PROPERTIES OF CONCRETE CONTAINING PALM OIL FUEL ASH (POFA) AS PARTIAL SAND REPLACEMENT

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PROPERTIES OF CONCRETE CONTAINING UNGROUND PALM OIL FUEL ASH (UPOFA) PARTIAL SAND REPLACEMENT

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Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2017

ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to the God for the good health and wellbeing that were necessary to complete this thesis. Besides, I would like to express my highest thanks and deepest appreciable to my supervisor, Assoc. Prof. Dr Khairunisa Muthusamy for the continuous support of my Bachelor's study and related research, for her patience, motivation, and immense knowledge. Her guidance helped me in all the time of research and writing of thesis. I could not have imagined having a better advisor and mentor for my research.

Moreover, I would like to thank Kilang Sawit LCSB Lepar for their kindness in supplying the palm oil fuel ash for this research. Next, I would like to express my heart full thanks to my friends, especially to Tamilvaanan and Dhijeedthiran who helped, motivated, and supported me in conducting the laboratory tests throughout the research.

I would like to extend my gratitude to the technicians of the concrete laboratory for their help and guidance throughout the research. Last but not the least, most importantly, none of this would have been possible without the love, continuous support and patience of my family. I would love to express my heartfelt gratitude to my parents, Mr. Paramasivam and Mrs. Kamala who always stand by there and being my pillar of strength all the time.

ABSTRAK

Sebagai pengeluar minyak kelapa sawit yang kedua terbesar di dunia, Malaysia mengeluarkan pembaziran harian yang terlalu banyak. Abu minyak kelapa sawit (POFA) biasanya didapati sebagai bahan buangan pertanian yang dibuang di tapak pelupusan sampah. Dijangka sebanyak 10MT/tahun POFA dihasilkan di Malaysia sahaja dan jumlah ini semakin meningkat setiap tahun. Di samping itu, untuk memenuhi permintaan industri pembinaan yang berleluasa, perlombongan pasir sungai juga semakin meningkat dan ini menyebabkan pelbagai masalah ekologi. Motif kajian ini adalah untuk mengurangkan perlombongan pasir sungai dan pencemaran alam sekitar yang disebabkan oleh POFA dengan menggantikan sebahagian daripada pasir dalam konkrit dengan POFA. Objektif kajian ini adalah untuk menyiasat kesan POFA sebagai separa pengganti pasir terhadap kekuatan mampatan, kekuatan tegangan pecah, penyerapan air dan asid rintangan konkrit. Untuk campuran konkrit, ia mengandungi pelbagai peratusan POFA iaitu 5%, 10%, 15% dan 20%. Saiz spesimen yang digunakan dalam eksperimen ini ialah kuib (100 x 100 x 100) mm dan silinder dengan diameter 100mm dan ketinggian 200mm. Spesimen yang telah tertakluk kepada rendaman air selama 28, dan 60 hari bagi ujian kekuatan mampatan dan ujian kekuatan tegangan. Bagi ujian penyerapan air, tempoh rendaman adalah 28 hari. Untuk ujian rintangan asid, kiub konkrit direndam selama 28 hari dalam air dan kemudiannya direndam dalam larutan asid hidroklorik selama 1800 jam dan seterusnya bacaan diambil bagi setiap 100 jam. Kajian dengan menunjukkan integrasi 10% POFA sebagai separa pengganti pasir dapat menghasilkan konkrit yang berkualiti dari segi kekuatan mampatan dan kekuatan tegangan pecah. Selain itu, konkrit yang mengandungi POFA menyerap lebih banyak air berbanding konkrit biasa. Apabila peratusan POFA yang digunakan di dalam konkrit semakin meningkat, peratusan air yang diserap oleh spesimen konkrit tersebut juga meningkat. Akhirnya, konkrit yang mengandungi 10% POFA sebagai separa pengganti pasir adalah mempunyai rintangan asid yang lebih baik daripada konkrit kawalan.

ABSTRACT

As the second largest global palm oil producer, Malaysia has the massive daily wastage. Palm oil fuel ash (POFA) is commonly found as agricultural waste that is uncontrollably dumped in landfills. An expected 10MT/year total POFA waste is produced in Malaysia alone and this amount rises every year. Besides, extensive mining of natural river sand in large amount to meet the increasing demand of concrete production for the use in rapidly developing construction industry has posed the risk of natural aggregate depletion and ecological imbalance in future. The motive of this kresearch is to reduce the river sand mining and environmental pollution caused by POFA by partially replacing the POFA with sand in concrete. The objectives of this study is to investigate the effect of POFA as partial sand replacement on compressive strength, splitting tensile strength, water absorption and acid resistance of the concrete. For modified mix the concrete contained various percentages of POFA which is 5%, 10%, 15% and 20%. The moulds that were used in this experiment were cube moulds (100 x 100 x 100) mm and cylinder moulds with diameter of 100mm and 200mm in height. The specimens were subjected to water curing for 28, and 60 days for compressive strength test and splitting tensile strength test. For water absorption test, the testing age was 28 days. For acid resistance test, the concrete cubes were water cured for 28 days and then immersed in Hydrochloric acid solution for 1800 hours and reading was taken for every 100 hours. The study efficiently shows that integration of 10% POFA as partial sand replacement is able to produce good quality of concrete in terms of compressive strength and splitting tensile strength. Moreover, concrete containing POFA absorbs more water than plain concrete. Increase the percentage of POFA used in concrete causes the increase in the percentage of water absorbed by the concrete specimens. Lastly, acid resistance of concrete containing 10% of POFA as partial sand replacement is better than the control concrete.

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LIST OF SYMBOLS

Mg	Magnesium
Cr	Chromium
Fe	Ferum
Al	Aluminium

LIST OF ABBREVIATIONS

POFA	Palm Oil Fuel Ash
UPOFA	Unground Palm Oil Fuel Ash
GPOFA	Ground Palm Oil Fuel Ash
HCl	Hydrochloric acid
SEM	Scanning Electron Microscope
OPC	Ordinary Portland Cement
FFB	Fresh Fruit Bunches
CPO	Crude Palm Oil
FAO	Food and Agriculture Organization
MPOC	Malaysian Palm Oil Council
MPOB	Malaysia Palm Oil Board
OPS	Oil Palm Shell

CHAPTER 1

INTRODUCTION

1.1 Introduction

Construction industry contributes altogether towards environmental degradation, and governments in numerous countries which are attempting to address the circumstance. Malaysia is no exception. Concrete is by a wide margin the most essential building material. Overall more than 10 billion tons are delivered every year. Appropriately produced concrete has great mechanical and durability properties. In any case, concrete enormously affects nature. In addition, the river sand has been utilized for the most part as fine aggregates as a part of development of pavements and other structures. Due to the fast development of the infrastructural development on the earth urges the request for river sand (Krishna Rao and Sravana, 2016). Additionally, as the supply of appropriate regular sand material close to the part of construction is getting to be depleted. The expense of the sand is also expanding.

On the other hand, Malaysia is the world second largest palm oil production. Moreover, our country accounts for the one of the largest producers and exporters of palm oil in the world. Khankhaje *et al*. (2016) has claimed that huge amounts of solid waste by-products in different forms such as kernels, fibers and empty fruit bunches are produced along with the crude palm oil. It is estimated that to produce one kg of palm oil, approximately four kg of dry biomass is produced. So, to save energy and fuels, these waste materials are frequently singed and utilized as a part of warming up the boilers to create power in palm oil production lines. This waste includes ash from fibers and shells which is known as palm oil fuel ash (POFA).

1.2 Problem Statement

As the second largest global palm oil producer, Malaysia has the massive daily wastage. Palm oil fuel ash (POFA) is commonly found as agricultural waste that is uncontrollably dumped in landfills. An expected 10MT/year total POFA waste is produced in Malaysia alone and this amount rises every year (Awal and Hussin, 2011). Nowadays, POFA use is exceptionally constrained and unmanageable, and vast majority of it is discarded in landfills. Subsequently, it has created various ecological issues, health-related issues and also financial issues. Al-Oqla and Sapuan (2014) found that the utilizing the waste from the palm oil industry as composite material will not only enhance sustainability but will also solve the huge issues resulting from waste problems. Moreover, many researchers have revealed that this agro waste contains massive amount of silicon dioxide in amorphous form and could be utilized as partially replacement for sand or cement.

Besides, sand mining is one of great importance to the Malaysian economy. It ought to, however, be perceived that the procedures of prospecting, extracting, concentrating, refining and transporting minerals have great potential for disrupting the natural environment (Rabie *et al.*, 1994). The morphologies of the mining territories have exhibited the effect of mining with the ability to crush the cycle of ecosystems. Physical effects of sand mining incorporate reduction of water quality and destabilization of the stream bed and banks. Mining can likewise upsets silt supply and channel structure, which can lead in a deepening of the channel and additionally sedimentation of habitats downstream. This process can also destroy river line vegetation, cause erosion, pollute water sources and reduce the diversity of animals supported by these woodlands habitats (Byrnes and Hiland, 1995).Therefore, the recommendation made in this paper is to partially replace sand with unground palm oil fuel ash (UPOFA) in concrete and determine its properties.

1.3 Objectives

The objectives of the study are as follows:

i. To investigate the compressive strength of concrete containing various content of unground POFA as partial sand replacement.

ii. To investigate the splitting tensile strength of concrete containing various content of unground POFA as partial sand replacement.

iii. To investigate the water absorption and acid resistance of concrete containing various content of unground POFA as partial sand replacement.

1.4 Scopes of Research

This research focused on investigating the properties of unground POFA as partial sand replacement in concrete. The concrete properties those were determined through compressive strength test, splitting tensile strength test, water absorption test and also acid resistance test. In this study, two mixes had been used. Firstly, plain OPS concrete were containing 100% river sand, aggregates, water and OPC as a control mix. Another four concrete contained UPOFA as partial sand replacement, aggregates, water and OPC. The unground POFA replacement percentage is 5%, 10%, 15% and 20%.

For compressive strength test, splitting tensile strength test, water absorption test and acid resistance test, concrete cubes and cylinders had been casted in cube moulds of (100 x 100 x 100) mm^3 and cylinders moulds of 100mm of diameter with 200mm of height which contained the UPOFA as partial sand replacement with ratio of 5%, 10%, 15% and 20% respectively. After the cubes and cylinders were casted and demoulded, the specimens had been water cured. After 28 days the some concrete has been used for water absorption test and acid resistance test. Then, the compressive strength test, and splitting tensile strength test were conducted on 28^{th} and 60^{th} day of water curing. All the test and experiments were conducted according to the existing standards.

1.5 Significance of Research

The main motive of this research is to reduce the environmental pollution that caused by palm oil fuel ash (POFA). Moreover, we also can save the space in landfill and transform this waste into fortune. This is possible when we partially substitute the unground POFA with sand. Therefore, we can reduce the depletion of river sand. Consequently, flash flood and water pollution caused by river sand mining could be avoided. In addition, partially replacing the POFA with sand in concrete can make the concrete to be stronger compared to normal concrete.

1.6 Layout of Thesis

The research paper outline is as follows with contents of five chapters. Firstly, Chapter 1 discussed about the introduction to the research to provide general explanations to reader about the research. The brief introduction has been given towards concrete containing unground palm oil fuel ash as partial replacement for sand. The information about the problem statement and objectives of the research has been provided in this chapter. Moreover, the scoped and significance of the study also presented in this chapter. Next, Chapter 2 explained more about the research topics in terms of techniques and methods that have been used in the research. This chapter presented the literature review and a short brief about the issues investigated in this study. In additionally, it focused on research done by previous student or researchers and finally the conclusion of the literature review also included.

Later, Chapter 3 the research's framework, and methods that have been taken as a part of the flow work to conduct the research has been discussed. It presented the methodology, materials and experimental work during research. The specific methods for each work elaborated in this study and the existing standard available were referred. Then, Chapter 4 recorded and stated all the results from the implementation of the methodology in Chapter 3. All the results from test presented in form of graphs and pictures. Chapter 5 served as the last chapter that concluded the research whether achieve the objectives and listed out the research constrains with any future works that has been done towards this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

After water, concrete is the most broadly utilized construction material on the earth (Gambhir, 2004), with a worldwide consumption rate of around 25 x 10^9 metric tons (25 gigatons) per year. All around, 40% of the energy consumption is credited with building operations, which contributes 40% of greenhouse gas emissions (Lippiatt, 2007). The huge consumption of non-renewable natural materials and the greenhouse gas emissions connected with concrete production exert substantial environmental impact. There is probably cleaner and more proficient management of different types of waste generation is getting more consideration in order to keep up sustainability in green construction.

Therefore, the usage of waste materials is one of the central issues of waste management method in numerous parts of the world. The benefits of recycling include reducing environmental pollution, diminishing land filling and disposal of waste and preserving natural resources (Thomas and Gupta, 2013). Mechanization and technological inventions produce massive amount of waste materials from pre-and post-consumers products every year. In the construction industry, the possibility of sustainability empowers the utilization of waste materials to replace crude materials, for example, fine and coarse aggregates, cement, and fibrous materials. This prompts sustainability, green and environmental friendly construction by decreasing the cost of the components contrasted with disposing the materials (Onuaguluchi and Panesar, 2014). As we all know we are having crisis in depletion of natural resources especially in river sand mining. Moreover, the by-products that are produced in palm oil mill also causing lot of problems to our environment and human being. So that, I suggested that partially replacing the sand with UPOFA will maintain the sustainability of construction.

2.2 Sustainable Construction

As Malaysia expects to be a developed nation by year 2020; the construction industry has since been distinguished as a noteworthy catalyst for the country to accomplish the status. It is one of the segments that add to most environmental contaminations. It is, accordingly, vital for the construction industry to actualize sustainable construction practices to lessen the negative effects that it has on the environment (Yoong *et al.,* 2014). Building and structures empowered mankind to meet their social requirements for shelter, to address economic issues for venture and to fulfill corporate destinations. In any case, the satisfaction of these needs usually comes with a high price like an irreversible harm to our surroundings.

On the other side, the construction industry is likewise an industry that adds to the vast majority of the negative effects to the environment, for example, soil erosion and sedimentation, flash flood, depletion of natural resources and the utilization of building materials which will influence human wellbeing (Yoong *et al.,* 2014). This lead to a developing realization around the globe to adjust or enhance our traditional method for advancement into a more dependable methodology which can fulfil our requirements for improvement without harming the world we live in. The concept of sustainability in building and construction has at first centered around issues of constrained assets particularly energy, and on the best way to diminish impacts on the natural environment with emphasis on specialized issues (Figure 2.1), for example, materials, building components, construction technologies and energy related design concepts (Nazirah, 2009).

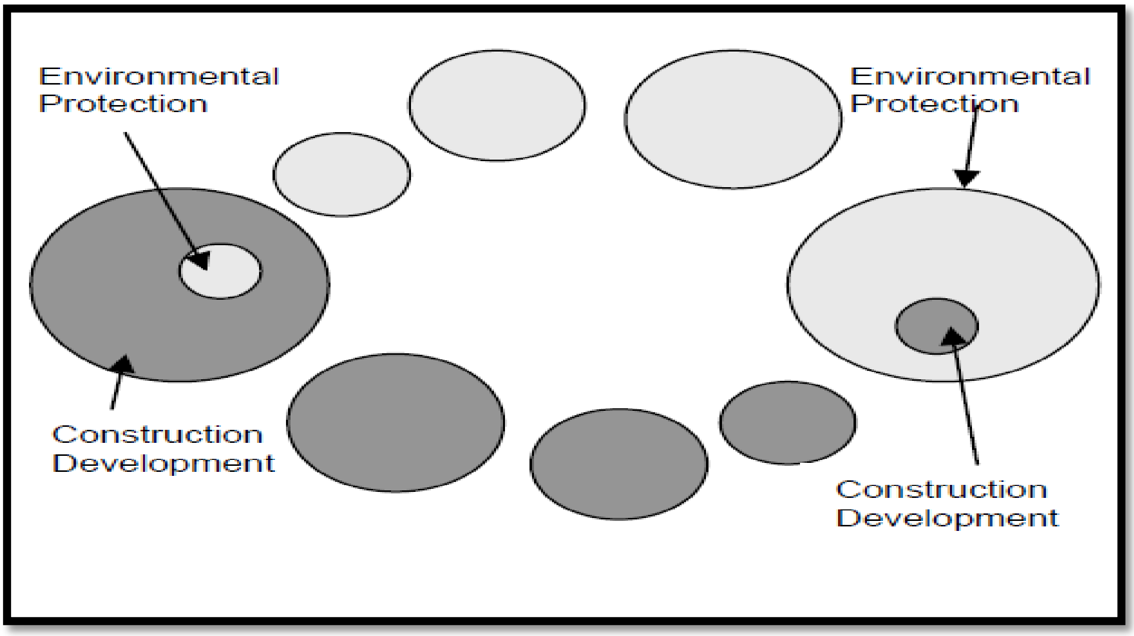

Figure 2.1 The movement for sustainable construction

Source: Nazirah (2009)

2.3 Sand Mining

Sand mining is the removal of sand from their natural configuration. Sand is utilized for a wide range of projects like land recoveries, the construction of artificial islands also, coastline adjustment. These projects have economic and social benefits; however, sand mining can likewise have natural issues. Ecological issues happen at the point when the rate of extraction of sand, gravels and other materials surpass the rate at which characteristic procedures create these materials. Moreover, physical effects of sand mining incorporate lessening of water quality and destabilization of the stream bed and banks.

Besides, mining can likewise upsets dregs supply and channel structure, which can bring about deepening of the channel and in addition sedimentation of natural surroundings downstream (Figure 2.2). In addition, channel insecurity and sedimentation from instream mining likewise can damage public infrastructure. The morphologies of the mining regions have shown the effect of mining with the ability to annihilate the cycle of biological systems. Various distributions have been written concerning these impacts and the following step is the thing that to do to minimize, prevent or remedy these ecological impacts, the so called mitigating measures (Pielou, 1966).

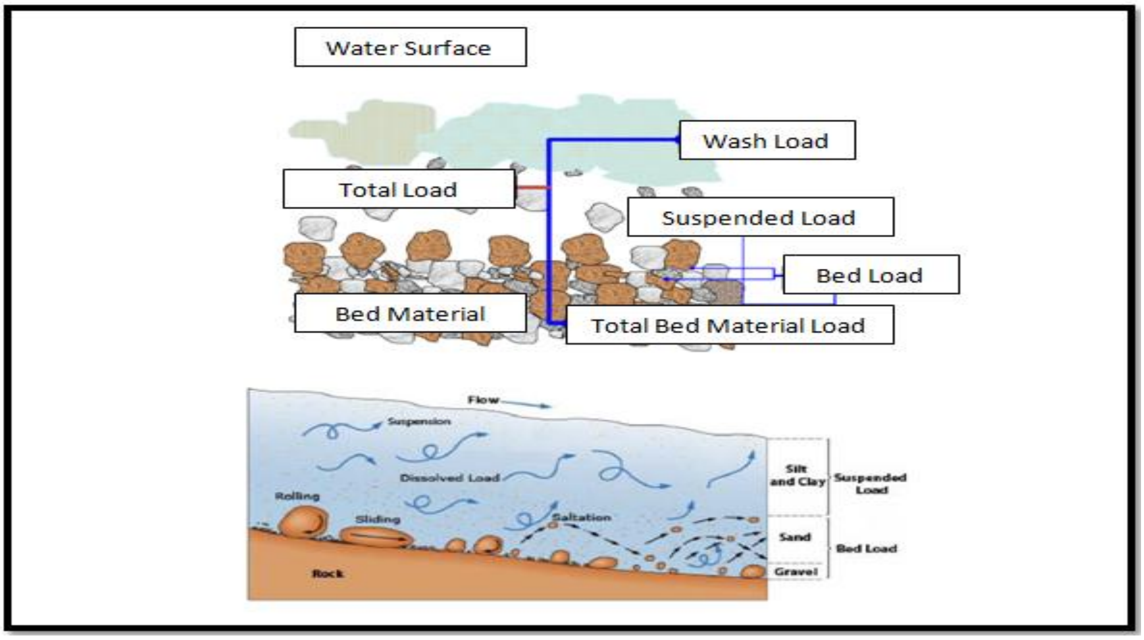

Figure 2.2 Modes of sediment transport in river
Source: Ashraf *et. al* (2011)

2.3.1 Sand Mining Globally

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles under the influence of weathering and abrasion. The most well-known common procedure of sand development is weathering which includes concoction, mechanical and organic procedure in breakdown of rock masses (Basavarajappa *et al*., 2014). Sand accumulation as layers in river courses is a dynamic phenomenon. Sand is crucial for the presence of the rivers. Riverbeds, streams, channels, shorelines are amazing wellsprings of sand. At the point when sand is naturally formed; the particles are generally angular and sharply pointed however they frame bit by bit littler also, more adjusted as they turn out to be continually exhausted by the wind or water. Sand has turned into an important mineral for the extension of society. In addition, sand is one of the segments of the riverbed furthermore a construction material with high economic value. Globally, between 47 and 59 billion tonnes of material is mined every year (Steinberger *et al.*, 2010).

Surprisingly, although more sand and gravel are mined than any other material, reliable data on their extraction in certain developed countries are available only for recent years (Krausmann *et al.,* 2009). Sand resources are a lot in a few streams, for example, the Yangtze River and Pearl River in China. Since the start of the most recent century, illegal sand mining activities have been uncontrolled in numerous streams in China and India (Figure 2.3), which have brought on a massive threat to the safety of levees. Illegal sand mining activities occurring before 2000 seriously consumed the lower portion of this levee and its base was vigorously incised, which threatened the safety of the levee. Under these conditions, a landslide finally occurred in February of 2001, creating a river waterway (Wang et al. 2004). Lake Poyang, the largest freshwater lake in China, is a distinctive site for biodiversity of international importance, including a Ramsar Wetland. It is also the largest source of sand in China (De Leeuw *et al.,* 2010) and, with a conservative estimate of 236 million cubic meters a year of sand extraction, may be the largest sand extraction site in the world.

Figure 2.3 Massive river sand mining in Amaravathu, India
Source: The Hindu (2012)

By comparison, the three largest sand extraction sites in the United States (Table 2.1) combined represent 16 million cubic metres a year (De Leeuw *et al.,* 2010). Sand mining has led to deepening and widening of the Lake Poyang channel and an increase in water discharge into the Yangtze River. This may have influenced the lowering of the lake's water levels, which reached a historically low level in 2008 (De Leeuw *et al.,* 2010). The city of Dubai in the United Arab Emirates is among the world's most stupendous architectural developments, yet one that has put noteworthy pressure on marine aggregates. The Palm Jumeirah, an artificial set of sand islands (Figure 2.4), required 186.5 million cubic meters (385 million tons) of sand and 10 million cubic meters of rock, and cost US$12 billion (Jan De Nul , 2013). Its own marine sand assets being depleted, Dubai imported sand from Australia, for instance, to manufacture the Burj Khalifa tower (Delestrac, 2013), the highest building on the planet at 828 meters. Therefore, we need to find one solution to reduce the mining of river sand before problems go worst.

Table 2.1 Industrial sand and gravel production in United States

Salient Statistics – United States	**2011**	**2012**	**2013**	**2014**	**2015**
Production	43,800	50,600	62,100	110,000	94,900
Imports for consumption	316	306	160	244	300
Exports	4,330	4.360	2,960	4,450	4,500
Consumption, apparent	39,800	46,600	59,300	106,000	90,700
Price, average value, dollars per ton	45.74	52.80	55.80	74.80	86.93
Employment, quarry and mill, number	3,000	3,500	3,800	4,000	3,800

Source: U.S. Geological Survey, Mineral Commodity Summaries (2016)

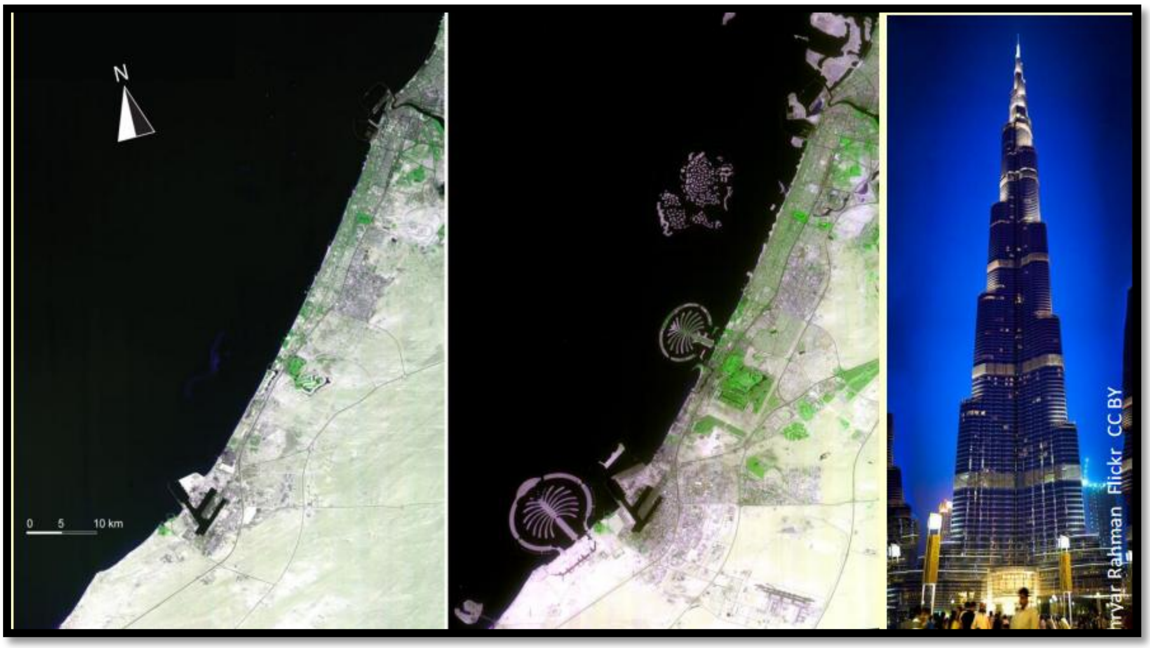

Figure 2.4 Left: Dubai February 2002 ASTER image. Right; July 2012 ASTER image and the two Palm island.

Source: Delestrac (2013)

2.3.2 Application of Sand

Sand is a standout amongst the most imperative non-living resources on the world's surface. The sand development is recorded just in the late periods of the world's history. Sand has turned into an essential mineral asset in our society because of its applications in different fields. Sands of river streams have not a viable replacement for use as building material in reinforced concrete cement. It can be utilized for making concrete, filling roads, building sites, brick-making, glass industries, sandpapers, reclamations to replace eroded coastline and etc (Basavarajappa *et al.*, 2014**).** Sand is a largest component of properly mixed concrete.

Of course, sand is a major part of the concrete and without the sand, concrete won't work as proposed. The properties of a particular concrete mix will be determined by the extent and sort of sand used to cast the concrete. Sand is normally a bigger part of the mix than cement. Sand is the common element for masonry mortars despite the fact that assortments of cementitious materials are utilized for mortars. Sand constitutes the majority of the mortar volume. Composition of sand and its evaluating can impact the characteristics of mortars in fresh and also in solidified state. Additionally, it could impact brick–mortar bond and other mansory attributes (Venkatarama *et al.*, 2007).

Besides, sand also can be used to make artificial reefs. Geotextile stowed sand can serve as the establishment for new reefs. River sand also can be used to construct artificial island, as in the Persian Gulf (Figure 2.5) for occurrence, often created by Arab states such as UAE for commercial reasons or as tourist resorts. Engine drivers and rail travel administrators use sand to enhance the footing of wheels on the rails. Furthermore, sand also can be utilized to do sandbags. These ensure against surges and gunfire. The modest packs are easy to transport when empty, and unskilled volunteers can rapidly fill them with nearby sand in crises. Lastly, sand is also vast used in landscaping for making little slopes and slants.

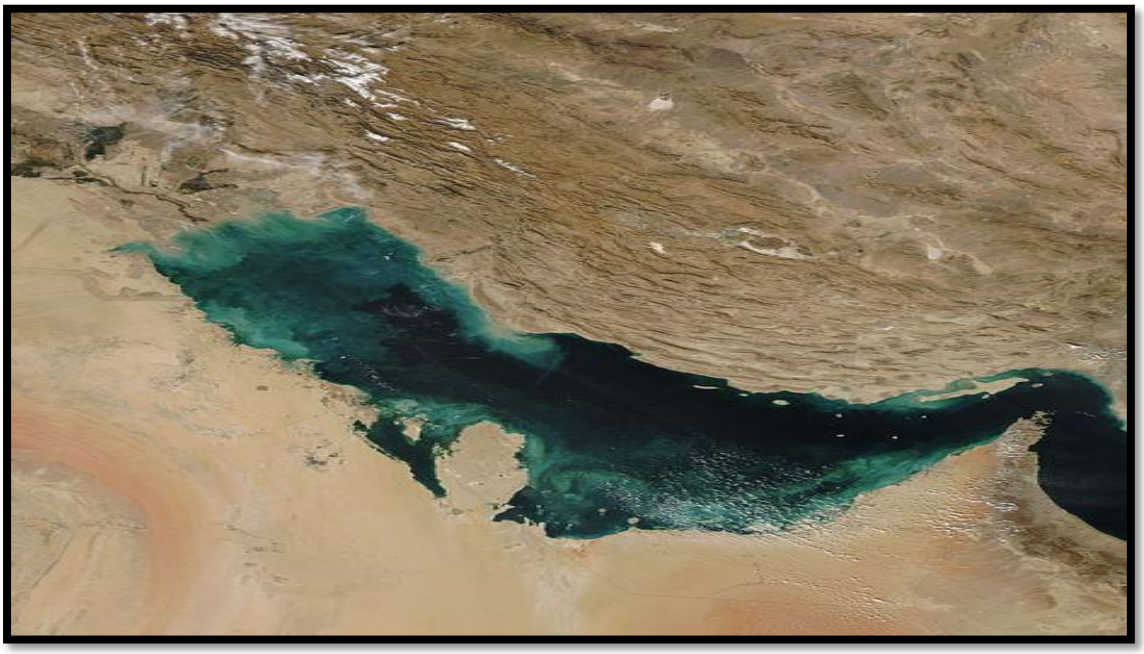

Figure 2.5 Satellite views of artificial islands in Persian Gulf
Source: EAWorldView (2010)

2.3.3 Negative Effects of Sand Mining

Naturally, sand has turned into an essential mineral for our society because of its numerous usages. The river sand has been utilized chiefly as fine aggregate in the construction of pavements and other structures. Because of the fast the growth of the infrastructural development in the world forces the demand for river sand. Additionally as the supply of suitable natural sand material near to the part of the construction is getting to be depleted, the expense of the sand is expanding (Krishna Rao *et al.*, 2016). Because of its expanding viable demand, sand is being over extracted at different depths varying from three to forty feet, from different river streams and basins (Manjunatha, 2014).

However, these impacts specifically on the river habitats, for example, the riverbed lose its capacity to hold water and influences groundwater threat to river banks and close-by structures and premature failure of irrigation wells associated in farming causes erosion or degradation of the rivers or nearby environment (Rinaldi *et al.*, 2005). In addition, if sand is extracted in quantities higher than the capacity of river to replenish them; that directly impacts on velocity, flow regime, river bed level, bank erosion, eco-system, migratory system, extinction of species, fish breeding and more others. On the contrary, wash-water release, storm runoff, and dredging activities from inappropriate sand and rock operations can increase the turbidity of streams. Turbidity is by and large most noteworthy at dredging destinations or wash-water discharge focuses. Turbidity diminishes with distance downstream, and can be controlled by containing runoff and by filtering or containing wash water.

For instant, numerous Selangor streams, rivers and their floodplains have rich amounts of sand and gravels that are mined advantageously and financially for an assortment of employment (Ashraf *et al.*, 2011). Frequently the conditions forced on the endorsement for sand mining activities are expressed in regulatory terms, without technical consideration of their potential effect on the biological system. Moreover, physical disturbance of the habitat caused by dredging activities includes generation of noise, which can interrupt breeding activities (Ashraf *et al.*, 2011). Yet, water temperature and dissolved oxygen of streams can be changed if in-stream mining lessens water speed or spreads out the stream over shallow territories. Indeed, sand mining in river channels can harm public and private property. Channel incision caused by sand mining can undermine bridge piers and uncover covered pipelines and other infrastructures.

In addition, instream sand mining activities will have an effect on the river's water quality. Impacts incorporate expanded short-term turbidity at the mining site because of resuspension of residue, sedimentation because of stockpiling and dumping of overabundance mining materials and natural particulate matter, and oil slicks or spillage from exhuming apparatus and transportation vehicles. Expanded riverbed and bank erosion increments suspended solids in the water at the removal site and downstream. Thus, suspended solids may adversely affect water users and aquatic ecosystems. Suspended solids can altogether increment water treatment costs.

Aside from water quality, sand mining changes the riverbeds into huge and profound pits; subsequently, the groundwater table drops leaving the drinking water wells on the banks of these streams dry. Bed corruption from instream mining brings down the rise of stream flow what's more, the floodplain water table which in turn can eliminate flow depth and a bar skimming operation expands stream width (Ashraf, 2010). Other than that, heavy equipment, processing plants and rock stockpiles at or close to the extraction site also caused side effects to environment. Heavy equipment additionally causes soil compaction, in this manner expanding disintegration by decreasing soil invasion and bringing about overland stream (NMFS, 1998).

2.4 Palm Oil Industry Globally

Oil palms are initially from West Africa, however were conveyed to South-East Asia toward the start of the twentieth century. The essential demand for the business' development originated from the British Industrial Revolution. At the time, 250,000 tons of palm oil was being sent out yearly from South-East Asia. This figure has ascended to more than 60,000,000 tons today. Malaysia was the world's biggest maker of palm oil by the mid twentieth century and this stayed true until the Indonesian government started putting into the business in the 1970s.

Palm oil is an essential and adaptable crude material for both food and non-food industries, representing more than 28 million tons of the world's yearly 95 million tons of vegetable oil (RSPO, 2006). Therefore, the production of palm oil has continued to grow dramatically (Figure 2.6). Palm oil is utilized as a part of different nourishment products, for example, cooking and frying oils, margarine, shortenings, vanaspati (vegetable ghee), non-dairy creamer and ice cream, frozen yogurt, treats, wafers, cake mixes, icing, instant noodles, biscuits, and so on. (MPOC, 1996). A few mixes have been created to deliver strong fats with a zero substance of trans-unsaturated fats (Berger, 1996). Non-food uses of palm oil and palm part oil are either directly or through the oleochemical course. Coordinate applications incorporate the utilization of unrefined palm oil (CPO) as a diesel fuel substitute, drilling mud, soaps and epoxidised palm oil products (EPOP), polyols, polyurethanes and polyacrylates (Salmiah, 2000).

Palm oil is likewise utilized for non-sustenance items critical applications, for example, diesel, motor greases, base for beauty care products, and so on. (Head servant, 2006).

This development authoritatively pushed the nation into the lead spot for top producer in 2007. The country now supplies most of the world's developing interest for this cheap edible oil. Indonesia has been worldwide the biggest palm oil producer. Palm oil production also contributes benefits to the country. The economic status of the country will increase. The more the country produces palm oil, the more the demand from other country. Moreover, when there is more palm oil industry, more people will be employed. Therefore, the number of poor people will reduce. According to Food and Agricultural Organization (2002), the fresh fruit bunches (FFB) are produced as end products which are crude palm oil (CPO) and palm kernel after being received from the oil palm plantations. Normally, a few palm oil mills in Malaysia include kernel crushing facilities in order to crush the palm oil kernel into palm kernel oil. However, by-product is produced throughout the crude palm oil and palm kernel production process. Thus, this study discusses the extraction process and the sources of pollution of Malaysia palm oil mills Figure 2.7 shows the process flow diagram for the extraction of crude palm oil.

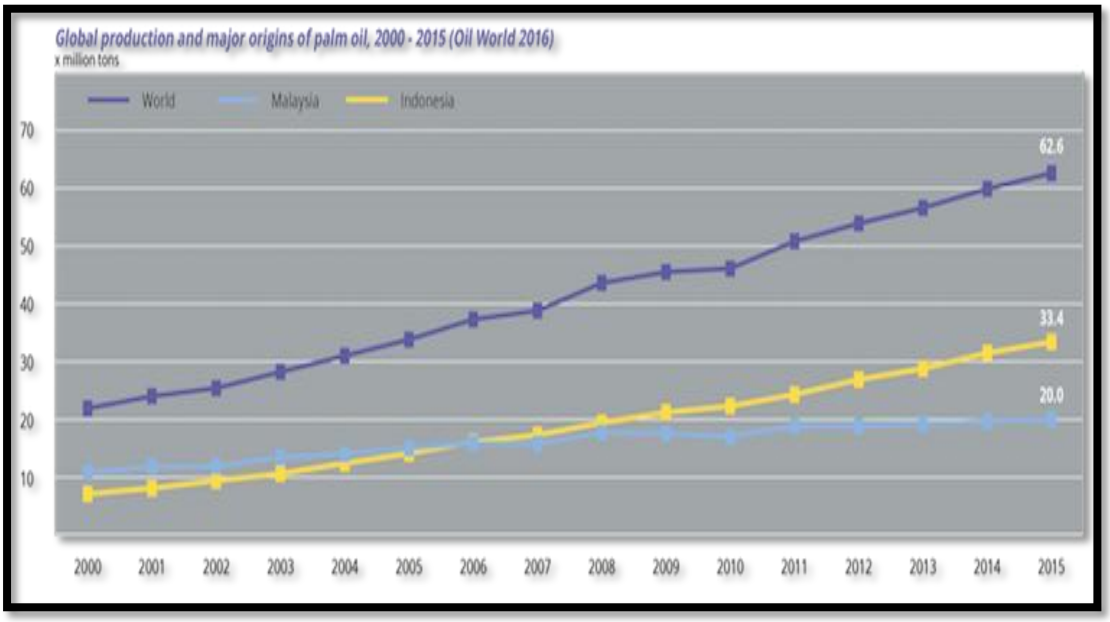

Figure 2.6 Global production and major origins of plam oil
Source: European Palm Oil Alliance (2006)

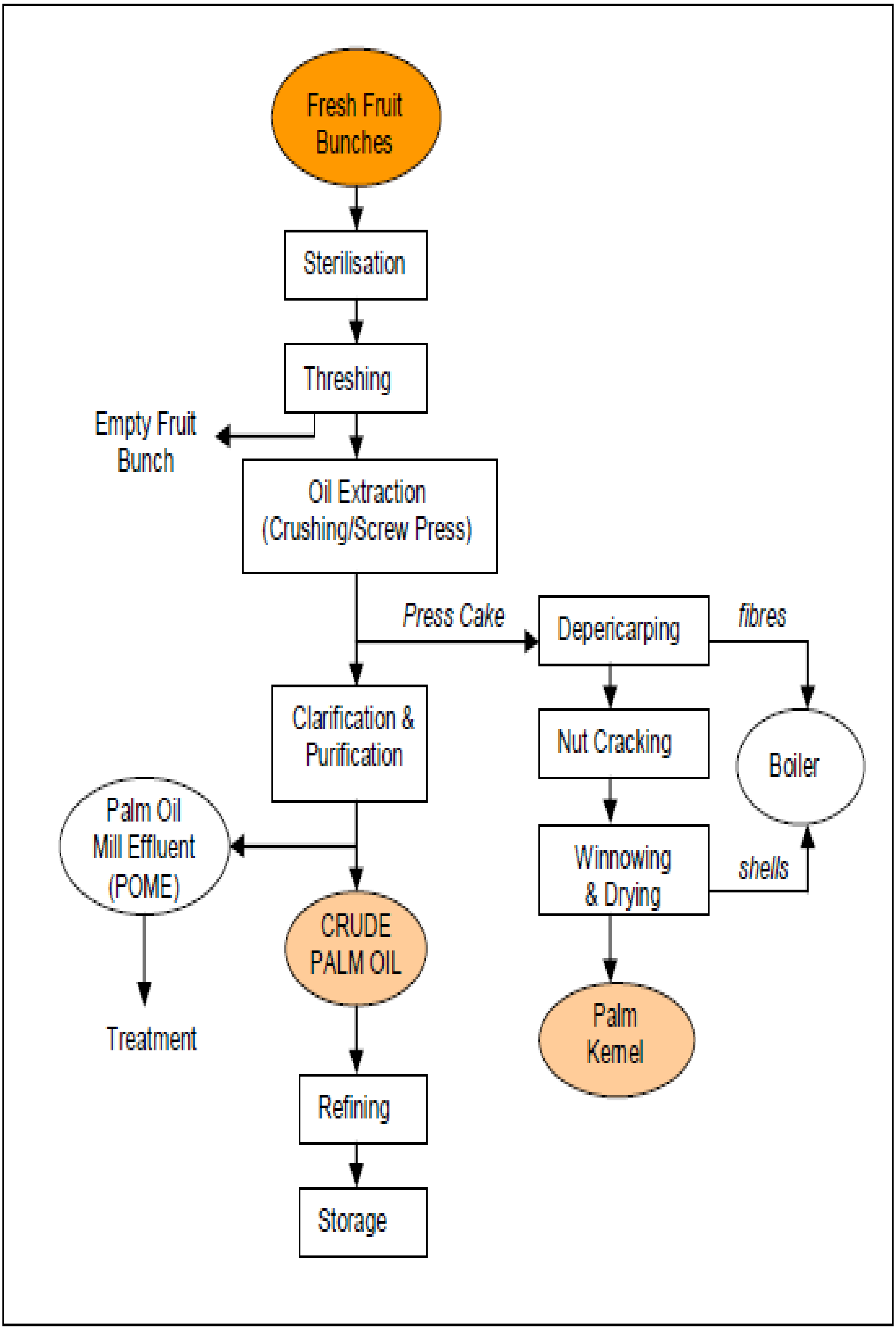

Figure 2.7 Palm oil process flow chart

Source: FAO (2002)

2.4.1 Malaysia Palm Oil Production

Malaysia is one of the premier trading countries of palm oil in the world. It was accounted for that 5 mil ha area of land was used for oil palm plantation in 2011 (MPOB, 2014). This prompts gigantic production of by-products, for example, fibres, nut shells, empty fruit branches throughout the palm oil processing process (Kanadasan and Razak, 2015). The palm oil tree plantation in Malaysia has grown vividly over the previous decades and has ended up one of the fundamental exporters of palm oil products to numerous countries of the world (Valipour, 2015). Malaysia is one of the biggest producers and exporters of palm oil overall (Figure 2.8). Among the nations that develop oil palms in Africa and Southeast Asia, Malaysia is the second biggest producer of oil palm and palm oil products on the earth (Ranjbar *et al.,* 2015).

Figure 2.8 Production of palm oil in Malaysia
Source: MPOB (2004)

Palm oil production in Malaysia has expanded throughout the years, from 4.1 million tons in 1985 to 6.1 million tons in 1990 and to 16.9 million tons in 2010. It achieved 18.9 million tons in 2011. The generation is anticipated to achieve 19.4 million tons in 2012 (Figure 2.9). The Malaysian palm oil industry effortlessly meets the local oils and fats request, and the overabundance can be sent out. Palm kernel oil production in 1999 was 1.3 million tons and achieved 4.7 million tons in 2011. Before

1970, the greater part of the palm portion created was exported. Since 1979, they were pounded locally to produce crude palm kernel oil and palm kernel cake (MPOB, 2016).

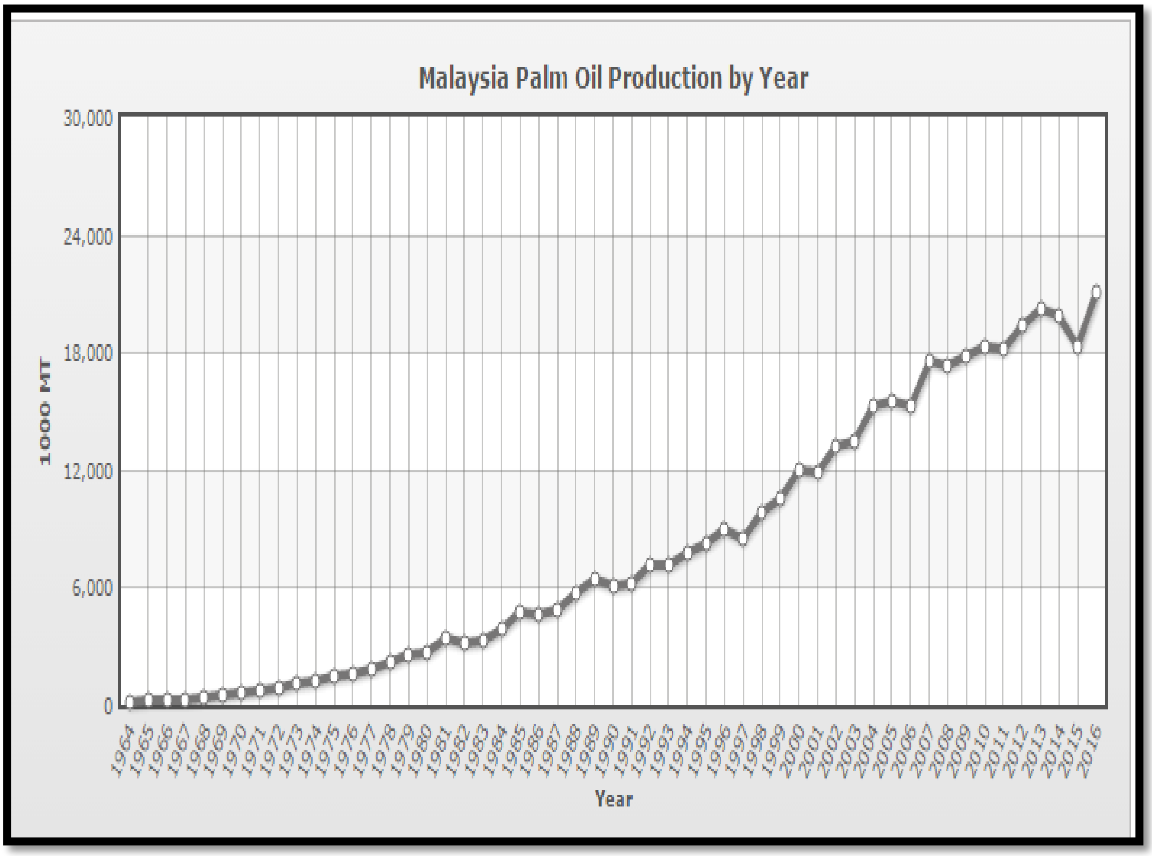

Figure 2.9 Production of crude palm oil in Malaysia

Source: MPOB (2016)

2.4.2 Palm Oil By-Products

In some tropical nations such as Malaysia, palm oil industry is considered as a standout amongst the most vital areas in agriculture. A massive amount of residues like fibers, nut shells and empty fruit bunches (Table 2.2 and Figure 2.10, Figure 2.11 and Figure 2.12) is produced from this industry which are burnt at temperatures of around 800–1000 °C as powers to give steam to power era in palm oil factories. After the blazing procedure, a fiery remains by-item is gotten, which is around 5% by weight of the buildups, known as palm oil fuel ash (POFA). It has been accounted for that around 3 million tons of POFA was created in Malaysia in 2007 (Safiuddin, 2011). Right now, POFA utilization is exceptionally constrained and unmanageable, and a large portion of it is discarded in landfills. Therefore, it has brought about various ecological issues. Al-Oqla and Sapuan (2014) have claimed that using the waste from the palm oil industry as composite material will not just improve maintainability yet will likewise settle the immense issues coming about because of waste issues.

Moreover, the uncontrolled dumping of POFA occupies not only valuable land but also creates environmental pollution and health hazard (Safiuddin *et al.,* 2011). Dumping POFA at landfill is not seen as the best approach as Singh *et al.,* (2011) suggests that land filling requires huge landmass and also an economically unsound process. Most of this wastes especially oil palm shells (OPS) are typically dumped at the factory yard (Alengaram *et al.,* 2013) and also as a palliative for un-tarred roads. Approximately 6.89 million of oil palm shell is produced annually, and this figure is on the rise (Chong *et al.,* 2013). The OPS waste dumped pollutes not only the environment but also causes unpleasant sight for the surrounding. The abundance of oil palm shell waste each day requires the palm oil industry to allocate larger areas for dumping site.

Table 2.2 Solid waste materials and by-products that generate from palm oil mill

Solid waste materials and by-products	**Percentage of total FFB**
Empty fruit bunches	23%
Empty fruit fiber	13.5%
Empty fruit shell	5.5%
Palm kernel	6%
Potash ash	0.5%

Source: Pui (2011)

Figure 2.10 Fruit bunches

Source: Donovon (2015)

Figure 2.11 Fibers

Source: Donovon (2015)

Figure 2.12 Oil palm shells
Source: Donovon (2015)

2.5 Palm Oil Fuel Ash (POFA) in Malaysia

Palm oil fuel ash (POFA) is produced by the palm oil industry as a aftereffect of the burning of empty fruit bunch (EFB), fiber and oil palm shell (OPS) as fuel to create electricity at temperatures of about 800 – 1000 °C and the waste, gathered as ash, gets to be POFA (Nagaratnam *et al.,* 2015). An estimated 10Mt/year of total POFA waste is produced in Malaysia alone (Khankhaje, 2016) and this generation rate is liable to increment because of expanded plantation of palm oil trees (Chindaprasirt *et al.,* 2007; Johari *et al.,* 2012a; Ranjbar *et al.,* 2014b; Tangchirapat *et al.,* 2007). The POFA created in the palm oil plants is dumped into landfills with no profitable return bringing about huge solid disposal which involves massive fields and causes ecological contamination (Chindaprasirt *et al.*, 2007, 2008; Sata *et al.*, 2004). Currently, POFA usage is very limited and unmanageable, and most of it is disposed of in landfills (Figure 2.13). Consequently, most POFA is discarded in landfills, bringing about ecological degradation and different issues.

Figure 2.13 Palm oil fuel ash dumped at the factory yard
Source: Muthusamy *et al.* (2010)

2.5.1 Properties of Palm Oil Fuel Ash

The ash produced from factory sometimes varied in colour, from whitish grey to a darker shade, based on its carbon content (Tangchirapat, 2009; Jaturapitakkul, 2007; Sata, 2004 and Hussin, 2007). At the end, it was noted that the raw materials for POFA could come from the fuel industry, self-combustion in a furnace or other milling industries. All the fine ash was trapped while escaping from the burning chambers of the boiler, then sieved through a 150–300 lm filter to remove the bigger sized ash particles as well as any materials that had not been considered. In other words, the physical characteristics of POFA are very much influenced by the operating system in the palm oil factory (Aprianti *et al*., 2015). Palm oil fuel ash (POFA), a by-product from thermal power plants, contains huge amounts of silicon and aluminum oxides in the amorphous and was as of late acknowledged as a pozzolanic material (Sinsiri, 2012 and Jaturapitakkul, 2004).

In addition, POFA can be utilized as constituents as a part of concrete due to the pozzolanic properties. Numerous researchers have concentrated on the utilization of POFA in typical cement (Tangchirapat and Jaturapitakkul,2007), high strength concrete (Abdul Awal, 2014), and lightweight concrete. The studies have uncovered that agricultural waste ashes contained high amount of silica (Table 2.3) and could be utilized as a pozzolanic material. Ground POFA (Figure 2.14) is one of the agro waste ashes whose chemical composition contains a large amount of silica and potentially used as a cement replacement (Tangchirapat, 2014) and unground POFA (Figure 2.15) as partially sand replacement. According to sieve analysis test (Figure 3.2 and Figure 3.7), the particle size of unground POFA is smaller than the river sand.

Pozzolanic reaction that undergoes by POFA is also called as secondary hydration process. At the first stage of hydration process, the cement will react with water and produce Calcium silicate hydrate (C-S-H) gel and Calcium hydroxide. Then, the silicon dioxide in pozzolanic ash will react with Calcium hydroxide and water to produce more C-S-H gel. The C-S-H gel will increase the strength of the concrete. The amount of C-S-H gel produce in the concrete mixtures is also depends on the fineness and surface area of the POFA. Based on researches that has been done before (Table 2.4), POFA is finer than OPC and it is also has bigger surface area if compared to cement. Therefore, it can produce more pozzolanic reaction. Additionally, POFA will improve the properties in concrete in terms of compressive strength, water permeability, resistance to alkali-silica reaction, chloride and sulfate (Altwair and Kabir, 2010).

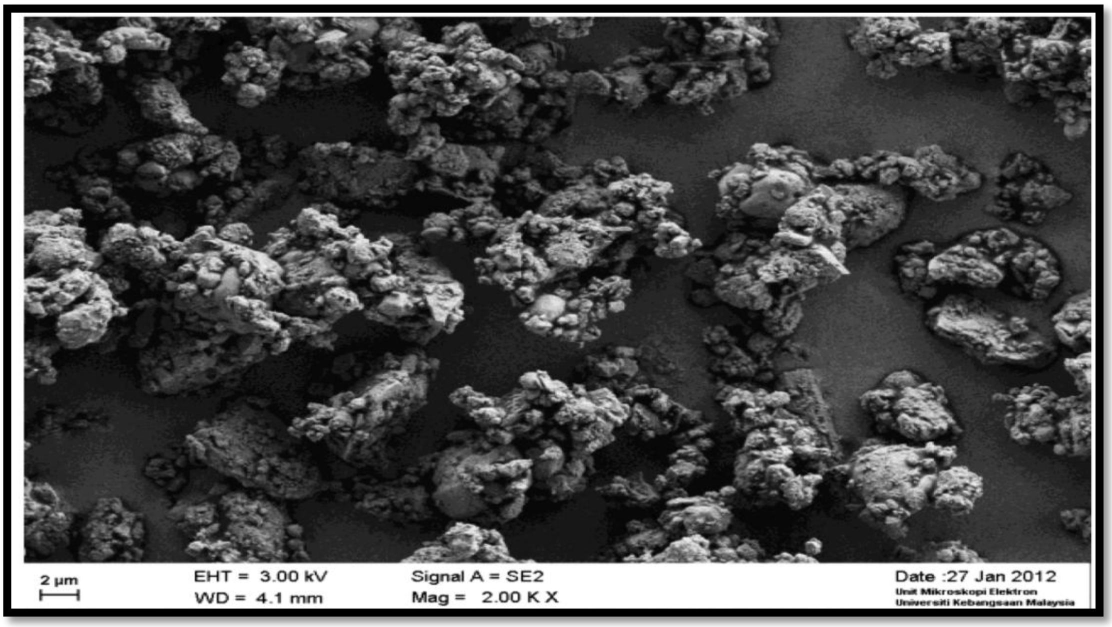

Figure 2.14 SEM image of ground POFA

Source: Khalid *et al.*(2016)

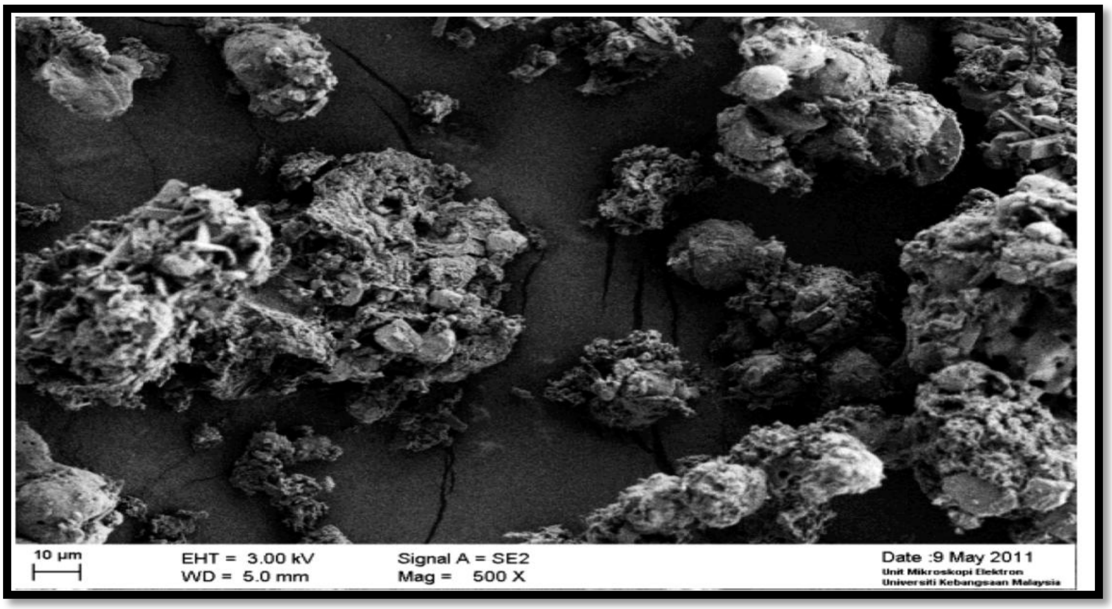

Figure 2.15 SEM image of unground POFA

Source: Khalid *et al.*(2016)

Table 2.3 Chemical analysis of the Portland cement and POFA

Chemical Composition	Portland Cement (%)	POFA (%)
SiO_2	17.60	64.17
Al_2O_3	4.02	3.73
Fe_2O_3	4.47	6.33
CaO	67.43	5.80
MgO	1.33	4.87
Na_2O	0.03	0.18
K_2O	0.39	8.25
SO_3	4.18	0.72
$SiO_2 + Al_2O_3 + Fe_2O_3$		74.24

Source: Ranjbar *et al.* (2016)

Table 2.4 Physical properties of course and fine aggregates, OPC and POFA

Property	Coarse aggregate	Fine aggregates	OPC	POFA
Maximum size (mm)	125	4.76		
Water absorption (%)	0.43	1.13		
Fineness modulus	6.3	2.88		
Passed from 45µm (no.325) sieve (%)			91	96
Medium particle size, d50 (µm)			14.6	10
Specific gravity	2.62	2.56	3.15	1.81

Source: Ranjbar *et al* (2016)

2.5.2 Negative Effects of Palm Oil Fuel Ash

The POFA produced in the palm oil mills is dumped into open fields without any profitable return resulting in massive solid disposal which occupies vast fields and causes environmental pollution (Chindaprasirt et al., 2007, 2008; Sata et al., 2004). POFA contains insufficient nutrient required for a fertilizer, hence dumped in the landfill as it does not have any fiscal values (Sumadi and Hussin, 1995 and Tonnayopas et al. 2006). Alsubari et al. (2014) reported that POFA are dumped in a large dumping site behind the palm oil mill. Dumping POFA at landfill is not seen as the best approach as Singh et al. (2011) suggests that land filling requires huge landmass and also an economically unsound process (Figure 2.16). The uncontrolled dumping of POFA occupies not only valuable land but also creates environmental pollution and health hazard (Safiuddin et al., 2011). The POFA might cause cancer if we breathe in the air that contains POFA.

Other than that, local palm oil factory dumped the POFA directly to the environment. As a result, the minerals and traces metals of POFA such as Al, Mg, Cr and Fe are emitted to soil when in contact with the ground. The effects of POFA are category under eco-toxicity (Subramaniam et. al, 2008). Additionally, the dumped POFA will also disturb the underground water quality.

Figure 2.16 The massive disposal of Palm Oil Fuel Ash (POFA) in palm oil mill

Source: Alamgir and Johnson (2015)

2.5.3 POFA Use in Concrete

In perspective of environmental contamination, palm oil industry has begun to search for an effective solution so that this immense volume of waste can be used. A fruitful way to deal with this issue can be linked to using POFA as an alternative material in concrete and construction material. POFA incorporates a lot of silica (44% - 66%) and has as of late been utilized as a cement substitution to deliver diverse sorts of concrete (Safiuddin et al., 2011a). It has been used to deliver typical and high-strength concrete (Awal and Hussin, 1999; Sata et al., 2004). But, problems related with the reduction in its workability, its early-age compressive strength and its restricted level of substitution have been encountered, as approved in last researches (Alsubari et al., 2014; Safiuddin and Jumaat, 2011; Tay, 1990).

Additionally, Muthusamy and Zamri (2015) contemplated the engineering properties in terms of the tensile and the compressive strengths of palm oil shell lightweight concrete containing palm oil fuel ash (Figure 2.17). Their outcomes demonstrated that palm oil shell concrete containing up to palm oil ash are reasonable for use as structural concrete elements. At present, loads of researchers are being coordinated into evaluating the use of ground POFA as partial cement replacement in the concrete mix. Tangchirapat et al. (2012) studied the utilization of ground palm oil fuel slag to enhance quality, sulfate resistance, acid resistance and water porousness of concrete containing the high amount of reused concrete aggregates. Their outcomes recommended that the addition of ground POFA enhanced the compressive strength and decreasing the permeability of water towards the recycled aggregates concrete. Jaturapitakkul et al. (2007) revealed that ground POFA (medium and small sizes) could be utilized as a pozzolanic material and could likewise enhance the sulfate resistance of concrete. Nonetheless, the unground POFA is not appropriate for use as a cement replacement in cement since it creates low compressive strength.

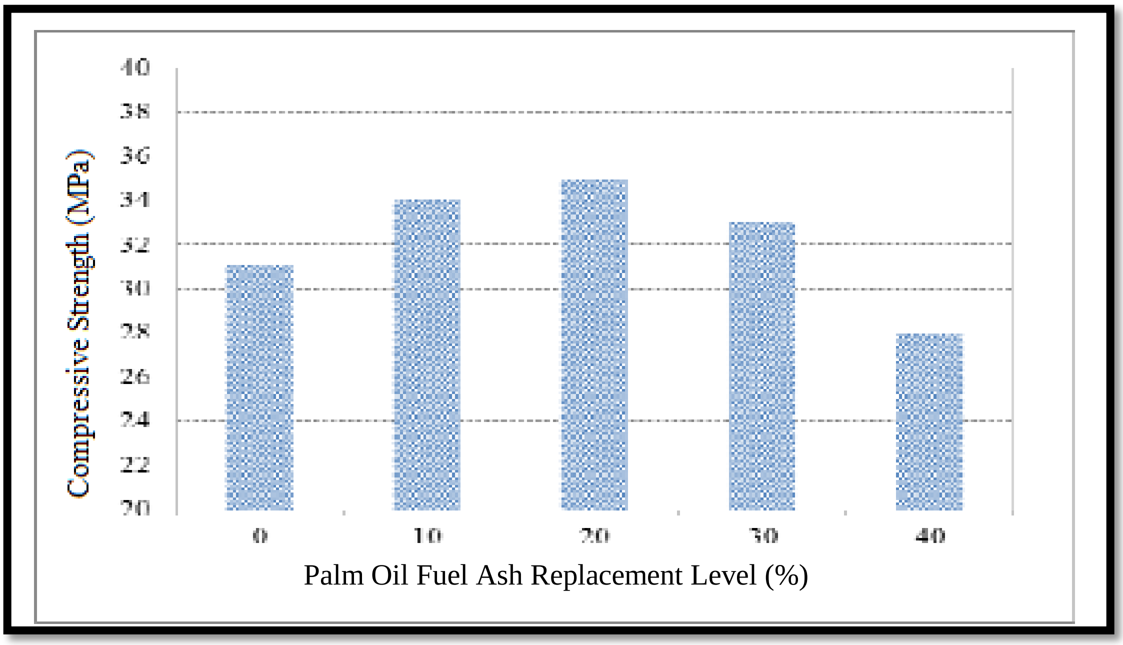

Figure 2.17 Effect of palm oil fuel ash towards compressive strength of lightweight aggregates concrete

Source: Muthusamy and Zamri (2015)

2.6 Concrete Properties

Concrete mixtures can be designed to give an extensive variety of mechanical and durability properties to meet the design prerequisites of a structure. Mechanical properties and durability of concrete may be defined as the ability of concrete to resist load applied, weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than an indoor concrete floor. Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of concrete.

2.6.1 Compressive Strength

Concrete mixtures can be designed to give an extensive variety of mechanical and durability properties to meet the design prerequisites of a structure. The compressive strength of concrete is the most common performance measure used by the engineer in designing a building or other structures. The compressive strength is measured by breaking cylindrical concrete or cube concrete specimens in a compression-testing machine. For cube test, two types of specimens either cubes of 150 mm X 150 mm X 150 mm or 100 mm X 100 mm x 100 mm depending on the size of aggregate are used. For most of the works cubical moulds of size 150 mm X 150 mm X 150 mm are commonly used.

Compressive strength test results are primarily used to determine that the concrete mixture as delivered meets the requirements of the specified strength, f'c in the job specifications. Cubes tested for acceptance and quality control are made and cured in accordance with the procedures described in BS EN 12390 – 3:2009. Concrete specimens are a casted and tested under the action of compressive loads to determine the strength of concrete. In very simple words, compressive strength is calculated by dividing the failure load with the area of application of load, usually after 28 days of curing. The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water, and various admixtures. The ratio of the water to cement is the chief factor for determining concrete strength. The lower the water-cement ratio, the higher is the compressive strength.

2.6.2 Splitting Tensile Strength

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack (Figure 2.18). The standard used to carry out this test is ASTM Designation C 490.

One of the factors that influencing tensile strength of the concrete is the type of coarse aggregate used, except in high strength concrete, because the properties of aggregate, especially its shape and surface texture, affect the ultimate strength in compression very much less than the strength in tension or cracking load in compression. Rather than that, the tensile strength of concrete is more sensitive to inadequate curing than the compressive strength, possibly because the effect of non-uniform shrinkage of flexure test beams are very serious.

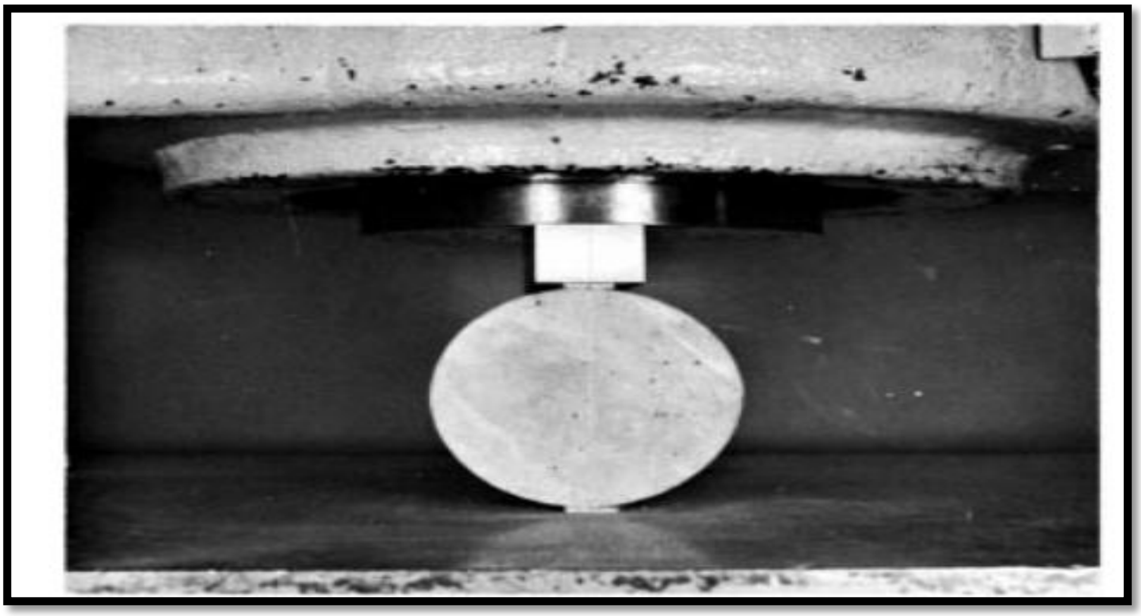

Figure 2.18 Specimen positioned in a testing machine for determination of splitting tensile stength

Source: ASTM C 496/ C 496M – 04

2.6.3 Water Absorption

The rate at which water is absorbed into concrete by capillary suction can provide useful information related to the pore structure, permeation characteristics and durability of the concrete surface zone that is penetrated (Parrott, 1992). The pore structure of concrete is known to be of high importance for the durability of the material. Furthermore, durability of concrete is mainly dependent on the capacity of a fluid to penetrate the concrete's microstructure, which was called permeability. High permeability led to the introduction of molecules that react and destroy its chemical stability (Mehta and Monteiro, 2006). Moreover, low permeability of concrete can improve resistance to the penetration of water, sulphate ions, chloride ions, alkali ions, and other harmful substances which caused chemical attack (Alhozaimy, Soroushian and Mirza, 1996). Concrete permeability had a close relationship with the characteristics of its pore structure in the cement paste and the intensity of microcracks at the aggregate-cement paste interface as well as within the paste itself (De Schutter and Audenaert, 2004).

Here, pore structure mainly involved volume and size of the interconnected capillary pores. As we know, the hydration reaction of cement results in a product consisting of solid and pore systems. The pore network of a cement paste matrix provides passage for the transport of fluid into concrete and its development depends on a number of factors including the properties and composition of the concrete constituent materials, the initial curing condition and its duration, the age at testing, and the climatic exposure during drying and conditioning of the concrete (Ramli and Tabassi, 2012). Therefore, water absorption was conducted for every three cubes (100 x 100 x 100) mm per mix by using BS 1881: Part 122:1998.

2.6.4 Acid Resistance

The acid attack depends on the collaboration of the environment and cement based materials, both being of an intricate character. The rate of the attack might be impacted, quickened or repressed by numerous factors. Every one of them ought to think about the evaluation of the aggressiveness of the medium and the resistance of cement-based materials and the decision of protective measurements (Zivica and Bajza, 2002). Concrete made of OPC are highly alkaline with pH values ordinarily above 12.5. Therefore, concrete not effectively affected by acidic solutions. As the pH of the solution diminishes, the equilibrium in cement is being disturbed, and the hydrated cement is basically modified by hydrolytic deterioration which prompts to the extreme corruption of the technical properties of the material. If pH diminishes lower than stability limits of cement hydrates, then the hydrate loses calcium and deteriorates to amorphous hydrogel. When the C-S-H gel is attacked, the concrete will become weak. Then, the fine aggregates in the corner and edges of the concrete start to disintegrate. Therefore, mass loss of the concrete will occur (Figure 2.19).

There are many factors that influence the rate of acid attack. Acid attack isolated by two which is weak acid like acetic, lactic and strong acid like hydrochloric, sulphuric and nitric acid. Therefore, kind of acid also one of the factor actors conditioning the rate of acidic attack. The significance of the concentration in the acidic attack is a result of the fact that the rate of the acidic attack, similar to that of other chemical reactions, is altogether reliant on the centralization of reaction participants. Accordingly, the estimation of the concentration of the acting solution ought to be the initial step in the evaluation of the aggressively of the solution.

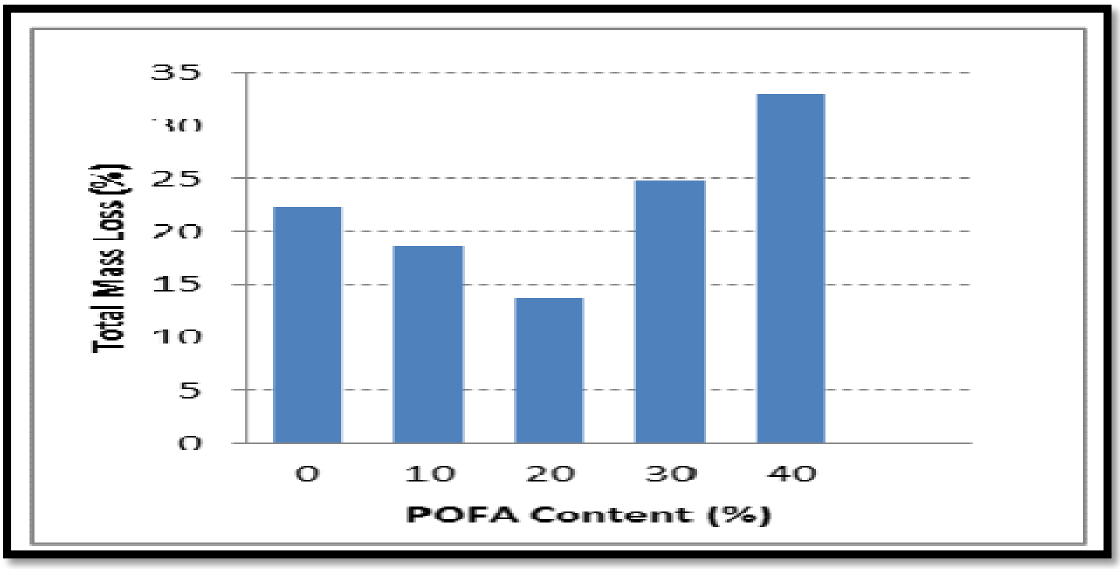

Figure 2.19 Total mass loss of lightweight aggregate with various POFA content after immersed in Hydrochloric acid solution

Source: Muthusamy and Zamri (2015)

2.7 Summary

Since our country is leading towards sustainability construction, a lot of researches had been done to reduce the use of natural resources. In this paper, I had been conducted a research on concrete that sand was partially replaced with unground palm oil fuel ash. This is because to reduce the sand mining activities in our country. Yet, sand mining causes massive amount of effects to our country such as flash flood, directly impacts on velocity, flow regime, river bed level, bank erosion, eco-system, migratory system, extinction of species, fish breeding, changes the shape of existing river and damages the public and private property. On the other hand, palm oil fuel ash that is dumped in the palm oil mill also leads to many environmental problem and health hazards. Despite, this POFA can be partially replaced with sand or cement to reduce these problems. Thus, properties such as compressive strength, splitting tensile strength, water absorption and acid resistance of unground POFA concrete also had been determined in this research.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, material characteristic, specimen detail, laboratory testing, and methodology chart are discussed in detail to carry out to the experimental study with expected data and results. Compressive strength test, splitting tensile strength test, water absorption test and acid attack test, has been conducted to support the experimental study with the data and the result that has been collected. The procedure of each experimental works is explained in detail with the support of methodology chart. Thus, the progress of an experimental study is more cleared for understanding.

3.2 Material Preparation

In this study, Ordinary Portland Cement (OPC), unground palm oil fuel ash (UPOFA), river sand, gravels and water were used.

3.2.1 Ordinary Portland Cement

Cement is the basic ingredient of concrete. Concrete is formed when portland cement creates a paste with water that binds with sand and rock to harden. Ordinary Portland cement was used throughout the experimental work.

3.2.2 Fine Aggregates

Local river sand was used for the fine aggregates. The river sand in laboratory was mined in Sungai Panching, Kuantan, Pahang (Figure 3.1). Figure 3.2 shows the particle size distribution of river sand.

Figure 3.1 River sand

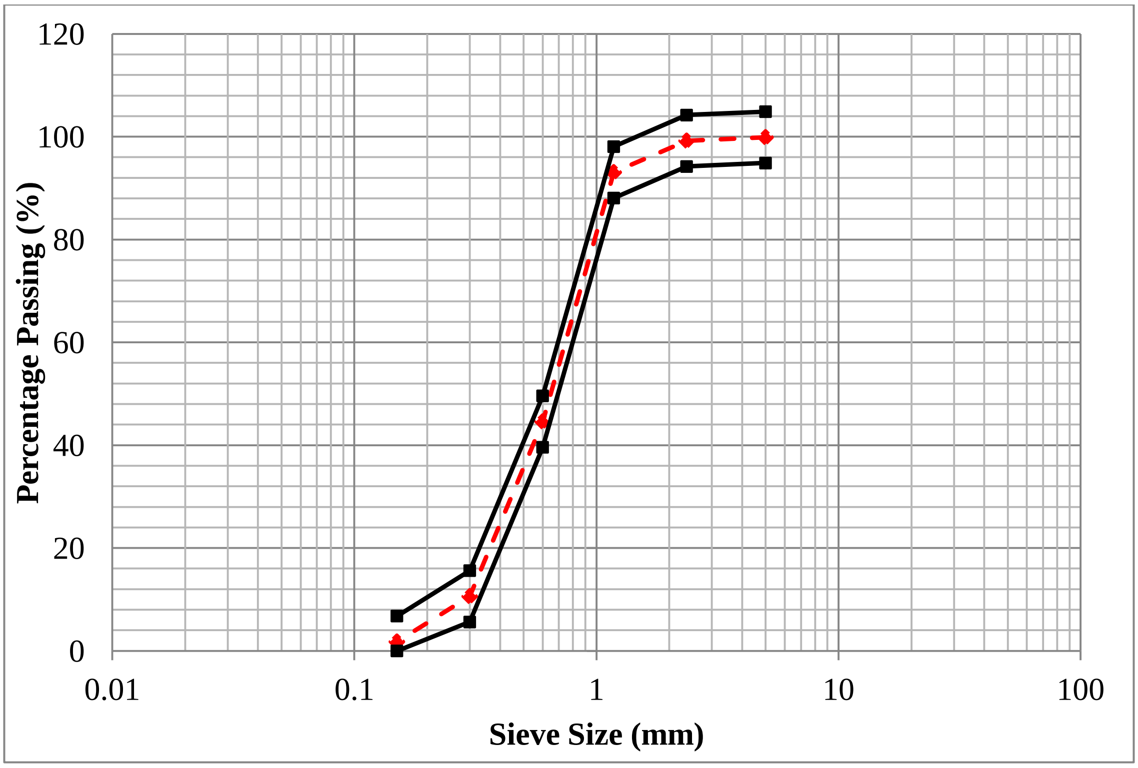

Figure 3.2 Particle size distribution of river sand

3.2.3 Coarse Aggregates

Aggregates comprise as much as 60% to 80% of a typical concrete mix. It must be properly selected to be durable and blended for optimum efficiency. It also should be properly controlled to produce consistent concrete strength, workability, finish ability, and durability. The course aggregates in laboratory was taken from Panching quarry at Kuantan, Pahang. The aggregates used in the experimental works were sieved passing 10 mm (Figure 3.3).

Figure 3.3 Sieved 10mm gravels

3.2.4 Water

Water is very important element in mixing concrete especially for the hydration process. Tap water was used for mixing and curing. Distilled water was used for acid resistance test.

3.2.5 Unground Palm Oil Fuel Ash (UPOFA)

Palm oil fuel ash (POFA) is a solid waste by-product of palm oil industry obtained in the form of ash from the burning of palm oil husk and palm kernel shell used as fuel in palm oil mill steam boiler. Thus, the POFA used throughout this study was collected from the local palm oil mill located in Kuantan, Pahang (Figure 3.4). The POFA was kept in an open area after production with unknown moisture content, prior to mixing process POFA was dried at 100 °C for 24 hours. Next, the dried POFA was sieved through a 300µm sieve to remove large particles and impurities before it can be used (Figure 3.5 and Figure 3.6). Figure 3.7 shows the particle size distribution of unground palm oil fuel ash (UPOFA).

Figure 3.4 POFA was collected from palm oil mill

Figure 3.5 Sieving machine was used to sieve POFA

Figure 3.6 Sieved unground POFA

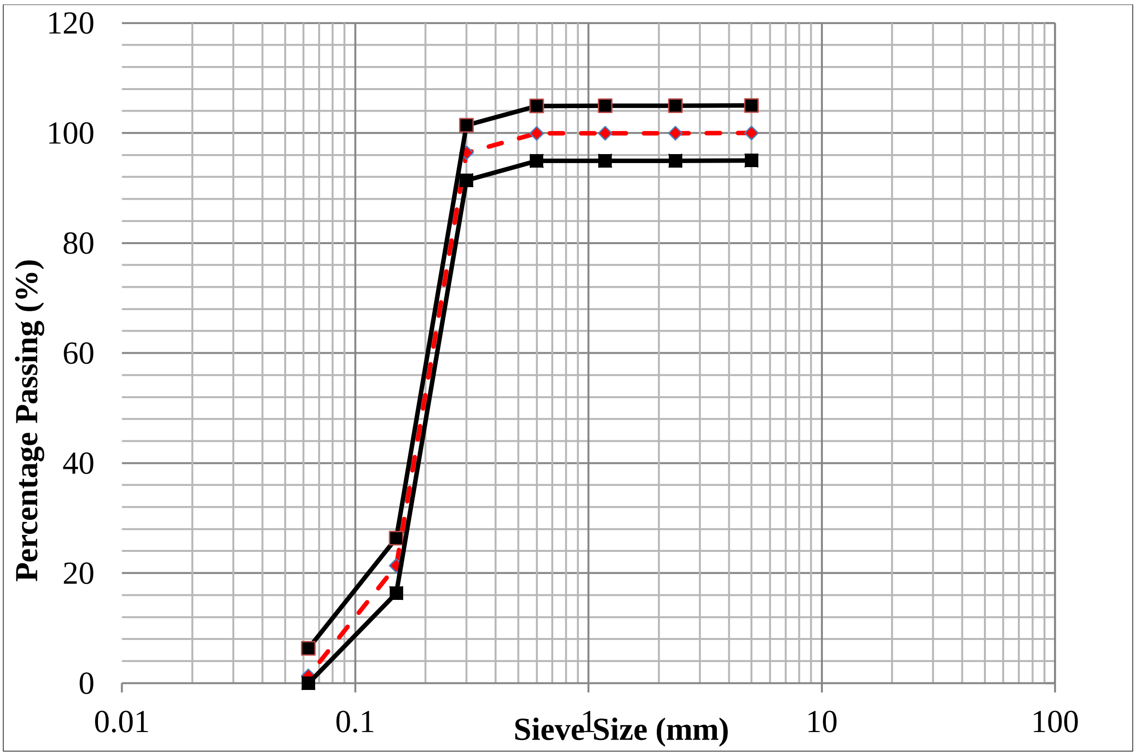

Figure 3.7 Particle size distribution of unground palm oil fuel ash (UPOFA)

3.3 Mix Proportion

For this experimental study, there was several trial mix designs will be used to identify the best mix design (Table 3.1). The trial mix design needed is made of several percentages of UPOFA such as from 5%, 10%, 15%, and 20% to replace with sand. The design grade for this mix proportion concrete is by 30N/mm^2. The table below shows the mix design of this experiment. The water cement ratio for this experiment was 0.7.

Table 3.1 Mix proportion of concrete

Element	**Weight (kg/ m^3)**
Cement	350
Fine Aggregate	980
Coarse Aggregate	850
Water	245

3.4 Preparation of Unground POFA Concrete

3.4.1 Mixing of Concrete

The design grade for this concrete is G30. There were five mixtures of concrete that were produced which including the plain concrete. For the control concrete, it contained Ordinary Portland cement, gravels, sand and water (0% UPOFA as sand replacement). On the other hand, another 4 mixtures produced by the combination of ordinary Portland cement, gravels, sand, water and different percentages of unground POFA which is 5%, 10%, 15% and 20%. The size of unground POFA is 300μm and the gravels size was passing 10mm.

3.4.2 Casting of Concrete

The size of moulds that were used in this experiment was cube mould (100 x 100 x 100) mm and 100mm diameter of cylinder (Figure 3.8). Before the concreting work takes place, the moulds surface were applied with some oil or grease to make the demolding work easier (Figure 3.9). Then, the mixed concrete was compacted into the cubes and cylinders. Figure 3.10 shows the casting work of concrete. The moulds were poured three layers of equal amount of concrete. Each layer compacted 35 times by the rod. After that the moulded concretes were closed with wet cloth to maintain the moisture of the concrete and dried for 24 hours.

Figure 3.8 The cube moulds which were applied with oil

Figure 3.9	The cylinders which were applied with oil

Figure 3.10	Casting of concrete specimen

3.4.3 Curing Method

After that, the dried concrete were demoulded and cured in the water tank. Water curing is the best curing method since complete hydration process will occur because if the adequate amount of water is given. The concrete cubes and cylinders were cured of 28 days (Figure 3.11). The concrete must reach 75% of strength at the 7 day of test.

Figure 3.11 The concrete cubes were cured in the water tank

3.5 Laboratory Testing

The tests that conducted in the laboratory for this experimental study are listed in Table 3.2. The data obtained in these experiments were used to identify the objectives which are stated in Chapter 1. Under this sub-topic, the clear procedure for water absorption test, splitting tensile test and acid resistance test (Table 3.2).

Table 3.2 Tests that were conducted in this study

Category of Test	Type of Test
Compressive strength of hardened concrete	Compressive strength test
Splitting tensile strength of hardened concrete	Splitting tensile test
Water absorption capacity of hardened concrete	Water absorption test
Acid resistance of hardened concrete	Acid attack test

3.5.1 Compressive Strength Test

The compressive strength test was conducted after the slump test with according to BS EN 12390 – 3:2009. The size of the cube is 100 mm x 100 mm x 100 mm. Three cubes per mix was casted. Before the concrete filled into the mould, a layer of oil was brushed in the inner layer of the mould for ease the cubes pulled filled into the mould and prevent the concrete stick with the mould. The concrete was filled into the mould by using the scoop with approximately 1/3 height of the mould in three layers. Each layer of the concrete inside the cube was compacted at least 25 times distributed uniformly by using the tamping rod. After the concrete is hard, the cube was dismantled. Every cube was put into a curing tank for the curing process for a period of 7 days and 28 days for compression strength test.

The main objective of the concrete compression strength test was to determine the compression strength of hardened concrete. The specimens were tested under the action of compression load at specific load until it failed. The compressive strength test was conducted according to BS EN 12390 – 3:2009. The dimension and the weight of each cube were measured. The surface of the cube, upper and lower bearing plate in the compression machine was cleaned. The cube was placed at the center of the lower bearing plate. After that, ensure the both plates gripped the cube in position. The compression machine was set up to apply continuously load and without stock until the cube failed under compression load. After the concrete compression test was done, the ultimate load and type of failure of the cube were recorded.

3.5.2 Splitting Tensile Strength Test

The purpose of this test is to determine the splitting tensile strength of cylindrical concrete specimens. The standard used to carry out this test is ASTM Designation C 490. Three 100 mm diameter of cylinder specimens for per mix were casted and cured in water. The testing age was 7, 28 and 60 days. Firstly, the diametral lines are drawn and the axes of the cylinder at each end were cut with the aid of a suitable alignment apparatus and it connected with the diametral lines. Then, the diameter of the concrete specimen was determined by averaging diameter measurements to the nearest 0.25mm, one at each end of the specimen and one at the center. After that, the length of the specimen was computed by measuring the length at two locations, approximately 180° apart, to the nearest 2.5mm and they were averaged.

Then, one of the plywood strips was centered on the lower platen of the compression machine and one of the diametral lines of the specimen was centered over the moddle of the wood strip. Next, another wood strip was centered over the top diametral line of the specimen. After that, the pressure head of the compression machine was slowly lowered to the top of wood strip until there is just enough preassure for the specimen to be held in place. Finally, a steady load was applied on a 100mm diameter x 200mm high concrete at an approximate rate of 4500kg of mass per minute. Then the load at failure, type of failure and the appearance of the concrete at the plane of fracture were recorded. The tensile splitting strength of a concrete cylinder will be computed as in Eq. (3.1).

$$T = \frac{(2\ x P)}{(\pi\ x\ l\ x\ d)} \tag{3.1}$$

T = Tensile splitting strength, kPa (psi)

P = Applied load at the time of failure of the specimen, (kN)

l = Length of the cylindrical in m

d = Diameter of the specimen in m

3.5.3 Water Absorption Test

The water absorption test was conducted for every three cubes (100 x 100 x 100) mm per mix by using BS 1881: Part 122:1998. The testing age of this test was 28 days. First of all, three samples of cubes for per mix were cured, weighed and recorded, Wi. Then, the weighed cubes were oven dried at 100 °C for 72 hours. Later, the oven dried cubes were immersed in water for 30 minutes. Next, the immersed were taken out from the water tank and the surfaces of the cubes were cleaned by using absorbent cloth. Lastly, the cubes were weighed and the data was recorded, Wf. The percentages of water absorption were calculated by using Eq (3.2).

$$Percentage\ of\ water\ absorption = \frac{Wf - Wi}{Wi} x\ 100 \quad (3.2)$$

Wi = Initial weight of the concrete cubes in gram

Wf = Final weight of the concrete cubes in gram

3.5.4 Acid Resistance Test

The acid resistance test was carried out to determine the durability property of the concrete. The test was conducted based on the other research papers. Six cubes (100 x 100 x 100) mm per mix was casted and cured in water tank for 28 days. The testing age of these cubes was 1800 hours. The only equipment needed for this test is weighing machine.

Firstly, the initial weight of the cured cubes were weighed and recorded, Wi. Then, the cubes were immersed in Hydrochloric acid (HCl) for 1800 hours. The cubes were taken out from the HCl solution and weighed, Wf for every 100 hours. Finally, the result of the acid resistance obtained through the mass loss of the HCL immersed concrete cubes. The mass loss of the concrete cubes was calculated by using Eq. (3.3).

$$Percentage\ of\ water\ absorption = \frac{Wf - Wi}{Wi} x\ 100 \quad (3.3)$$

Wi = Initial weight of the concrete cubes (g)

Wf = Final weight of the concrete cubes (g)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this research, five concrete mixes were prepared, one mix was used as a control mix and other four mixes were concrete containing the various percentage of unground palm oil fuel ash (POFA). The results for control concrete were used as a benchmark for concrete containing various percentages of unground POFA for performance estimation. All concretes were tested and observed for compressive strength, splitting tensile strength, water absorption and also acid resistance. Thus, this chapter presents and discusses the results obtained from the research.

4.2 Compressive Strength

The compressive strength test was conducted according to BS EN 12390 – 3:2009. The size of the cube was 100 mm x 100 mm x 100 mm. The sample cubes were cured in water and tested for compressive strength at 28 and 60 days. Figure 4.1 shows the result of compressive strength of concrete mixes containing various percentage of unground POFA as partial sand replacement. Evidently, the use of POFA as partial sand replacement influenced the strength of concrete. It is also observed that strength of concrete specimen continue to increase throughout the curing age. It is estimated that concrete reaches 75% of strength within 28-day of water curing, and its strength will remain stable or even increase over time (Kosmatka et. al, 2002).

The compressive strength of concrete containing 5% and 10% of POFA replacement exhibit higher strength than control specimen. The compressive strength of control mix concrete for 28 days water curing is 29.773 MPa. Meanwhile, the compressive strength of concrete which containing 5% and 10% POFA as the sand replacement are 31.074 MPa and 35.329 MPa for 28 day water. On the other hand, it is shown that the compressive strength of concrete begins to decrease when more that 10% of POFA insisted as the partial sand replacement. The compressive strength of concrete containing 15% and 20% POFA are 30.842 MPa and 25.057 MPa for 28 days water curing.

The strength of the concrete increases due to the ability of POFA to fill the voids inside the concrete. This is because the particle size of POFA is smaller than sand where POFA was sieved through size 300μm (Figure 3.2 and Figure 3.7). This made the concrete to become denser and stronger. However, the replacement percentage has a limit, and in this case, it is from 5% until 10% replacement level. Although the strength of concrete contain 15% of POFA lower than concrete contains 10% POFA, its strength can still be accepted because the concrete still has a higher strength compare to plain concrete. It is observed, beyond 15% replacement the concrete failed to reach the targeted strength.

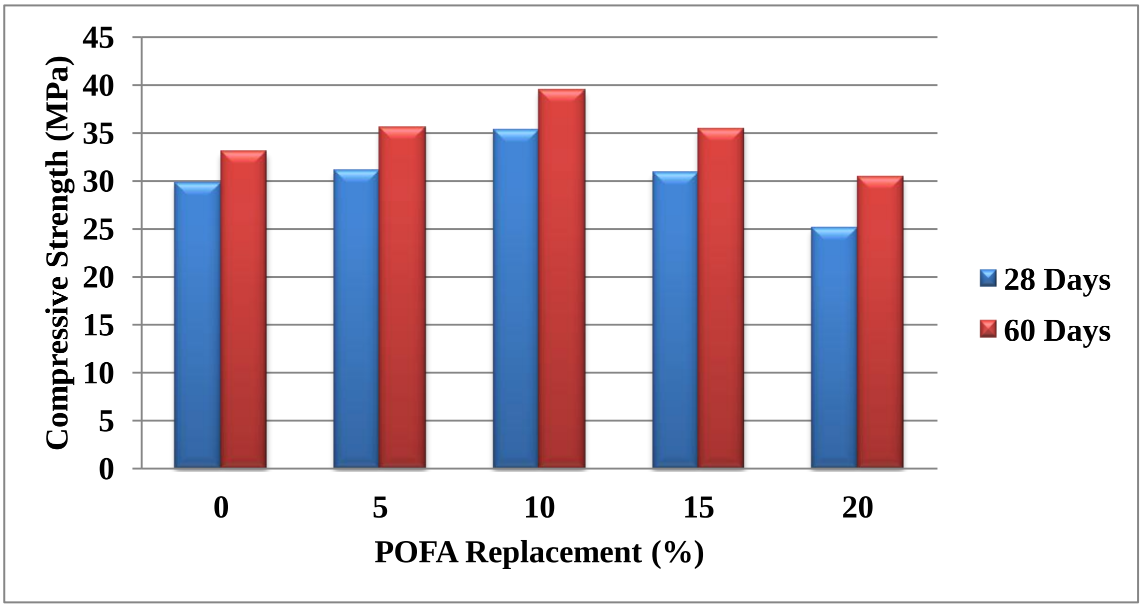

Figure 4.1 Compressive strength test result

4.3 Splitting Tensile Strength

The purpose of this test is to determine the splitting tensile strength of cylindrical concrete specimens. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack. The standard used to carry out this test is ASTM Designation C 490. Three 100 mm diameter of cylinder specimens for per mix were cast and cured in water. The testing ages were 28 and 60 days. Figure 4.2 shows the cylinder before and after the load was applied.

Figure 4.3 above shows the results of splitting tensile strength of concrete specimens which containing the various percentage of unground POFA as the partial sand replacement at 28 days and 60 days of water curing. Based on the result, the concrete has obtained optimum tensile strength at 10% POFA replacement for 28 days. It can be observed that tensile strength of concrete containing 5% and 10% of POFA replacement has higher strength value than control specimen. The tensile strength of control mix concrete for 28 days water curing is 2.263 MPa.

Meanwhile, the tensile strength of concrete which containing 5% and 10% POFA as the sand replacement are 2.449 MPa and 2.549 MPa for 28 day water curing. On the other hand, it is shown that the tensile strength of concrete begun to decrease when more that 10% of POFA insisted as the partial sand replacement. The tensile strength of concrete containing 15% and 20% POFA are 2.411 MPa and 1.761 MPa for 28 days water curing.

The strength of the concrete increased due to the ability of POFA to fill the voids inside the concrete. However, the replacement percentage has a limit, and in this case, it is from 5% until 10% replacement level. The strength of the concrete decrease with increase in the percentage of POFA. Although the strength of concrete contain 15% of POFA lower than concrete contains 10% POFA, it strength can still be accepted because the concrete still has a higher strength compare to plain concrete. Generally, this result shows similar trend with compressive strength result.

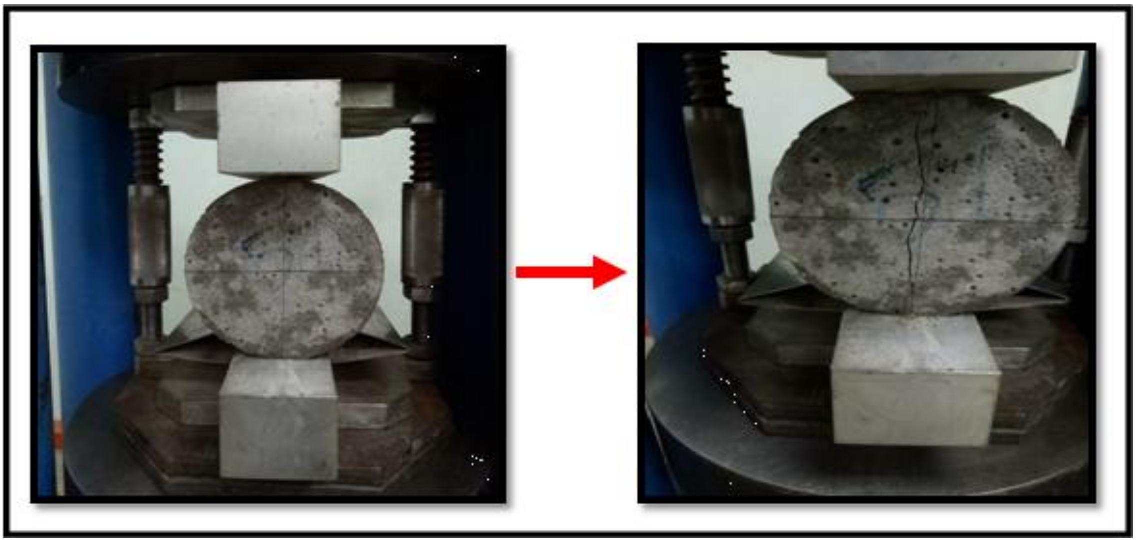

Figure 4.2 The cylinder before and after the load was applied

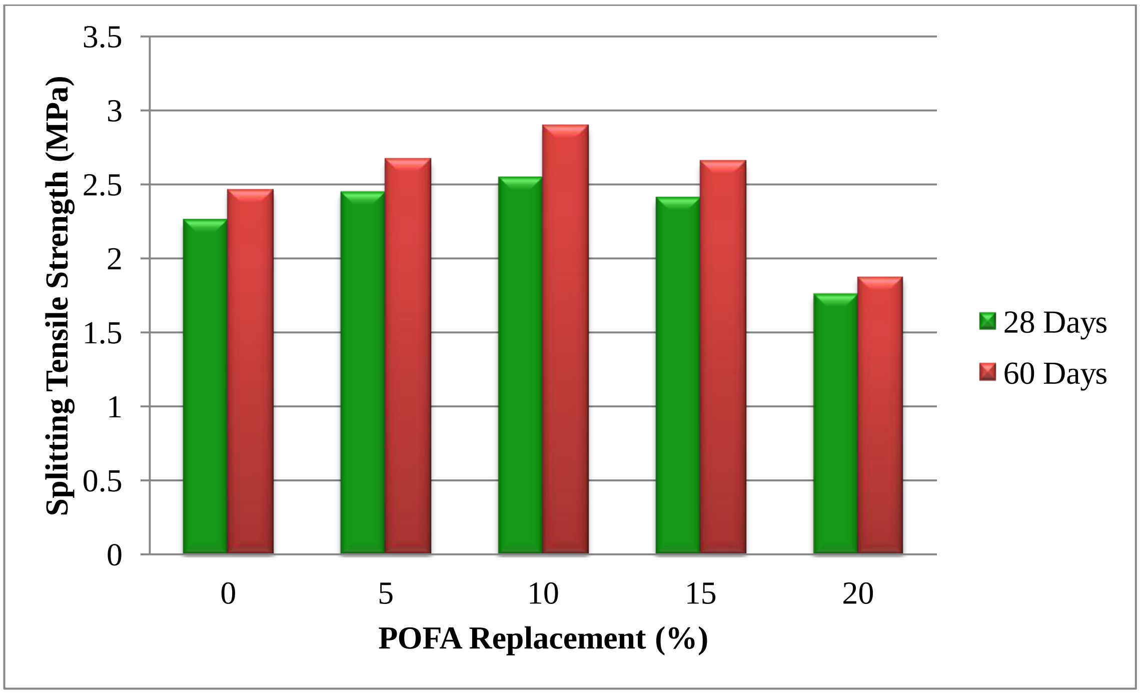

Figure 4.3 Splitting tensile strength test result

4.4 Water Absorption

Water absorption is used to determine the amount of water absorbed under specified conditions. The water absorption test was conducted for every three cubes (100 x 100 x 100) mm per mix by using BS 1881: Part 122:1998. The testing age of this test was 28 days. Figure 4.4 shows the result of water absorption of concrete containing POFA as the partial sand replacement. The percentage of water absorption of concrete keeps increasing when percentage of POFA replaced in the concrete increases. The percentage of water absorption when sand in concrete was partially replaced with 0%, 5%, 10%, 15% and 20% of POFA are 0.95%,1.22%, 1.33%, 1.45% and 1.6% respectively. The reason behind this result is due to the greater porosity of POFA which tend to favor water absorption (Safiuddin, 2011). The porous structure of POFA particle will act as a storage place for water. Moreover, increase percentage of POFA replacement will cause increase percentage of concrete porosity (Asrah, 2015). In conclusion, increase in POFA content will increase the absorption of water by the concrete.

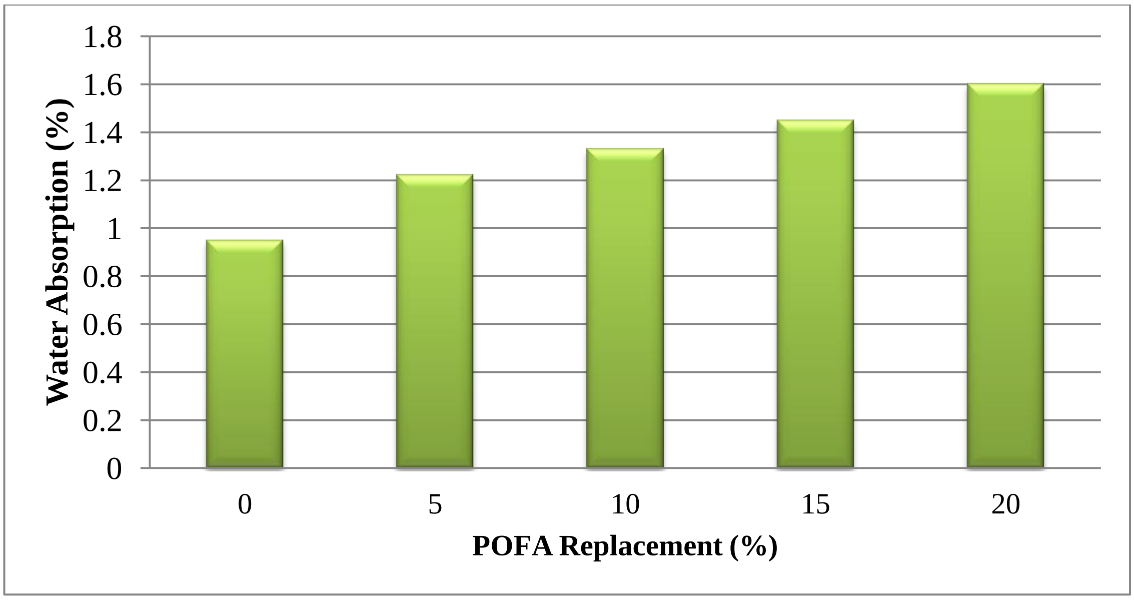

Figure 4.4 Water absorption result for 28 days water curing

4.5 Acid Resistance

The acid attack test was carried out to determine the durability property of the concrete. The test was conducted based on the other research papers. Six cubes (100 x 100 x 100) mm per mix was cast and cured in the water tank for 28 days. The concrete cubes were immersed in Hydrochloric acid solution for 1800 hours and reading was taken for every 100 hours. Figure 4.5 until Figure 4.10 show the result of acid resistance test.

The concrete lost least mass when 10% of POFA was insisted as partial sand replacement and followed by 5% of POFA replacement. This is because the POFA made the concrete more dense and compacted. So, the acid solution takes time to infuse into the concrete. Meanwhile, the concrete containing 15% and 20% POFA as partial sand replacement loss more mass than control mix concrete, 5% and 10% POFA containing concrete. When the acid infused into the voids of concrete, it started to attack the Calcium Hydroxide and Calcium Silicate Hydrate gel (C-S-H gel) in the hardened concrete.

Normally C-S-H gel contributes to the strength of the concrete. The acid will destroy C-S-H gel and weakens the concrete structurally and reduces its durability and service life. After that, the fine aggregates in the edges and corners of the started to disintegrate. This process will continue until the concrete loses its strength fully (Allahverdi, 2000). Figure 4.11 to Figure 4.15 show the comparison of specimens before and after immersing in Hydrochloric acid solution. When the concrete specimens were compared before and after immersing in acid solution, colour changes were noticed. There was some orangish deposition on the concrete specimens after immersed in acid solution for 1800 hours. Moreover, the deposition noticed to be decreased gradually when the amount of unground POFA replaced to the concrete increased.

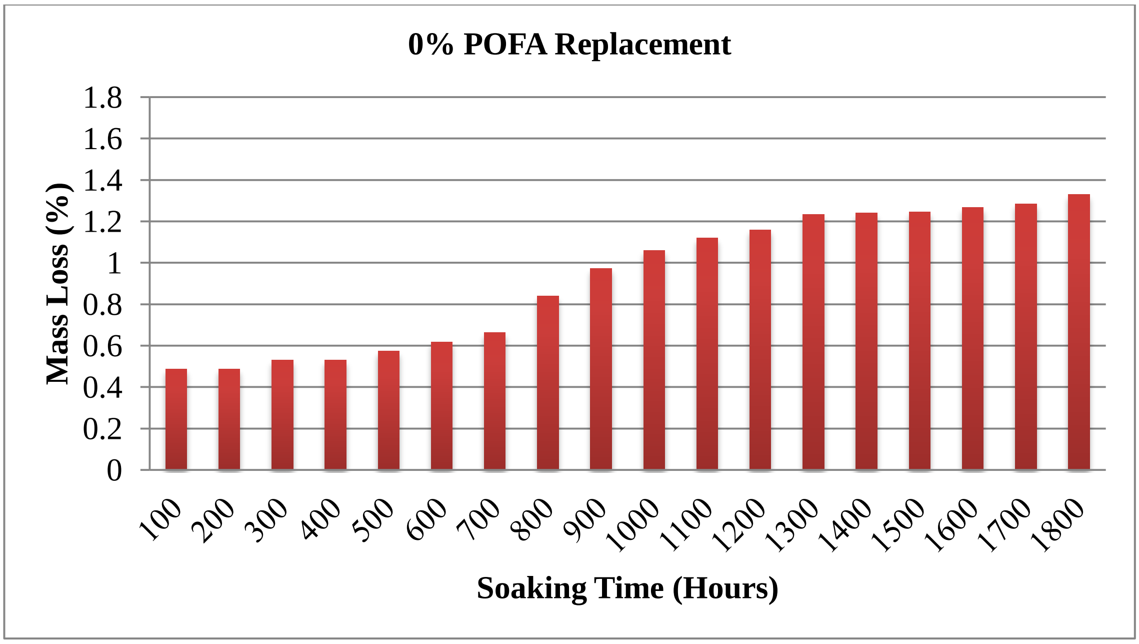

Figure 4.5 Acid resistance result of control mix concrete

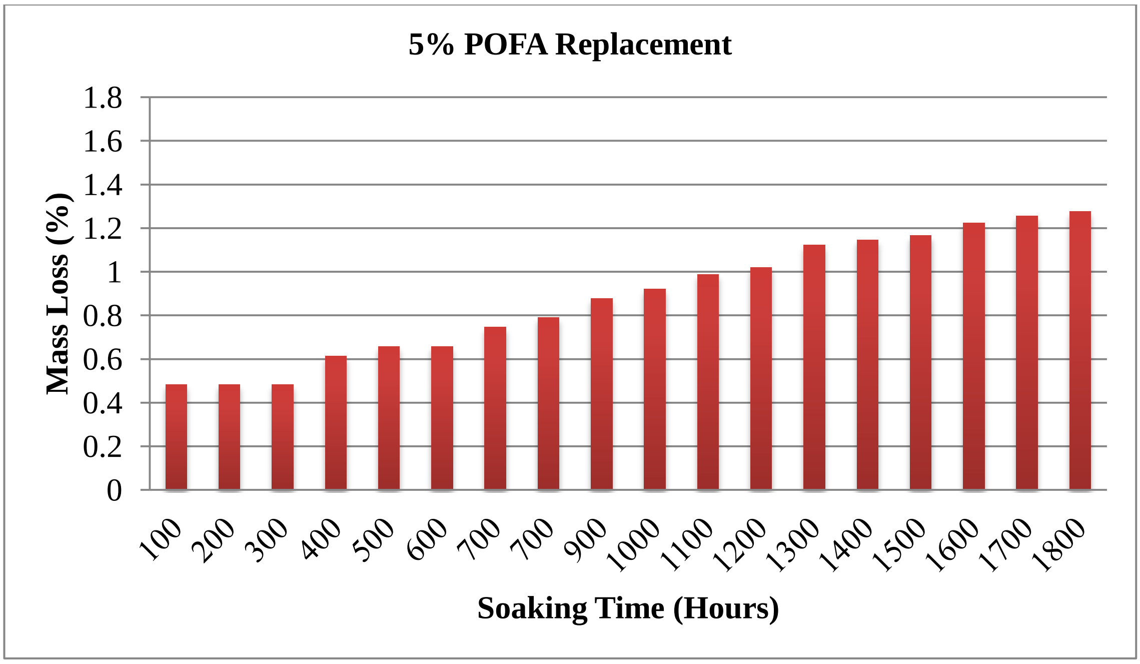

Figure 4.6 Acid resistance result when 5% of POFA replaced with sand

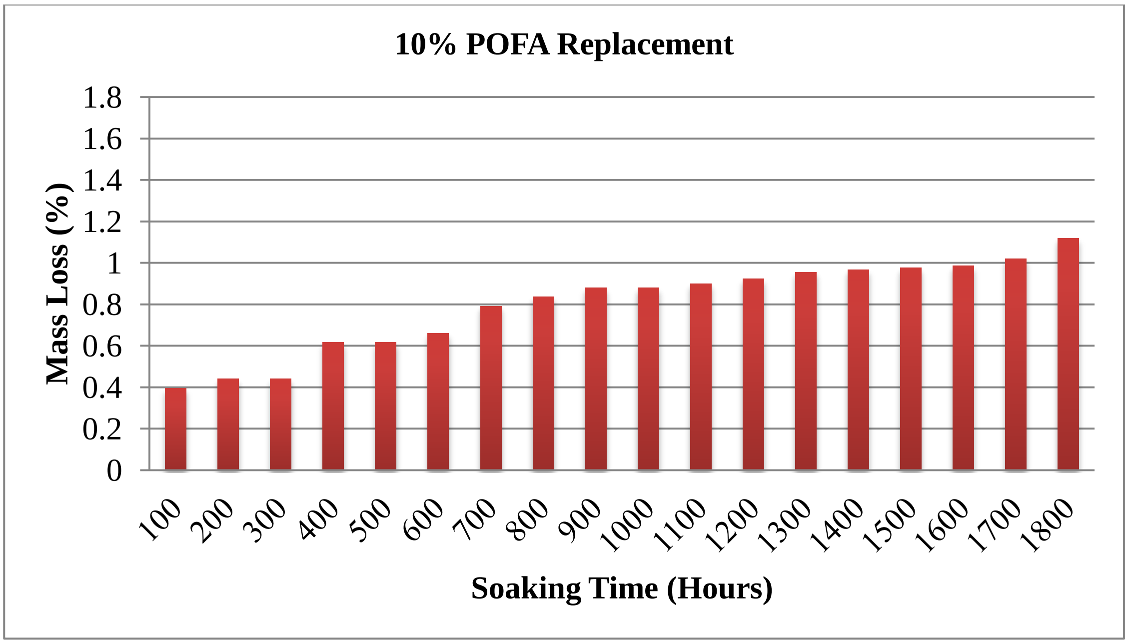

Figure 4.7 Acid resistance result when 10% of POFA replaced with sand

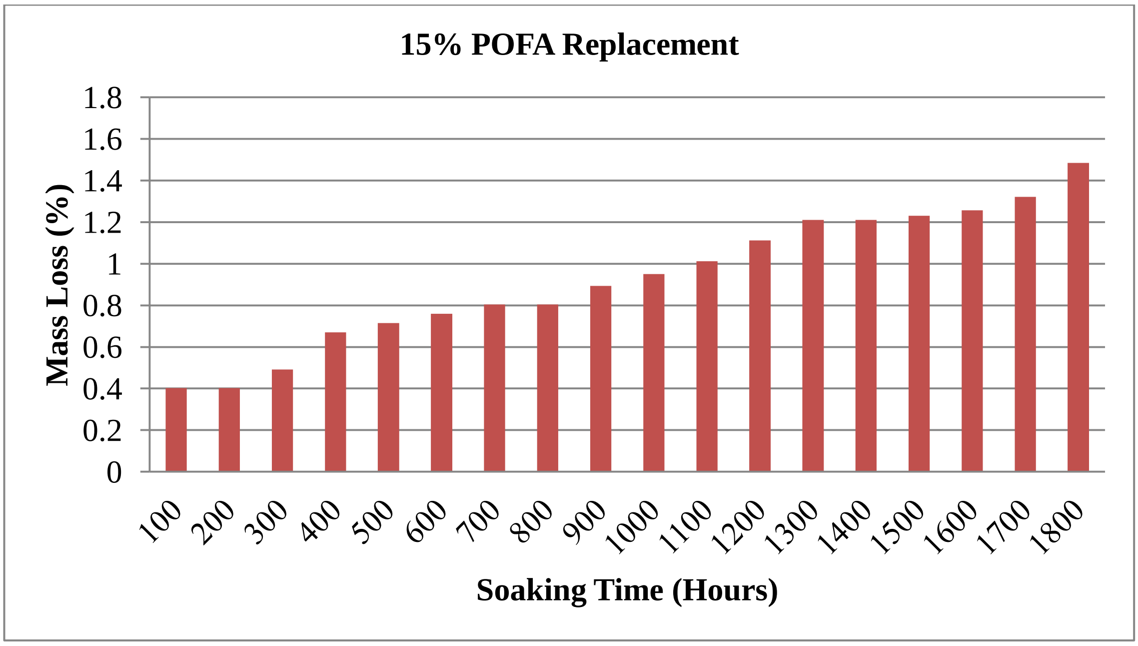

Figure 4.8 Acid resistance result when 15% of POFA replaced with sand

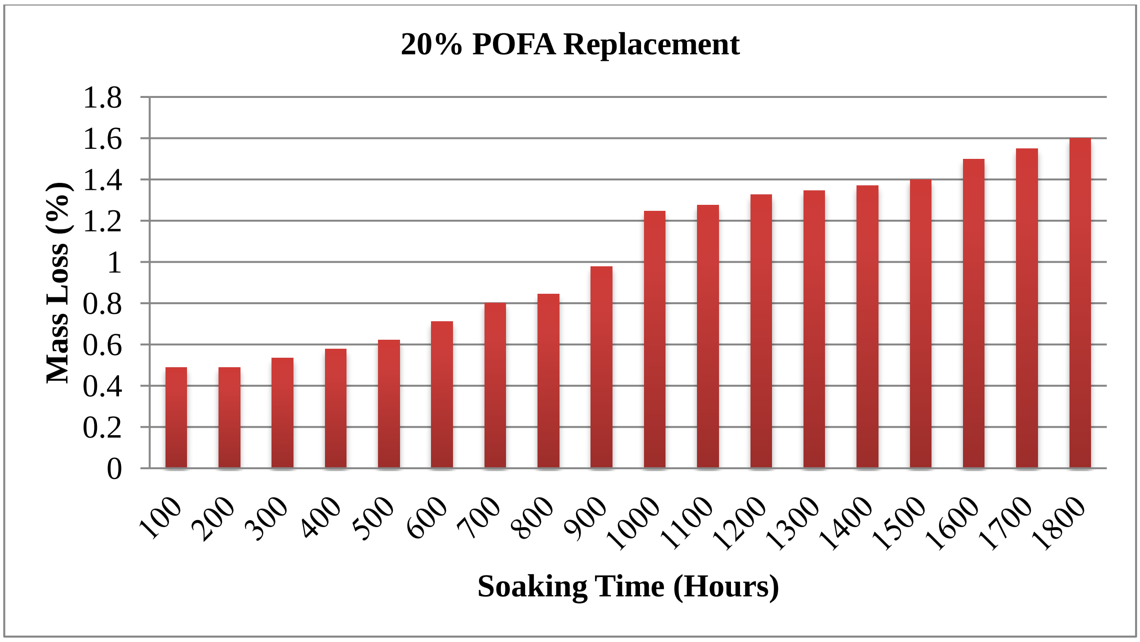

Figure 4.9 Acid resistance result when 20% of POFA replaced with sand

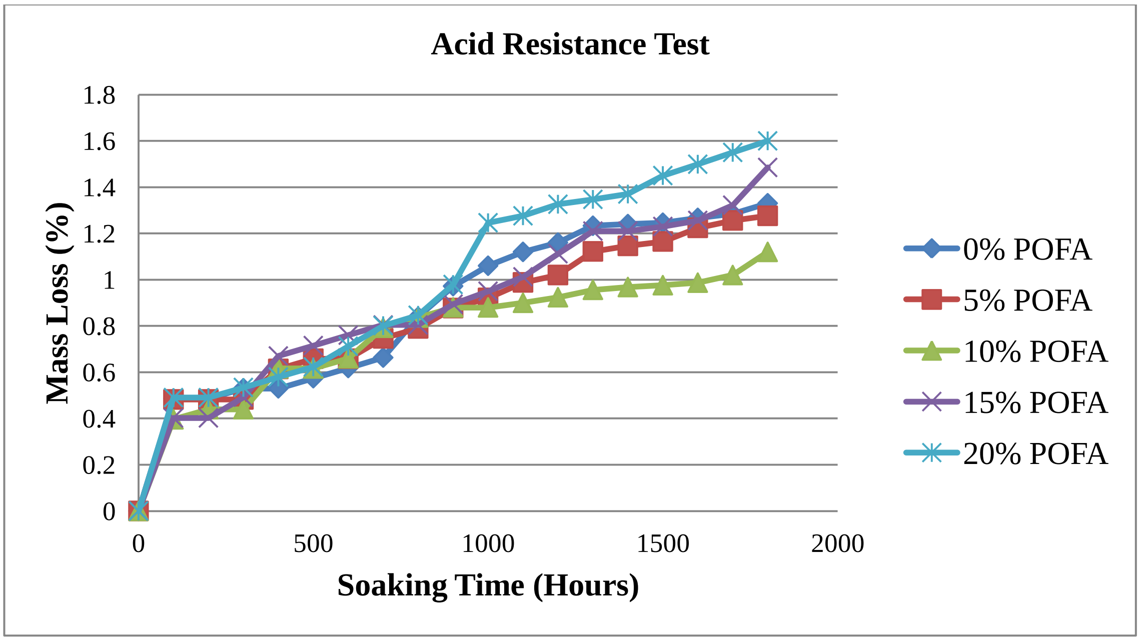

Figure 4.10 Acid resistance test result based on soaking time in HCl acid solution

Figure 4.11 The comparison of control specimen before and after immersing in acid solution

Figure 4.12 The comparison of specimen that contains 5% POFA before and after immersing in acid solution

Figure 4.13 The comparison of specimen that contains 10% POFA before and after immersing in acid solution

Figure 4.14 The comparison of specimen that contains 15% POFA before and after immersing in acid solution

Figure 4.15 The comparison of specimen that contains 20% POFA before and after immersing in acid solution

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

The main aim of this research is to determine the compressive strength, splitting tensile strength, water absorption and acid resistance of the concrete containing unground POFA as partial sand replacement. The following conclusions can be drawn from the results obtained.

i. In terms of compressive strength, the concrete containing 10% of unground POFA as partial sand replacement achieved the optimum strength compared to plain concrete because POFA particles are smaller than the sand particles. So, the POFA particle would be fill the voids inside the concrete and made the concrete denser and stronger.

ii. Concrete containing 10% of unground POFA shows the highest tensile strength of all mixes. This is because the particle size of POFA is smaller than sand. Therefore, it can fill the voids inside the concrete and consequently made the concrete denser and stronger.

iii. Concrete containing POFA absorbs more water than plain concrete. Increase the percentage of POFA used in concrete causes the increase in the percentage of water absorbed by the concrete specimens. The structure of POFA is more porous than sand, thus the increase the porosity of the concrete and increase the concrete water absorption value.

iv. When exposed to acid attack, the concrete containing 10% of POFA as partial sand replacement shows highest durability of all mixes. This is because the POFA made the concrete more dense and compacted.

v. This research shows that unground POFA seems to have good potential for sand replacement in concrete. The concrete can be used for construction of low-cost building projects. Consequently, the use of POFA also reduces waste material disposed at landfill.

5.2 Recommendation

There are a few recommendations suggested for future development for this concrete. Thus, the following recommendations are:

i. To study the durability of concrete containing unground POFA as partial sand replacement in terms of sulfate attack and alkali silica reaction.
ii. To study the fire resistance of concrete containing unground POFA as partial sand replacement.
iii. To determine the structural performance of concrete containing unground POFA as partial sand replacement.

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