-products such as OPA and POBS as partial material replacement in the manufacture of concrete can decrease the use of natural resources, while also contributing to the reduction of pollution to the environment.

1.3 Research Objective

The objectives of the research are as follows: –

i. To investigate the effect of Oil Palm Ash (OPA) as mixing ingredient on sulphate attack of lightweight concrete.
ii. To investigate the effect of Oil Palm Ash (OPA) as mixing ingredient on acid resistance of lightweight concrete.
iii. To investigate the effect of Oil Palm Ash (OPA) as mixing ingredient on water absorption of lightweight concrete.

1.4 Significance of Research

The main purpose of conducting this research is to contribute in decreasing the pollution of the environment. With the excessive development and demand from the agricultural industry, lots of by-products or waste were involuntarily produce that can affect the environment. Sustainability of the construction industry is kind of the major issue that need to be immediately focused on. Therefore, the ability to properly reuse or integrate POBS as waste product of palm oil industry should be greatly utilised. This is because, proper management of these products would not only reduce the amount of natural resources to be use in the construction industry, but, it will also minimize the contribution to the environment pollution. This act also reduces the dependency of the construction industry on natural resources only. Since supposedly, concrete should be environmentally friendly, using POBS as partial cement replacement can contribute to a greener production of concrete.

1.5 Scope of Research

Technically this research focused on the investigation of the durability of lightweight concrete with OPA. Initially, the concrete specimens were casted into a square mould with sides of 100mm and left hardened for one day. The hardened concrete will then be cured in water for seven days initially and left air cured until it reached 28 days period of concrete curing. Then, the cured specimen were tested accordingly to the objectives of the research. The durability of the concrete performance toward acid resistance, sulphate attack and water absorption were observed in terms of mass losses and strength deterioration. Respectively, hydrochloric acid and sodium sulphate solution were each used for acid resistance and sulphate attack respectively in its durability test. Within the whole period of six months, the specimen were tested. The amount of OPA in terms of percentage that were set as partial cement replacement were 0%, 10%, 20%, 30% and 40%. The water absorption test were also conducted on the concrete specimens upon reaching the curing period of 28 days.

1.6 Layout of Thesis

Chapter 1 introduces about the main concept of ‘Durability of Lightweight Concrete – Initially Seven Days Cured Containing Oil Palm Ash (OPA)’. Among the topic that is discussed in this chapter is the background of the study and some problem that might be related to the topic. Objectives of this thesis are pointed out in this chapter. In order to continue with the study, the scope of research is selected and explained as to provide a more systematic process toward the project completion.

Chapter 2 highlights the literature review of works that was done in the past regarding OPA in lightweight concrete. This chapter discussed about the palm oil industry in Malaysia, where it seems like it is the major cause for environmental problem. Through this, it is concluded that these wastes produced from the palm oil industry in Malaysia, such as OPA and POBS, can be used in the manufacture of concrete. So, details on OPA and POBS and its usefulness in concrete manufacture are highlighted in this chapter. Few characteristic and important point about lightweight concrete are also explained in this chapter. This is due to the capability of OPA and POBS to be used in producing lightweight concrete.

Chapter 3 discusses about the methodology and experimental value regarding the topic of the research. Material to be used and method of testing are further explained in this chapter. Method of testing included in the study are also detailed. Chapter 4 presents the result obtained from all of the testing involve. Results, are then concluded in figures of graph regarding the observation that were during the testing. Chapter 5 are where the conclusion of this whole project are made. Conclusion is based on the results that are presented in Chapter 4.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Generally, this chapter helps develop the idea of the whole topic by giving some reviews from the former related researches. This is as to strengthen the idea of the whole topic of this thesis. Basically, it had already been known that Malaysia is one of the country that involves a lot in the palm oil industry and the products from this industry generate a huge amount of waste that requires suitable disposal. The utilization of waste by-products can help to improve the waste management to reduce environmental pollution (Kanadasan et al., 2015). In addition to that, by far the most widely employed construction materials worldwide is concretes made with hydraulic binders in terms of volume, and as such have a huge impact on the environment and on sustainable development (J., et al., 2008). The conflicts and affects upon the production of cement is a huge concern. Based on an analysis carried out by Battelle, shows that cement sector Carbon Dioxide emissions are set to rise dramatically in the coming decades (Humpreys et al., 2002). Therefore, it is critical that the Carbon Dioxide emissions associated with such growth in cement production be settled with lots of international efforts to reduce environmental effects. On a bright side, the cement industry itself is fully aware of the sustainable development stakes and has been actively involved in seeking ways to consume less energy and natural resources, and emit less Carbon Dioxide per unit of cement produced over the past decades.

2.2 Palm Oil Industry in Malaysia

The oil palm in Malaysia is over a century old. Introduced as an ornamental in 1871, the oil palm was commercially exploited as an oil crop only from 1911 when the first oil palm estate was established (Basiron and Weng, 2004). From a humble beginning of a mere four original palms introduced from West Africa to Indonesia in 1848 that soon arrived on Malaysian shores in 1871, the palm oil industry in Malaysia has developed progressively over the past few decades. Based on the success of the first commercial planting in Tenammaran Estate, Kuala Selangor, the area expanded quickly, the most rapid increases occurring during the 1930s, 1970s and 1980s (Basiron and Weng, 2004). Studies show that almost 57 million tons of palm oil was produced in total by Malaysia and Indonesia in 2012, which is 85% of the global production (Murphy, 2014). Based on a research (Basiron et al., 2004), there has been a growth in area during the various decades of the last century in Malaysia is shown in Table 2.1 and a huge increase of palm oil production as shown in Figure 2.1 up until the year of 2008.

Table 2.1 Area of oil palm planting and growth in the decades of the last century.

Years in Decades	Hectares	% Growth
1870 – 1910	<350	-
1920	400	14.2
1930	20 600	5 050.0
1940	31 400	52.4
1950	38 800	23.5
1960	54 638	40.8
1970	261 199	378.0
1980	1 023 306	291.8
1990	2 029 464	98.3
2000	3 376 664	66.3

Source: Adapted from Malaysian Oil Palm Statistics (2001)

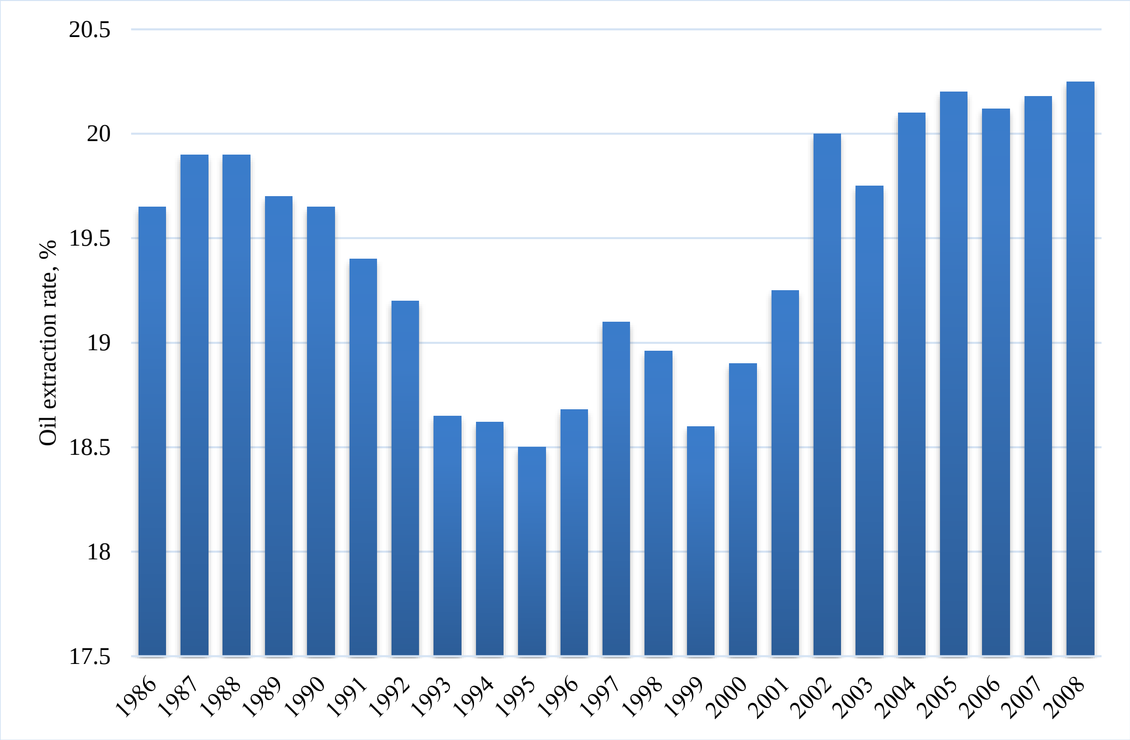


Figure 2.1 Annual oil extraction rate for 1986-2008

Source: MPOB, 2008

Consequently, the industry has been a great economical support to the country. The palm oil industry is also known to have been producing a large diverse amount of product annually. It goes from the basic fresh products up to the completely processed goods such as food products. At present, there are more than three million hectares of palm oil plantation in Malaysia making it as the world's largest exporter of palm oil and palm products. In 2011, it exported 24.3 million metric tons of the oil (Chin, 2011). However, a huge amount of production tends to produce a huge amount of wastes or by-products. In total, about 90 million metric tons of trunks, shells, husks, palm press fibres, and empty fruit bunches are produced every year. In addition to that, palm oil factories generate various types of waste, which include, oil palm fibre, oil palm shell (OPS), palm oil mill effluent (POME), POBS, OPA and empty fruit bunches (EFB). Figure 2.2 shows the huge quantities of products and by-products from the Malaysian palm oil industry in 2004. Improper management of these wastes could lead to environmental pollution, hence, this called for a very serious consideration for a solution (Kanadasan et al., 2015).

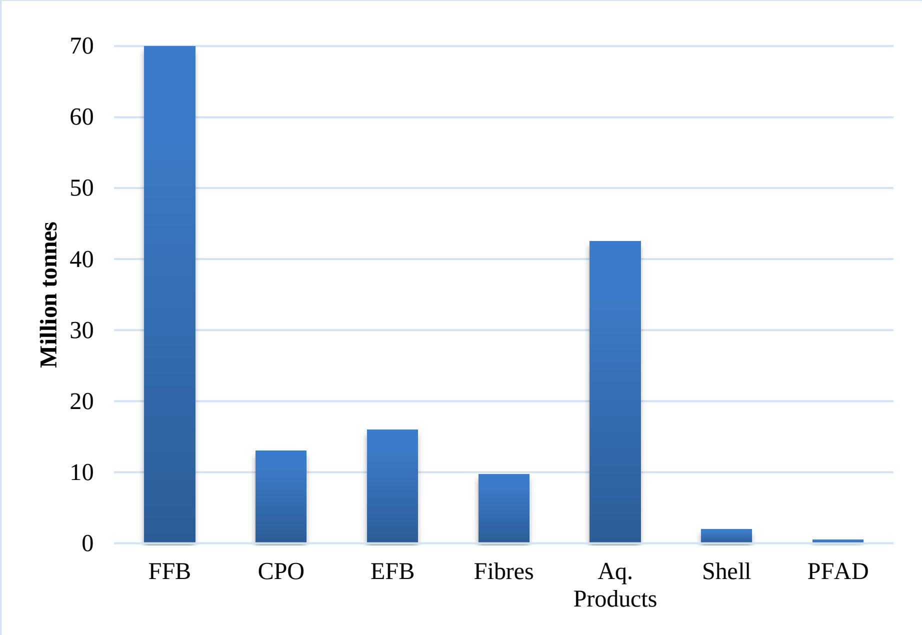


Figure 2.2 Malaysian production, in 2004, of crude palm oil and by-products from palm oil mills and refineries

Source: Tan, 2006

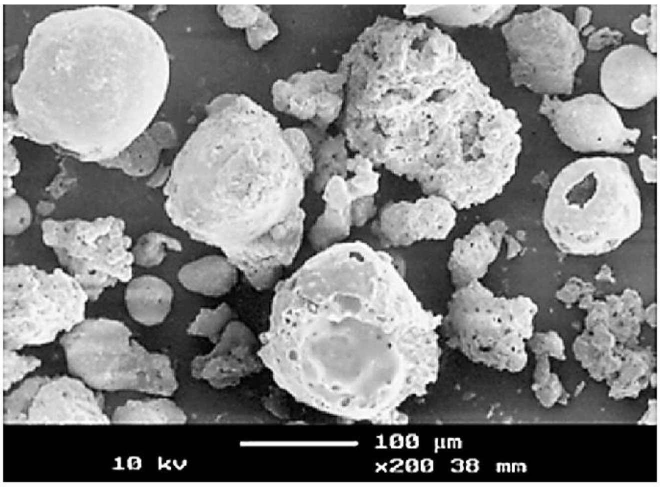
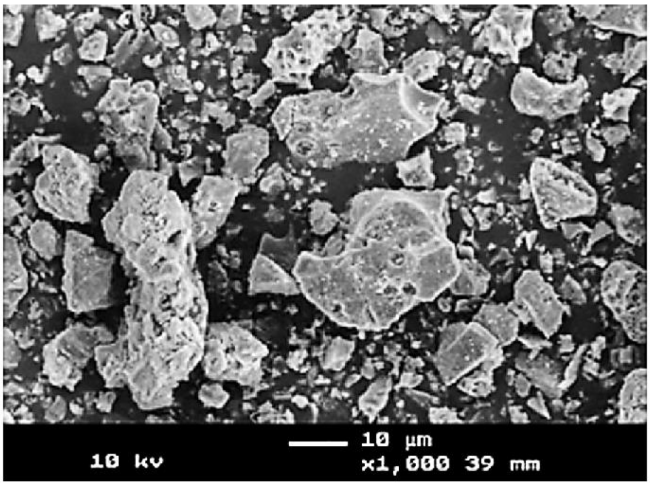
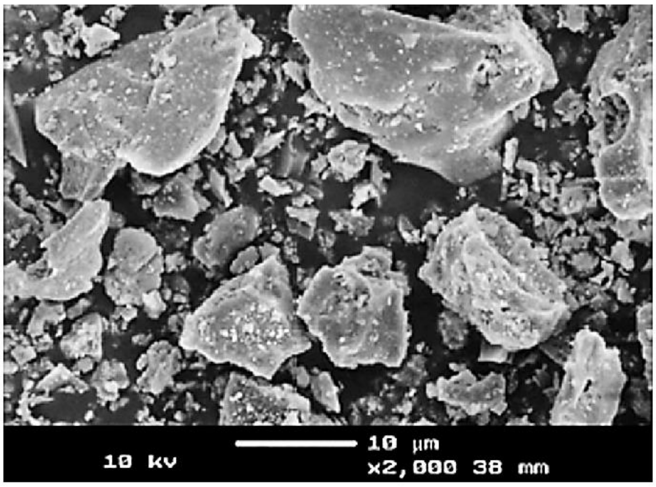
The oil palm industry has always been linked to the environment because it is a land intensive industry. Any unplanned development will lead to the degradation of the forest systems, loss of habitats including plants and animals, extreme land degradation and pollution (water and airborne) due to the use of large quantities of pesticides and herbicides required to maintain the plantation. To solve this abundantly production of waste problem, one of the possible ways is by introducing the suitable industrial waste in the manufacture of concrete; this is to either reduce the use of aggregate (Mohammed et al, 1990) or reduce the amount of natural resources needs for the construction, other than reducing waste from palm oil mill. The utilization of palm oil by-products in concrete has garnered some positive outcomes over the past few decades in term of the cost savings and conservation of natural resources. What is more when some of the resources that are currently being employed for concrete production are prone to affect negatively on the environment, besides being a waste of non-renewable resource (Kanadasan et al., 2015).

2.3 Oil Palm Ash (OPA)

Oil Palm Ash (OPA) is the by-product that are produced after the burning of palm fibre, shell and empty fruit bunches as fuel at 800-1000 degree Celsius. Due to this incineration process, ash by-product or OPA is obtained and produced at about 5% by weight of the incinerated solid fuels (Sata et al., 2004). The quantity of OPA produced in Malaysia alone is about 4 million tonnes a year (Foo et al., 2009). Recently, OPA as an abundantly available throwaway waste from the fired-boiler furnaces, has outstandingly emerged to be one of the ideal materials that is suitable to be used in construction. Because of that, OPA has been utilized in many applications such as raw material for geopolymer composite (Chub-uppakarn et al., 2011) and cement replacement in production of concrete (Johari, et al., 2012).

The physical properties of OPA produced every time during the incineration tends to be different as the incineration temperatures affect its physical properties. Lower burning temperatures produce OPA having a black to dark grey colour due to the increasing amounts of unburned carbon (Abdul and Hussin, 1997). Higher burning temperatures produce a lighter coloured ash as a result to the decreased amounts of unburned carbon. Therefore, different palm oil mills produce OPA with different characteristics due to the different temperatures used in the incineration process. Similarly, with the chemical composition, different sources produce different characteristics of OPA. OPA is not similar to the other in its chemical composition due to the difference in its production process such as the burning temperatures used. OPA, due to its production process, complies with the chemical composition of class N fly ash (Tangcharipat, et al., 2009), class C pozzolan, class F pozzolan (Husin et al., 2010) or between class C and class F. Figure 2.3 show the particle of OPA at a microscopic view.

Table 2.2 OPA particles at microscopic views.

Original size OPA particles	
Medium size OPA particles	
Small size OPA particles	

Source: Almulali et al., 2015

2.3.1 OPA as Waste

Oil Palm Ash (OPA) – a throw away product that is produced abundantly and commonly disposed either by tipping or dumping. Hence, the waste, as such in Figure 2.6, is either spread over the premises of the mill or dumped to fill in low economic value dumps or selected types of land such as swamplands, abandoned sand quarries. These disposal methods were conducted without taking into consideration the surrounding environment or taking precautions to compact, cover and prevent the spreading of pollutants into the ground water levels (Foo and Hameed, 2009). This have somehow cause an abundantly wasted landfill that would contribute to pollution and an eyesore for the society and the tourism industry. In addition, due to its fine particles, OPA can be easily carried away by wind, which make it a reason for having smog on a humid day. If OPA, an agriculture waste ash from the palm oil industry, can be developed for use in concrete, it will form a new material for concrete production as well as a good way to eliminate the waste (Tangchirapat, et al., 2007). Therefore, the utilisation of OPA in concrete production has a number of environmental benefits such as reducing the amount of OPA that is disposed of into landfills, reducing the amount of energy used and the emitted greenhouse gases when OPA is used to replace manufactured cement and the conservation of other natural resources when OPA is used as filler replacement.

Figure 2.3 OPA as waste at the dump site in Maran, Pahang. October 30, 2017.

2.3.2 OPA Used in Concrete

In the manufacturing of concrete, Oil Palm Ash (OPA) can be used as constituents in concrete due to the pozzolanic properties. In general, a pozzolanic material has little or no cementing property; however, when it has a fine particle size, in the presence of moisture it can react with calcium hydroxide at ordinary temperatures to provide the cementing property. Many researchers have studied the use of OPA in normal concrete (Tangchirapat, et al., 2007 and Sata, et al., 2010). OPA is one of the agriculture waste ashes whose chemical composition contains a large amount of silica. This makes OPA as a high potential material that can be used as a cement replacement in the manufacturing of concrete (Tangchirapat, et al., 2003). Table 2.2 shows the chemical composition of both the cement and OPA that proved how similar OPA is to cement that it can used as a constituent.

Table 2.3 Chemical composition of cement and OPA.

Chemical composition (%)	Cement	OPA
Silicon Dioxide (SiO_2)	19.98	66.64
Aluminium Oxide (Al_2O_3)	5.17	3.82
Iron Oxide (Fe_2O_3)	3.27	3.70
Calcium Oxide (CaO)	63.17	5.23
Magnesium Oxide (MgO)	0.79	2.29
Sulphur Trioxide (SO_3)	2.38	0.43
Loss on Ignition (LOI)	2.50	2.32
$SiO_2 + Al_2O_3 + Fe_2O_3$	-	74.16

Source: Awang et al., 2014

The use of agricultural waste materials in concrete that are intensively studied recently (Safiuddin, et al., 2010), have shown that, the compressive strength is consistently decreased by increasing of OPA content in the concrete mix. OPA has a higher content of residual organics, higher alkali content and it is coarser when compared to fly ash (Tay, 1990). This makes it necessary to be sieve first before being used in concrete. In addition to that, the large particle size of OPA is proven to be a low pozzolanic reactive material. So, it is one of the aim of this research to utilize OPA as a pozzolanic material in concrete to reduce the environmental problems and the landfill area required to dispose the excessively production of OPA.

In term of the workability of the concrete, various researchers have studied that the effect of OPA incorporation on the workability of fresh concrete decreases with increasing of OPA replacement levels. A research had discovered that OPA having a fineness of 10 and 45 µm when integrated at a replacement level of 20% displayed lower compacting factors and higher VeBe readings in comparison to the control mix (Hussin, et al., 2009). The authors reasoned the low workability of OPA concrete mixes is due to the OPA's increased surface area that was caused by the grinding process. The authors observed that concrete mixtures containing high volumes of OPA as a cement replacement had lower slump readings but with the usage of water reducing super plasticiser the workability was improved to a satisfactory level.

Based on compressive strength, numerous studies have taken the task of studying the compressive strength of concretes and mortars incorporating OPA as a constituent. Compressive strength tends to decrease with the increase of OPA's replacement level. When OPA's fineness is increased (median particle size of 8.0 µm), a mix having a 20% level of replacement of cement by fine OPA showed a slightly higher compressive strength than that of the control concrete at the age of 90 days (Chindaprasirt et al., 2007). However, when investigating the compressive strength of concrete mixes designed according to the British concrete mix design (DOE method), using a constant water/binder ratio of 0.4 and replacing the cement up to 50% with raw and sieved through a 45 µm sieve OPA, observed that the finer OPA obtained double the strength of the raw OPA (Abdul & Hussin, 1997).

Water absorption of concrete mixes with unground OPA (sieved through a 150 lm sieve) was tested for its water absorption using the procedure specified in BS 1881 (Tay, 1990). Water absorption also increases with OPA replacements. This was attributed to the fact that the higher ash content in concrete would produce a more porous concrete. Concrete bars containing OPA were exposed to 5% $MgSO_4$ solution for 24 months. It was found that higher the fineness of OPA used reduced the expansion level of the concrete bars. The use of fine OPA in replacing cement not only decreased the calcium hydroxide content of the hydrated cement, but also assists as a filler leading to the reduction of voids between the aggregates and hydration products, leading to a denser concrete.

2.4 Palm Oil Boiler Stone (POBS)

Palm Oil Boiler Stone (POBS) is the recycled of by-product from the palm oil industry. In Malaysia, a country that produces and manufactures lots of palm oil based products; these waste products are usually dumped abundantly as waste. Its abundant in amount made it an easier option for material replacement as it is easily available. If this palm oil boiler stone is put into good use, in this case as a main material in high performance concrete mix, then it will largely reduce the production cost of high performance concrete. At the same time, it will also reduce the amount of waste generated by the palm oil industry thus achieving a global aim of sustainable development. Not only it reduces the waste, it also preserves the nature by eliminating the need to harvest natural aggregates from natural sources.

The production process for obtaining the palm oil boiler stone starts from palm oil extraction process which contains fibres and shells. In order to run the generator to produce electricity in palm oil industries, palm oil fibre and OPS are burnt at 850 ℃. After the cooling process the palm oil boiler stone can be obtained. These days, palm oil boiler stone is known as a relatively new sustainable material in the development of LWC as it actually has an almost same properties as the properties of normal aggregate that are used in the production of concrete. Besides, palm oil boiler stone is available in boulders of sizes ranging from 100 to 300 mm (Shafigh, et al., 2014). These boulders can be crushed into suitable sizes for concrete production making it’s an easier and eco-friendly material substitution for the production of concrete.

2.4.1 POBS as Waste

Palm Oil Boiler Stone (POBS) is a waste material produced from the burning of fibre and shell as a fuel to heat the steam for the generation of electricity and palm oil extraction process (Amalina & Mohamad, 2010). This throw away product is produced abundantly and commonly disposed either by tipping or dumping, as such shown in Figure 2.7. Hence, the waste will normally be treated as disposal waste and the government is required to provide large space to dispose huge amount of waste. Improper management of these waste would cause dumping site to be constructed. Apart from that, this waste is not treated to be recycled at all initially. Not only until the research involving the reuse of these material as a construction material – these wastes are seen as a valuable waste that could bring benefits to the factory. Therefore, it is important to find ways to treat these wastes and one of the potential ways of doing so is by constituting these wastes into construction material. And one recycle ways for sustaining green environment is by using the palm oil boiler stone in construction material industry.

Figure 2.4 POBS at palm oil mill in Lepar Hilir, Pahang. October 6, 2017

2.4.2 POBS Used in Concrete

Substitution with environmentally safer materials is vital to ensure that the concrete produces a lower emission factor. It is important to know the suitability of using POBS as substitute in concrete mix. In term of workability, the surface of POBS might be rougher but it does have a consistent slump values. This can be seen from the research about workability requirement in LWC for all the mixes with the use of water to cement ratio of 0.353 and SP content of 1.7% of cement weight (Monteiro, 2006).

A self-compacting concrete using POBS showed that almost 68% of the compressive strength can be achieved when POBS is replaced with natural aggregates (Jegathish & Hashim, 2014). Moreover, studies performed by Kanadasan and Abdul Razak (2014) shows that the uses of POBS aggregates produce concrete with "good" category ultrasonic pulse velocity (PUV) values. Complete replacement of POBS as aggregates reduced the weight of concrete by 16% compare to control specimen. A feasibility study performed on POBS utilization in construction industry using samples from all state in Malaysia showed that POBS specimens can produce structural efficiency in the range of 0.035 – 0.05 Mpa/(kg/m^3) which is similar to control specimen (Kanadasan et al, 2015). From structural point of view, singly reinforced POBS concrete beams which have a reinforcement ratio lower than 0.5% exhibited satisfactory deflection within the acceptable range (Mohammed, et al., 2014)

In contrast, using POBS as the lightweight aggregate in concrete, the ratio of MOE/fcu was in the range of 480e – 670e and with the increase in the concrete strength, the ratio improves (Mohammed, et al., 2013). Consequently, POBS aggregate also improves the properties of LWC. This is because, based on a research the deflection of a POBS concrete beam is less than the desired code limit (Mohammed, et al., 2014). Based on another investigation, the compressive strength of the concrete mixes in water curing up to 56-d as provided in Table 2.3, shows that the increase in the POBS content enhanced the compressive strength of the concrete (Ahmed et al., 2016).

Table 2.4 The compressive strength of OPS and POBS based LWC at different ages.

Mix	**Cube compressive strength f_{cu} at different ages**				
	1-d	3-d	7-d	28-d	56-d
P0	28.37	37.44	42.11	43.09	43.52
P25	29.35	39.35	45.37	49.45	49.73
P50	31.60	45.11	48.07	51.62	51.47
P75	32.10	47.63	51.76	55.37	56.82
P100	41.85	51.64	53.86	61.67	63.20

Source: Ahmad et al, 2016

2.5 Lightweight Concrete (LWC)

Lightweight concrete (LWC) has been successfully used since the ancient Roman times and it has gained its popularity due to its lower density and superior thermal insulation properties. Compared with normal concrete, LWC can significantly reduce the dead load of structural elements, which makes it especially attractive in multi-storey buildings. Reducing the weight of concrete is not new, both the Colosseum and Pantheon, built during the days of the Roman Empire, were partly constructed with materials that can be characterised as lightweight aggregate concrete (aggregates of crushed lava, crushed brick and pumice).

LWC was successfully used for marine applications and in shipbuilding. During the Second World War in the USA many ships were constructed with lightweight aggregate concrete. LWC ships were produced in the USA during the 1914-1918 war, and their success led to the production of the USS Selma (a war ship). In both 1953 and 1980 the Selma’s durability was assessed by taking cored samples from the water line area. On both occasion little corrosion was noted. In 1984, Thomas A. Holm estimated that there were over 400 LWC bridges throughout the world especially in USA and Canada. The research carried out by The Expanded Clay and Slate Institute proves that most of the bridges appeared to be in good condition. According to a journal, it was found that in Japan, LWC had been used since 1964 as a railway station platform (Marcia et al., 1994). The study on durability was carried out in 1983 has proven that LWC exhibited similar carbonation depths as normal concrete. Even though some cracks were reported, but these posed no structure problems. A second structure comprising both LWC and normal concrete which had been in seawater for 13 years was examined for salt penetration. Their success has led on to its use in structural lightweight aggregate concrete (LWAC) in buildings and bridges

A cubic metre of ‘normal’ concrete, in situ, weighs around 2300kg/m3. Reducing this weight by 25% or more, would give positive advantages to the architect, engineer and client. Designing with this reduced weight in mind can give benefits such as reduced foundation size, increase the number of floors, reduce column size and increase spacing, reduce steel reinforcing etc. One of the major problems and concerns in construction of big towers and skyscrapers is the dead load induced by the weight of roofs, floors and walls. The use of light weight concrete is a possible solution for decreasing such dead loads which will lead to economic benefits as well. While the density of ordinary cement concretes is typically about 2400 kg/m^3 the density of low weight concrete varies typically in the range of 300 and 850 kg/m^3.

While the description of LWC is fairly simple – LWC simply weighs less due to lower density aggregates than standard concrete, and can range from 35-100 pounds per cubic foot – it quickly becomes apparent that with both advances in technology and new materials being tested, LWC is not all created equal. For the production of LWC various fillers with smaller density than a conventional gravel and crushed stone are used. Lightweight aggregates (LWAC) differ in density, strength, water absorption, surface characteristics and shape actually affect the mechanical and durability properties of the concrete. LWC (LWC) is a very versatile material for construction, which offers a range of technical, economic and environment enhancing and preserving advantages and is destined to become a dominant material for construction in the new millennium (Al-Khaiat et al., 1999; Haque et al., 1999). Now with a range of proprietary LWA available, manufactured mainly using industrial by-products such as fly ash and blast furnace slag, LWC in the strength range of 30–80 Mpa can be easily made (Haque et al., 2002).

Therefore, a large number of experimental research works have been performed in the past for designing and manufacturing lightweight aggregate concretes. In the mentioned studies some physical and mechanical properties such as thermal expansion behaviour at elevated temperatures (Uygunoğlu & Topçu, 2009), carbonation resistance (Gao et al., 2013), harsh environment effects (Thomas & Bremner, 2012), drying shrinkage (Kayali et al., 1999), tensile creep , microstructure , durability, fire resistance, fracture and crack growth resistance (Aliha & Ayatollahi, 2009) and compressive strength and failure modes (Bogas & Gomes, 2013) of lightweight aggregates concretes have been studied (Hashemi, 2014).

Structural LWC has an in-place density (unit weight) on the order of 90 to 115 lb / ft^3 (1440 to 1840 kg/m^3) compared to normal weight concrete a density in the range of 140 to 150 lb/ft^3 (2240 to 2400 kg/m^3). For structural applications the concrete strength should be greater than 2500 psi (17.0 Mpa). Usually the concrete mixture would have been made with a lightweight coarse aggregate. In some cases, a portion or the entire fine aggregates may have already be a lightweight product. Before, lightweight aggregates used in structural LWC are typically the expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure or air-cooled blast furnace slag are also used. But with these popular researches about using palm oil waste in construction, the lightweight aggregate seems to be also suitable to use from these agricultural wastes.

2.5.1 Classification of Lightweight Concrete (LWC)

The LWC is conveniently different based on their method of production. Because of that the light weight concrete are actually classify into some types, which are – lightweight aggregate concrete (LWAC), aerated, cellular, foamed or gas concrete and no-fines concrete. LWAC are made by using porous lightweight aggregate of low apparent specific gravity as such it is lower than 2.6. The types of concrete knows as aerated, cellular, foamed or gas concrete is made by introducing large voids within the concrete or mortar mass, where the voids are made clearly distinguished from the extremely fine voids produced by air entrainment. The no-fines concretes are made by the omitting of the fine aggregate from the mix so that a large number of interstitial voids is present; normal weight coarse aggregate is generally used.

Aerated concrete is a lightweight, cellular material consisting of cement and/or lime and sand or other silicious material. It is made by either a physical or a chemical process during which either air or gas is introduced into a slurry, which generally contains no coarse material. It has the lowest density, thermal conductivity and strength. Its full strength development depends upon the reaction of lime with the siliceous aggregates, and for the equal densities the strength of high pressure steam cured concrete is about twice that of air-cured concrete, and shrinkage is only one third or less. Other than that, there’s also the no-fines concrete which generally means that the concrete is composed of cement and a coarse (9-19mm) aggregate only (at least 95 percent should pass the 20mm BS sieve, not more than 10 percent should pass the 10mm BS sieve and nothing should pass the 5mm BS sieve), and the product so formed has many uniformly distributed voids throughout its mass.

Although the strength of no-fines concrete is considerably lower than that of normal-weight concrete, this strength, coupled with the lower dead load of the structure, is sufficient in buildings up to about 20 storeys high and in many other applications. However, in the early 1950s, the use of Lightweight Aggregate Concrete (LWAC) blocks was accepted in the UK for load bearing inner leaf of cavity walls. Soon there after the development and production of new types of artificial LWAC made it possible to introduce LWAC of high strength, suitable for structural work. These advancement encouraged the structural use of LWAC, particularly where there is a need to reduce weight in a structure was an important consideration for design or economically. Structurally, LWAC is suitable to be made for the construction from pumice, foamed slag, expanded clays and shales, sintered pulverised – fuel ash aggregate and palm oil wastes.

2.5.2 Advantages of Lightweight Concrete (LWC)

There are a few advantages of LWC. These advantages are the uses of LWC help in reducing the dead load of wet concrete allowing a longer span to be poured unpropped. This would save both labour and circle time for each floor. The use of LWC has sometimes made it possible for engineer to come up with other important design related to the structure. Normally, this would have been abandoned because of excessive weight that could lead to failure. In addition to that, most building materials such as clay bricks the haulage load is limited not by volume but by weight. With suitable design containers much larger volumes of LWC can be haul economically. A less obvious but nonetheless important characteristics of LWC is its relatively low thermal conductivity, a property which improves with decreasing density in recent years, with the increasing cost and scarcity of energy sources, more attention has been given the formerly to the need for reducing fuel consumption while maintaining, and indeed improving, comfort conditions buildings. The point is illustrated by fact that a 125-mm thick solid wall of aerated concrete will give thermal insulation about four times greater than that of a 230-mm clay brick wall.

2.6 Durability of Concrete

Durability is defined as the ability of a material to withstand the effect of its environment. In a building material as chemical attack, physical stress, and mechanical assault need a serious attention in order to avoid failure of the building structure that would cause lots of loss. For example the sulphate attack condition. This can happen to those concrete cement-based materials that are exposed to sulfate-bearing solutions such as some natural or polluted ground waters (external sulfate attack), or by the action of sulfates present in the original mix (internal sulfate attack) can show signs of deterioration – which also known as sulphate attack (Taylor et al., 1997 and Skalny et al, 2002). Besides, concrete is also susceptible to attack by acid that could be present at the atmosphere or environment. This attack is due to the high alkalinity of portland cement concrete, which can be attacked by other acids as well. There were some researches that found that the damages starts at the surface of the concrete and progresses inward. Lastly, water absorption is regarded as the process whereby fluid is drawn into a porous, unsaturated material under the action of capillary forces.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provide an overview on the methodology used in conducting the research. An overall process of preparing all the material, producing samples, curing of the sample and testing involved are explained in detail in this topic. In order to achieve the objectives of this research, palm oil mill have been visited many times to acquire the palm oil industries' by-products that are used for the production of the concrete specimens. The samples that are made of certain shape are casted, produced and cured for 28 days before proceeding with the durability test, which are in term of acid resistance test, sulphate attack test and water absorption test. The processes involved starts from the preparation of material, samples, curing process and testing of the specimens are further interpreted by Figure 3.1.

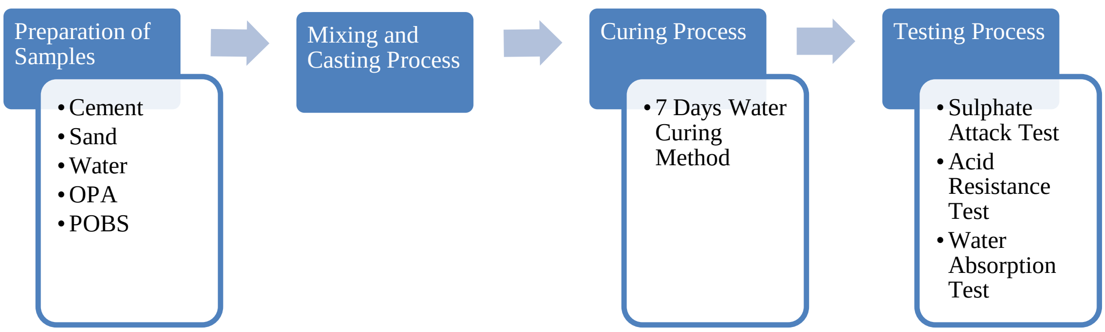


Figure 3.1 Flowchart of work process.

3.2 Raw Material

3.2.1 Cement

For this project, the type of cement used was as in Figure 3.2 which was an Ordinary Portland Cement (OPC). Specifically, the type of the cement was obtained from the YTL Cement Marketing Sdn. Bhd. manufacturer. The brand used was Orang Kuat.

Figure 3.2 Ordinary Portland cement.

3.2.2 Lightweight Aggregate

The aggregate used in this production of concrete for casting usually have a diameter in between 9.5 – 37.5mm. In other words, the aggregate will have to firstly pass the 4.75mm sieve during the sieve test. For this project, the aggregate obtained are firstly oven dried before being able to be used in the production of the concrete for the casting. For this project, it is required that the aggregate to be oven dried for at least 24 hour in the temperature of 110±5℃. After being dry, the course aggregate were tested through a sieve test. This was to make sure the course aggregate pass 10mm but retained at 5mm. the retained aggregate were then used in the production of the concrete.

3.2.3 Oil Palm Ash (OPA)

OPA that was used in the production of concrete was originally collected from a palm oil mill located in Maran, Pahang. Upon collection of the OPA from the palm oil mill, it was firstly oven dried for 24 hours at 110±5℃. Then, it is ground to be very fine.

3.2.4 Water

Water was used as the mixture medium of the all the other ingredients making it an important element in the production of concrete.

3.2.5 Fine Aggregate

The fine aggregate used in this project was sand. The sand obtained from the local sand mining operation that would have a size 4.75mm.

3.3 Mix Proportion

Two types of concrete mix are used in this research. The types used are the plain lightweight concrete with 0% content of OPA that are set as the control specimens and lightweight concrete with various percentage content of OPA. Therefore, the sample will be of 5 different types, which are – 0%, 10%, 20%, 30% and 40% content of OPA as replacement of cement. The details of the mix proportion for the sample is presented in Table 3.1.

Table 3.1 Mix proportion of samples.

Material	OPA LWAC	OPA LWAC with 10% POFA	OPA LWAC with 20% POFA	OPA LWAC with 30% POFA	OPA LWAC with 40% POFA
OPC	480	432	384	336	288
Water	216	216	216	216	216
Sand	750	750	750	750	750
POC	565	565	565	565	565
OPA	0	48	96	144	192
SP	5	5	5	5	5

3.4 Mix Proportion

Before the ingredients of concrete can be mixed, the proper proportion of each ingredient – cement, water, OPA, SP and sand – was weighted. Then, these ingredients were mixed in the mixer in the laboratory. After properly mixing the ingredients, the mixture was put to a slump test. This was to measures the consistency of the concrete before it sets. It was performed also to check the workability of the freshly made concrete mixture that will ease the concrete flows for the casting process. Later on, the mixture was put into the oiled mould of 100 x 100mm cube. These will be done in three layers, for each layer of the mixture will be compacted on the vibrator. The samples will then be set to harden in time. A total of 90 samples were casted. Figure 3.3 shows how the samples are actually prepared. The type of curing used in this project is the initially seven day's water curing method. This method simply required the concrete to be firstly placed in water for duration of seven days. While, from the 28 days duration total of being cured, the concrete will be left air dried with the remaining durations.

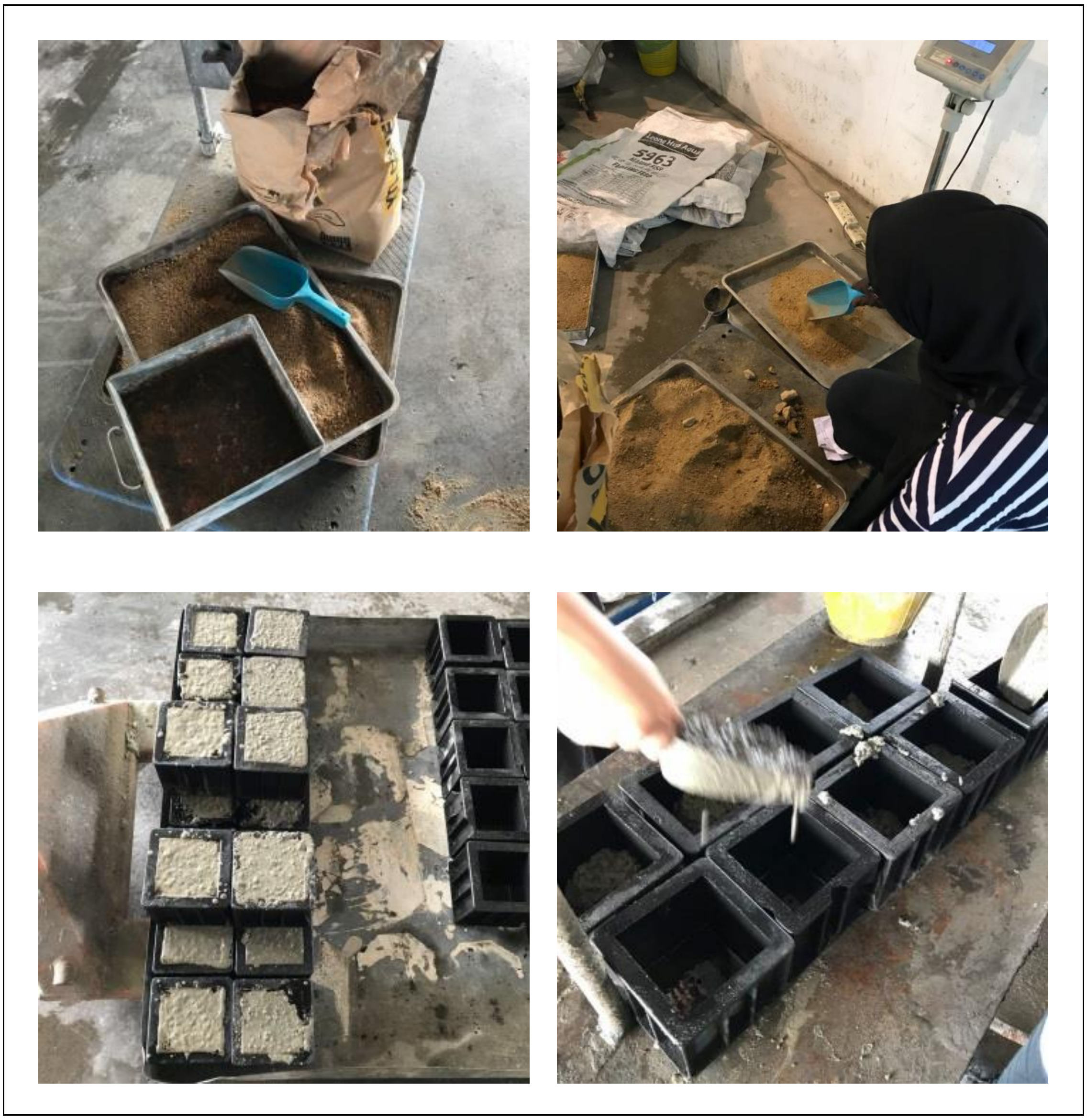


Figure 3.3 Preparation of samples.

3.5 Durability Testing

Upon reaching its mature condition after being cured for certain duration, the concrete will then be ready for testing. There will be four types of testing that will be done on the concrete, which are – acid resistance test, sulphate attack test, compressive strength test and water absorption test.

3.5.1 Sulphate Resistance Test

The samples will be submerged in sulphate solution for 23 weeks period. Through this period, the samples were constantly weighed every 1000 hours of gap. After this certain period, the samples were then be dried and weighed again before going through compressive test to obtain the maximum loading (kN) and strength (Mpa) for that particular cube samples. The solution needs to be checked consistently to make sure that the sample was always submerged in the solution. The percentage mass change during curing period was observed. The comparison between losses of mass of cubes immersed is observed. The test conducted follows the study procedure of past researches (Murthy et al., 2007).

3.5.2 Acid Resistance Test

In this project, the hydrochloric acid solution was firstly prepared. The samples will be submerged in hydrochloric acid solution for a certain period. Through this period, the samples were constantly weighed every 100 hours of gap for 1800 hours (Abdul Awal, 1998). The solution is to be checked consistently to make sure that the sample was always submerged in the solution. The deterioration process of the specimens was followed by a record of visual observations, mass measurement – as shown in Figure 3.4, and compressive strength loss will be monitored. Compressive test – as shown in Figure 3.5, were done upon each samples at the end of the acid resistance test. This test was referred to BSEN 12390-3. According to the reference module, the compression testing machine was the apparatus used to test the compressive strength of the samples after being cured for 28 days.

Figure 3.4 Compressive test in progress.

3.5.3 Water Absorption Test

By referring to BS 1881-122:1983, the water absorption testing on the lightweight concrete was done accordingly. Firstly, for 28 days, the samples were placed in the oven for drying purpose of the sample. This oven drying took around 72±2 hours at the temperature of 105℃. Later on, the samples were cooled down to the room temperature for at least 24±0.5 hours. After that, the samples were weighted, and set as first reading, w1, before being submerged into water for 30±0.5 minutes. The samples prepared were fully submerged in water like in Figure 3.6, for a set time of 30±0.5 minutes. After being submerged in water, the samples were weighted again and the value was recorded as, w2. The water absorption rate is calculated by using the formula in Equation 3.1.

$$\text{Water Absorption (\%)} = \frac{\text{final weight (w2)} - \text{initial weight (w1)}}{\text{initial weight (w1)}} \times 100 \qquad \text{Equation 3.1}$$

w1 The weight of the specimens taken before being submerged in the water

w2 The weight of the specimens after being submerged in the water

Figure 3.5 Water absorption test in progress.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses about the results obtained accordingly to each testing done on the samples for a duration of time. For each testing, very particular observation were made, thus, results in some discussion and conclusion below.

4.2 Sulphate Resistance

Figure 4.1 shows the five different mass changes of LWAC specimens that were initially water cured for seven days at five different percentages content of OPA – 0%, 10%, 20%, 30% and 40% after 23 weeks of immersion in sulphate solution. The specimens with 0% content of OPA were set as the control specimens for this testing. Based on Figure 4.1, the highest mass changes occurs when the content of OPA as partial cement replacement is 40%. The highest rate of mass change is 0.0062%. The lowest rate of mass changes is when the content of OPA is 10%, where the rate is around 0.0033%. The rate of mass changes seemed to be proportionally increase as the content of OPA increase – with the range between 0.0036% to 0.0060% each for the control specimen and between 20% to 40% content of OPA as cement replacement. Based on Figure 4.1 also, although the mass changes seemed to increase gradually all along the week the specimens were submerged in the sulphate solution.

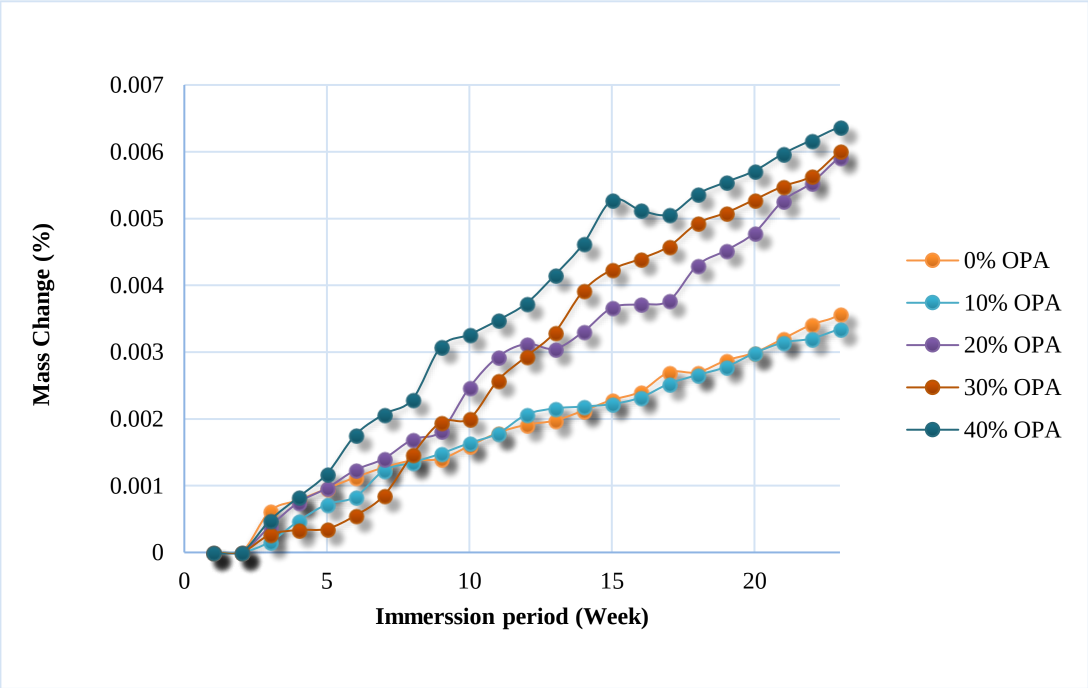


Figure 4.1 Sulphate resistance of seven days initially water cured LWAC with different percentage of OPA at 23 weeks.

Based on the result shown in Figure 4.1, it shows that the integration suitable amount of OPA as partial cement replacement enhances the resistance of LWAC against sulphate attack. The increasing of mass for all types of concrete was increasing at the beginning stage. This is due to the formation of ettringite that fills in the pores of the concrete. However the specimen did not show any change in shape and remained structurally intact without any visible deterioration. The consumption of $Ca(OH)^2$ during the pozzolanic reaction have lowered the amount of $Ca(OH)^2$ available in LWAC with OPA. This has causes the sulphate ion to produce lower quantity of ettringite. The formation of Ettringite results in an increases of volume as it requires more space than the original compounds that they replace. This has somehow creates internal pressure that would causes expansion on the specimens. Since ettringite causes expansion in cement concrete upon exposure to sulphate solution, the larger expansion and cracking resulting more strength deterioration of the control specimen is justified (Bonen et al., 1992). Conclusively, this study shows that the OPA can be integrated as partial cement replacement in LWAC because it enhances the durability of the concrete towards sulphate attack.

4.3 Acid Resistance

The effects of different percentage of OPA as partial cement replacement towards acid resistance of the investigated LWAC were discussed in this section of the chapter. There are three main observations that were done for this involved testing, which are – the visual observation, the mass loss and strength deterioration measurement of the samples accordingly to the testing. The results were obtained from immersed samples in the hydrochloric acid solution for duration of 1800 hours continuously.

4.3.1 Mass Loss

Respectively, Figure 4.2 shows the percentage of mass loss of seven days initially water cured LWAC at five different percentages content of OPA – 0%, 10%, 20%, 30% and 40%. The specimens with 0% content of OPA were set as the control specimens for this testing. Based on the Figure 4.2, the mass for all specimens appear to be decreasing gradually as the HCl immersion period increases. By referring to the graph, at 1800 hours of immersion age, the highest percent of mass loss occur when 40% of OPA is presence in the mixture of the concrete. Besides, the percentage of mass loss is the lowest when the content of OPA is 10% in the mixture of concrete. Apart from that, there have been a rapid changes of mass loss as early as 100 hours immersion ages based on Figure 4.2.

Resistance of a cement matrix to acid corrosion will depend on the pore structure characteristics, ability of the matrix components to neutralize acid and products of acid corrosion (Shi & Stegemann, 2000). Acid attack is the reaction between the acid and the cement component of the concrete – calcium hydroxide ($Ca(OH)_2$). This reaction produces a highly soluble calcium salt as its by-product. And this by-product, which are actually a soluble salt, can be leached out. Without even introducing any internal stresses unto the concrete, leaching of concrete when in contact with acid will eventually affect the mass loss of the concrete and will cause micro cracking. This is because the leaching will loosen the aggregate binding that leads to the dropping of materials from the concrete, thus, reduces its weight.

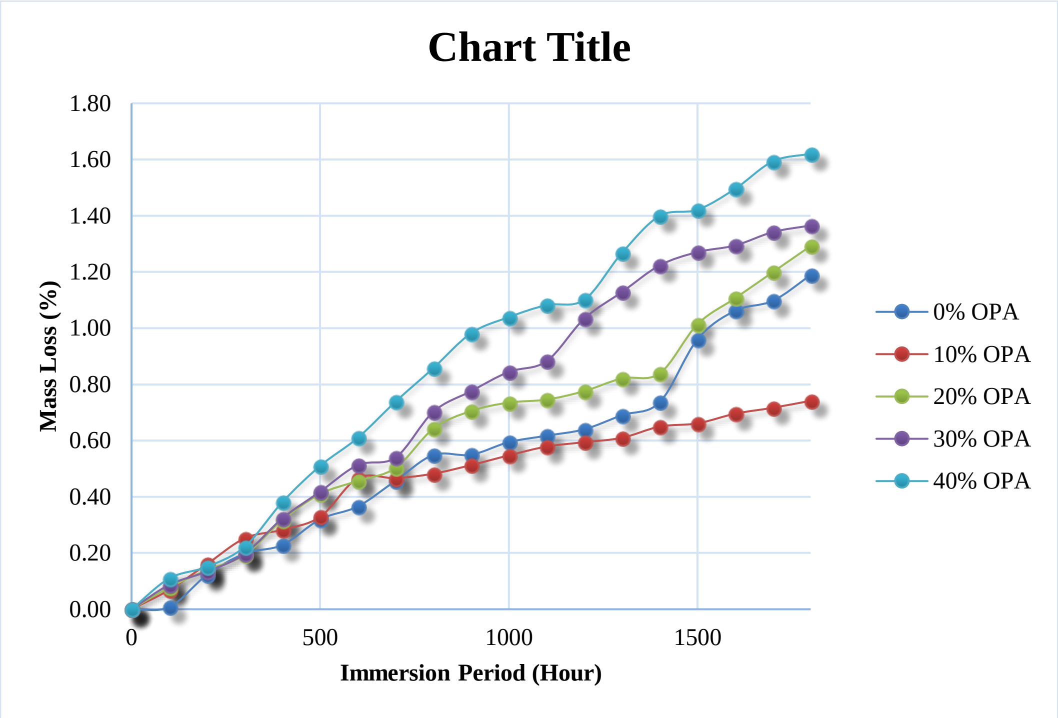


Figure 4.2 Mass loss percentage of seven days initially water cured LWAC with OPA specimens immersed in HCl solution for 1800 hours.

On the other hand, with optimum replacement of pozzolanic materials such as OPA in the concrete as cement replacement, the amount of $Ca(OH)_2$ that is susceptibly vulnerable towards acid attack could be reduce. In addition, $Ca(OH)_2$ produced during hydration process would be consume by silica in OPA converting it into C-S-H gel making the concrete denser which contributes towards increasing of its durability. Only optimum amount of OPA is able to provide resistance towards acid attack. The amount of cement in the mixer would be lower if there is higher amount of OPA used. Sufficient amount of CaO is essential for hydration process to take place. Therefore, if the amount of OPA is not optimum and there is excessive amount of OPA, as partial cement replacement, dryness of fresh state of concrete occur will affect the concrete as it hardens. The dryness of the concrete fresh state will cause difficulty during the compaction process. This will eventually produces undesirable pores that would promote the intrusion of acid into the concrete when immersed in the HCl solution.

4.3.2 Strength Deterioration

Figure 4.3 compares the different strength deterioration of LWAC specimens that were initially water cured for seven days at five different percentages content of OPA – 0%, 10%, 20%, 30% and 40% after 1800 hours immersion in HCl solution. The specimens with 0% content of OPA were set as the control specimens for this testing. Referring to the graph, the strength of the control specimen with 0% OPA content deteriorate about 0.033% after being immersed in HCl solution for 1800 hours. The lowest rate of strength deterioration is when the content of OPA is 10%, where it deteriorate about 0.025%. The rate of strength deterioration seemed increasing with the increasing content of OPA – 0.035%, 0.051% and 0.078% each respectively for 20%, 30% and 40% content of OPA.

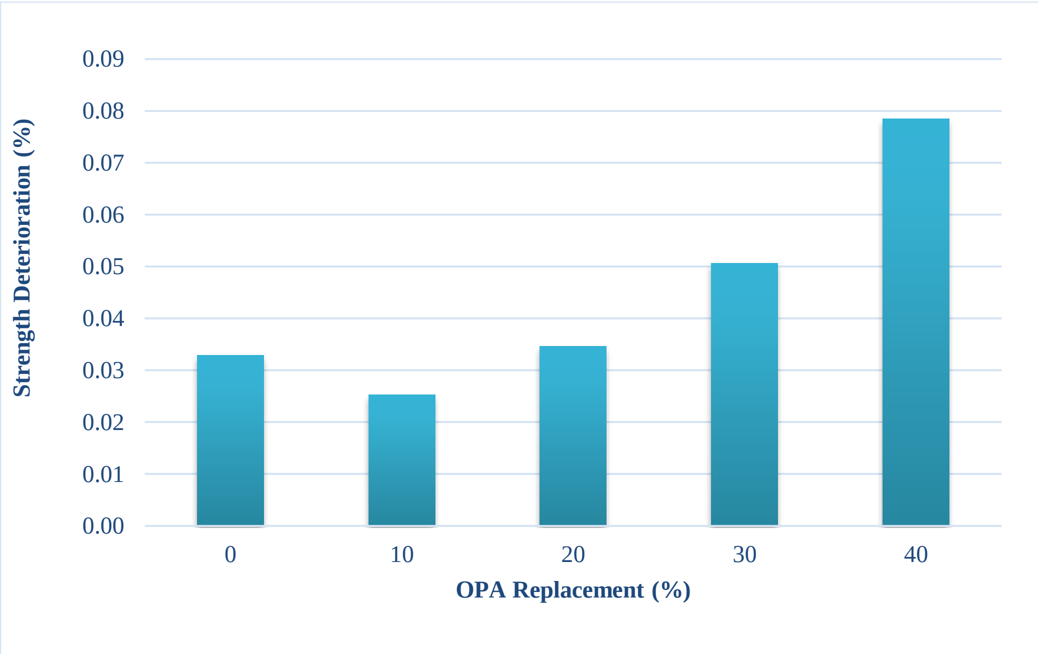


Figure 4.3 Strength deterioration of seven days initially water cured LWAC with OPA immersed in HCl solution for 1800 hours.

The strength deterioration for concrete is reduced when there is an optimum content of OPA in concrete. This indicates that the LWAC specimen is high in durability. The presence of OPA in the concrete results a pozzolanic reaction that generates a large amount of secondary calcium silicate hydrate (C-S-H) gel that fills in the void presence in the structure of the concrete. Sata et al. (2004) found a similar trend where OPA increases the production of calcium silicate hydrate (CSH) by reacting with calcium hydroxide ($Ca(OH)_2$), which improved the strength of the conventional concrete. The generation of the gel resulted from both hydration process and pozzolanic reaction make the concrete more durable against acid. Several studies have been performed to investigate the effect of substitution of Portland cement by OPA on the durability performance of concrete by Tangchirapat et al (2009), Awal et al (1999) and Chindaprasirt (2007). These studies have shown that OPA can be used to improve the durability characteristics of concrete. The decreasing strength in the concrete with higher content of OPA as compared to its optimum content may be attributed due to its lower cement content.

4.4 Water Absorption

Figure 4.4 illustrates the different percentages of water absorption on seven days initially water cured LWAC at five different percentages content of OPA – 0%, 10%, 20%, 30% and 40%. Specimen with 0% content of OPA were the control specimens for the water absorption test. As the result shows, the control specimen's water absorption percentage is 0.46%. While, when the content of OPA in LWAC is 10%, the rate of water absorption is 0.38% and seemed to be the lowest among all of the other specimens. The percentage of water absorption increases as the content of OPA in LWAC increases after 10% content of OPA, which are – 0.53% and 0.56% when the content of OPA is 20% and 30% respectively. And the highest rate of water absorption occur when the content of OPA is 40% which is 0.77%.

In addition to that, when the water absorption rate of a concrete is not more than 10 %, it is classified as high-quality concrete (Neville, 2011). Fortunately, based on Figure 4.4, all the rate of water absorption for specimens were in the range of 0.38 to 0.77 %. Therefore, it is worth mentioning that the water absorption value based on this testing is, in fact, within the range for high-quality concrete that is lower than 10%.

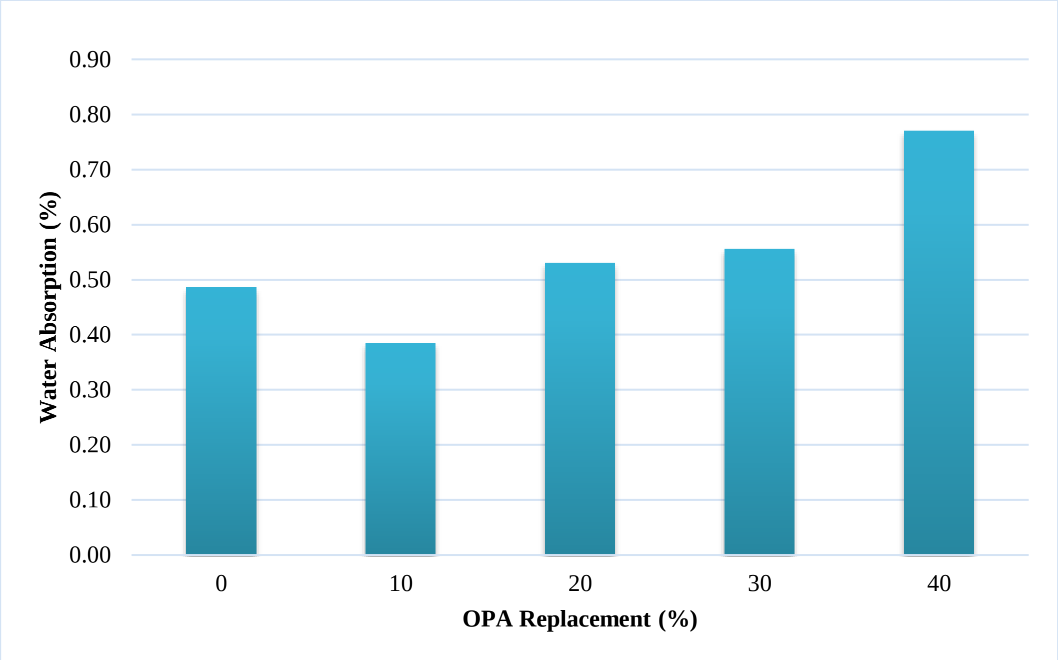


Figure 4.4 Water absorption of seven days initially water cured LWAC with different percentage of OPA at 28 days.

The water absorption has been observed to be decrease with the usage of optimum amount of OPA as compared to the other samples of different content of OPA. This notable effect of using 10% of OPA as content in the concrete included that OPA does contributes in the improvement of concrete microstructure. The reaction of OPA with the free lime has resulted in the creation of more C-S-H gel. Concurrently, the resulted C-S-H gel would fill the internal capillary and micro pores in the cement matrix. Besides, this would somehow made the structure denser than plain concrete. Somehow, this reduced the percentage of water absorption because less voids occupies the space in the concrete as water evaporate. This finding is in confirmation of the results of the study by a researcher (Bui, et al., 2005). Besides, the seven days initial water curing method does promotes early hydration process of cement in the concrete. This allows $Ca(OH)_2$ to be fully used during the pozzolanic reaction that refines the internal structure of concrete.

CHAPTER 5

CONCLUSION

5.1 Introduction

The objective of this study is to investigate the effects of oil palm ash (OPA) as mixing ingredient on sulphate attack, acid resistance and its compressive strength and water absorption of lightweight concrete.

5.2 Conclusion

It can be concluded also that the most optimum content of OPA that can be used as partial cement replacement is only around 10%. Incorporation of OPA in concrete production would environmentally reduce the numbers of dumping site needed for palm oil waste and cost for its management.

5.2.1 Sulphate Resistance

The uses of optimum OPA as cement replacement in concrete contributes to its increases of strength and durability toward sulphate attack. The mass losses is the lowest when optimum content of OPA is used. If beyond 10% of OPA is used in the production of concrete, the resistance toward sulphate will be reduced.

5.2.2 Acid Resistance

The uses of optimum content of OPA as replacement of cement in concrete contributes to the increases of strength of concrete when in contact with acid for some duration of time. The concrete strength is the highest with optimum OPA content used. In addition, the mass losses is the lowest with the optimum uses of OPA. However, if too much of OPA is used in the production of lightweight concrete, it would reduce the resistance of concrete toward acid.

5.2.3 Water Absorption

With the uses of optimum OPA as partial cement replacement in concrete the rate of water absorption is lowest, thus, help in improving the microstructure of the concrete. Excessive uses of OPA in the concrete production will make the concrete less dense than a plain concrete.

5.3 Recommendation for Further Study

Based on this study, it is recommended that further study of the concrete should be done in other scope of durability. There are many interesting topic that can be further investigated regarding the LWAC with OPA, such as follows:

i. Investigation of the durability performance of LWAC with OPA against corrosion and chloride penetration.
ii. Investigation of the durability performance of LWAC with OPA when placed in seawater environment.

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