RDU 160341

PROPERTIES OF FOAMED CONCRETE CONTAINING PALM OIL FUEL ASH

(SIFAT KONKRIT RINGAN YANG MENGANDUNGI ABU TERBANG KELAPA SAWIT)

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Universiti Malaysia Pahang

2018

ACKNOWLEDGEMENTS

Alhamdulillah, All praises to Allah S.W.T for making everything a success. Thanks to my research members and three postgraduate students Muhammad Nazrin Akmal, Muhammad Hariz and Mohd Hanafi for working hard to complete this research. Despite of the obstacles faced during the undertaking of this research project, the team manages to produce 6 conference papers related to concrete fields, a patent and won 6 medals in various exhibitions with the assistance of the postgraduate student whom i would like to thank. The determination of Muhammad Hariz in his effort to continue working on foamed concrete research related to the grant which yet to be completed is gratefully acknowledged. Thank you for contributing 2 conference papers related to this research. The long delays in Muhammad Hariz research due to difficulties in obtaining good quality of palm oil fuel ash has opened a new research on utilizing of low quality palm oil fuel ash in concrete. This research work has been carried out by Mohd Hanafi who manage to develop a new product and patent it as “Green Sand” 2017400010 under this research. A word of thanks also goes to Mohd Hanafi who is in the final stage of his master project research related to palm oil fuel ash. Continuous work hard of Muhammad Nazrin in completing his master research related to this area and helping the team in preparing this report entitled “Properties of Lightweight Concrete Containing Industrial Waste” before graduating this semester is gratefully acknowledged. Thanks for the publication of 2 scopus proceedings papers and 2 conference papers. My sincere appreciation goes to the management of Kilang Sawit Lepar Hilir for providing the palm oil wastes. Thanks to the technical staff at Heavy Structure Laboratory, Faculty of Civil Engineering and Earth Resources of Universiti Malaysia Pahang.

Thank you

PROPERTIES OF LIGHTWEIGHT CONCRETE CONTAINING INDUSTRIAL WASTE

(SIFAT KONKRIT RINGAN YANG MENGANDUNGI SISA BAHAN INDUSTRI)

ABSTRACT

In Malaysia, industrial by-products namely oil palm shell, palm oil fuel ash, fly ash, and coal bottom ash continuously generated in increasing amount over the years. These materials are usually dumped as wastes which cause environmental pollution. Success in utilizing these by-products in production of construction materials would reduce amount of waste disposed. This research was conducted to investigate the properties of lightweight concrete containing industrial wastes as mixing ingredient. Five types of lightweight concrete mixes were prepared consisting of various percentages of industrial ashes. Three types of curing were employed that is water curing, tropical air curing and 7 days initial water curing. The finding shows that selection of suitable type of curing and amount of industrial ashes used would contribute towards concrete strength enhancement. Water curing is recommended for lightweight concrete containing industrial ashes as the continuous presence of water during curing period ensure undisturbed pozzolanic reaction that vital for concrete densification. As a result, the water cured concrete specimens containing 10% ashes exhibit better strength and durability performance at all time.
Water cured specimen exhibit the lowest percentage of water absorbed. Upon exposure to acid and sulphate attack, water cured specimen with 10% ashes exhibit the higher resistance with lower mass loss and strength deterioration value. Using too much of ashes as mixing ingredient in lightweight concrete is not recommended as it cause adverse effect to concrete strength and durability. Conclusively, lightweight concrete produced using industrial ash has the potential to be used in building construction.

ABSTRAK

Di Malaysia, sisa industri sawit tempurung kelapa sawit, abu terbang kelapa sawit, abu terbang arang batu dan abu arang batu semakin banyak dijana dari tahun ke tahun, Kesemua sisa buangan ini lazimnya dibuang di tapak pembuangan sampah yang menyebabkan pencemaran alam sekitar. Pengintegrasian bahan-bahan terbuang ini dapat mengurangkan kuantiti sampah yang dibuang di tapak pelupusan. Justeru itu, kajian ini dijalankan untuk mengkaji sifat-sifat konkrit ringan yang mengandungi sisa buangan industi sebagai salah satu bahan campuran. Sebanyak lima bancuhan yang terdiri dari pelbagai peratusan campuran sisa buangan industri telah digunakan di dalam kajian ini. Tiga jenis kaedah awetan telah digunakan iaitu awetan air dan awetan udara tropika dan awetan air serta udara. Kajian mendapati kaedah awetan dan kuantiti abu buangan industri yang digunakan memberi kesan kepada peningkatan kekuatan konkrit. Penggunaan awetan air adalh disarankan kerana kewujudan air secara berterusan memastikan reaksi pozzolan tidak terganggu. Hasilnya, konkrit ringan yang mengandung 10% abu buangan industri diawet mempamerkan kekuatan dan ketahanlasakan yang lebih baik. Konkrit yang diawet dengan kaedah awetan air mempamerkan nilai penyerapan yang terendah. Apabila didedahkan di dalam persekitaran berasid dan bersulfat, konkrit yang mengandungi 10% abu buangan industri menunjukkan ketahanan yang lebih tinggi dengan nilai kehilangan berat yang rendah. Walaubagaimanapum, pengggunaan abu buangan industri yang terlalu banyak tidak disarankan kerana ia memberi kesan buruk kepada kekuatan dan ketahanlasakan konkrit. Kesimpulannya, konkrit ringan yang dihasilkan dengan menggunakan abu buangan industry berpotensi untuk digunakan di dalam pembinaan bangunan.

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LIST OF SYMBOLS

%	Percentage
MPa	Megapascal
°C	Celcius
mm	Milimeter
m	Meter

LIST OF ABBREVIATIONS

POFA	Palm Oil Fuel Ash
OPS	Oil Palm Shell
LWC	Lightweight Concrete
$Ca(OH)_2$	Calcium hydroxide
CSH	Calcium Silicate Hydrate gel
OPC	Ordinary Portland Cement

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Green technology aims to minimize environment degradation, low greenhouse gas emission, encourage usage of renewable resources and preserve the use of energy and natural resources. In Malaysia budget, Malaysian Government prepared few billion to intensify for green and sustainability awareness. In industry, green technology promotes to minimize the use of energy, water and other natural resources while providing a healthy environment. Issues on increasing utilization of sand and granite in concrete production to meet the continuous demand of construction industry as well as depletion of these aggregate has lead towards efforts in producing a new green concrete material by using by-product from industry as mixing ingredient. Utilization of local generated industrial wastes for material production would help the industry to be more environmental friendly, promote cleaner environment and ensure the healthy surrounding for the local community. In relation to the stated issue, both Malaysian palm oil industry and coal fired electric-power plant generates increasing solid waste which poses negative impact to the environment.

At present, there are more than 5 million hectares of oil palm in Malaysia due to the increasing development of this industry each year since 1971. In worldwide, Malaysia contributes 50% of the total production of vegetable oil production (Embrandiri et al., 2013). The steadily growing palm oil industry has led to generation of the palm oil mill by-product known as oil palm shell (OPS) that will left at landfill. Chong et al. (2013) stated every year palm oil industry approximately produced 6.89 million tonnes of oil palm shell (OPS). According to Muthusamy et al.(2015), increasing by product from oil palm mill will lead toward larger amount of material disposed which consume larger landfills area, more harm to the environment and need more cost to be spent by palm oil mill for waste management. Fly ash (FA) which is a by-product of coal-fired electric power plants also generated in this country. Generally, fly ash are disposed on the landfill and required more area due to large production. Meanwhile, landfill area is a place where all fly ash is disposed and significantly affects the environment state. Jain and Islam (2013) reported that fly ash that left at the landfill without any treatment were lead to leaching of toxic heavy metals happen to water, soil and underground aquifers. The increasing wastage from industry requires more storage area and high economic cost. Thus, innovation of a new concrete product through integration of these freely available industrial would be one of the solutions to convert this environmentally polluting by-product into beneficial material for the development of human civilization.

1.2 PROBLEM STATEMENT

Concrete which is widely used globally possess a drawback as compared to lightweight aggregate concrete in terms of its higher density. Lightweight aggregate concrete is made of combination of cement, water and lightweight coarse aggregate concrete with natural fine aggregate is attractive to the construction industry as it is lighter and ease the construction activity. Among the benefits offered by this lightweight concrete is in terms of reduction in member size, longer spans, improved fire resistance, smaller foundations and better thermal properties. To date, it can be used in a wide range of construction applications such as floor and roof screeds, wall casting, complete house, casting, sound barrier walls, floating homes, void infill, slope protection and outdoor furniture. However, natural lightweight aggregate which is needed for manufacturing of lightweight aggregate concrete is unavailable in this country. Moreover, options of manufacturing the lightweight aggregate to produce this lightweight concrete is energy consuming and less environmental friendly as compared to using locally available material. On top of that, to import lightweight aggregate concrete from overseas would be more costly and not accessible at all-time as wished by local contractors as compared to having it produced in this country using local materials preferably waste materials that would be more environmental friendly.

Besides that, environmental issues caused by increasing sand mining activity and aggregate quarrying to meet the growing construction industry needs to be resolved to ensure healthy life of future generation. Sand mining causes the stream bottom lowers, which may lead to bank erosion. Moreover, the availability of natural sand is decreasing for the last few years (Rashad 2014). This would result in negative impact towards environment if the concrete producer depends solely on natural sand supply due to unavailability of alternative material that can either fully or partially replace the natural sand use. Apart from that, quarrying activity to obtain granite for construction material causes deforestation. Continuous quarrying of this non-renewable resource would result in aggregate depletion and also destruction of flora and fauna. In other words, researchers need to identify alternative materials to reduce the dependency of the growing construction industry on the supply of both natural sand and aggregate which extracted from the environment.

Besides the environmental problem posed by growing construction industry, other industries such as palm oil industry and coal power plant also generates waste that affect the environment. The prosperous Malaysian palm oil industry continue to produce huge amount of oil palm shell (OPS) annually which then disposed as waste. Continuous dumping of this material would consume larger dumping area, worsening environmental pollution and also creates unpleasant views to the surroundings. Muntohar and Rahman (2014) stated waste that produced after extraction process at palm oil mill was one of the contributors to the environment pollution such as air, river, sea and groundwater pollution. Same as stated by Mo et al., (2015d), the OPS were disposed in landfill as a waste and could lead to health-related issues, environmental problems and also financial loss. Other than waste from palm oil industry, fly ash (FA) that is a waste generated from local coal power plant also creates environmental problem. According to Yu et al.(2016), 70% of the by-product from coal industry is FA and the current annual worldwide production of coal ash is about 700 million tons. Malaysian coal fired thermal power plant produces both by products, bottom ash and fly ash. Fly ash is disposed at landfills without any treatment. From the massive production lead to disposal problems such as huge stockpiled in landfills and environmental problems (Arulrajah et al., 2016; Alaka & Oyedele, 2016). Heavy metals can leach from stored fly ash into groundwater and endanger the health of the surrounding population. Also, it would lead to unhealthy to community, spend much more time to manage the waste and lead to high cost.

Realization on the importance of reducing the negative impact of these, research has been carried out to incorporate the waste materials in concrete production. The availability of OPS in abundance has also resulted in development of environmental friendly concrete research . Similarly, the availability of FA as waste also inspired researchers (Zhao et al., 2016; Puthipad et al., 2016; Arulajah et al., 2016) e to integrate it as mixing ingredient in concrete production. However, no research has been conducted by exclusively combining oil palm shell (OPS) as coarse aggregate and fly ash (FA) as fine aggregate replacement in lightweight aggregate concrete production. Incorporation of both OPS and FA would produce green concrete called as OPS lightweight aggregate concrete containing FA as sand replacement. This would also offer the solution to reduce amount of waste ending at landfill and also reduce natural sand consumption. These will help to minimize the environmental impact and to ensure a sustainable development.

1.3 OBJECTIVE OF RESEARCH

The objectives of the present research are as follows:

a) To determine the effect of fly ash content as partial sand replacement on workability and compressive strength of oil palm shell lightweight aggregate concrete.

b) To determine the effect of different curing regimes towards mechanical properties of oil palm shell lightweight aggregate concrete containing fly ash as partial sand replacement.

c) To determine the properties of oil palm shell lightweight aggregate concrete containing fly ash as partial sand replacement in terms of sulphate resistance, carbonation, and water absorption.

1.4 SCOPE OF STUDY

This research concentrates on investigation of mechanical, durability and thermal conductivity of oil palm shell (OPS) lightweight aggregate concrete consisting fly ash (FA) as partial sand replacement. Trial mixes has been carried out by varying the mixing ingredients to produce oil palm shell lightweight aggregate concrete with the targeted workability, compressive strength and density to be used as control mix. After obtaining the best control mix, a series of OPS lightweight aggregate concrete mix design with FA as partial sand replacement comprising different percentage of FA by the total weight of sand namely 10%, 20%, 30% and 40% are prepared. The influence of FA content on the workability and compressive strength of OPS lightweight aggregate concrete has been tested .

Then in the next stage of the experimental work, the hardened concrete were cured using three types of curing regimes namely water curing, 7days water curing + continuous air curing and air curing in order to observe the effect of curing method on the mechanical properties of the concrete. The mechanical properties testing comprising compressive strength test, splitting tensile strength test, flexural strength test and modulus of elasticity test have been carried out on the concrete specimens up to one year of curing age. The durability aspect namely sulphate resistance, carbonation and water absorption of OPS lightweight aggregate concrete have been investigated as well. Other than that, the behaviour of OPS lightweight aggregate concrete towards thermal conductivity were also investigated in this research.

1.5 SIGNIFICANCE OF STUDY

Discovery from this research provide information on the effectiveness of fly ash (FA) content as partial sand replacement towards the mechanical, durability and thermal conductivity of OPS lightweight aggregate concrete. The result from this research also provides more information on the strength performance of OPS lightweight aggregate concrete when subjected to three types of curing regimes. Utilization of FA from coal industry as partial sand replacement and OPS from palm oil industry as coarse aggregate in lightweight concrete production is expected to be able to reduce amount of waste at landfill. In addition, the use of river sand in concrete production can also be reduced thus assisting the construction industry to be more environmental friendly. The smart utilization of FA in concrete production would also assist the coal industry to manage their waste in a more environmental friendly approach. Most importantly, the production of lightweight aggregate concrete using locally available waste materials would be able to provide cheaper and more environmental friendly construction material.

1.6 REPORT LAYOUT

This thesis consists of six chapters that are introduction, literature review, methodology, results of mechanical, durability and conclusion. The first chapter gives a brief description of this study which consists of introduction, problem statement, research objective, scope of research, significance of study and thesis layout. In the second chapter, the reviews of previous paper related to this study were discussed. The early part of the chapter presents literature review on the implementation of green technology in Malaysia and development of local construction industry along with the environmental problem related to it. The next section elaborates about the growing Malaysian palm oil industry and coal industry with waste generation from these industries that creates environmental pollution. After that, discussion on properties of lightweight concrete along with research and development in this research area has been included. Towards the end of the chapter review on the mechanical, and durability has been included.

The third chapter discusses the methodology used in this research. Discussion covers about mixing ingredients, materials preparation, trial mix, experimental program consist of method of testing including the standard used, processes and the work flow that used in this research. All testing process follows the existing standard. Then, chapter four discusses the data obtained from the mechanical and durability properties testing. All the data were analysed and discussed. The influence of curing regimes towards the development of compressive strength, splitting tensile strength, flexural strength and modulus of elasticity were also discussed in this chapter. The analysis on the performance of concrete in terms of sulphate resistance, carbonation and water absorption were included in this chapter. The last chapter concludes the report by drawing conclusions from the experimental results obtained in this research. Several recommendations were also made for further investigation related to this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lightweight concrete has been discovered as one of the most important building material that offers a lower density than conventional concrete while minimizing the structural loads. Lightweight concrete also offers cost savings for handling and transportation. Apart from that, lightweight concrete has the ability to absorb sound as well as being economical. This type of concrete may be demarcated into three types namely no-fines concrete, aerated concrete and lightweight aggregate concrete. At present, Malaysia is the second largest producer of palm oil in the world (Toh, 2017) and one of the coal producer in the world. The presence of waste arising from these industries has created a significant waste management problem. Thus, in order to cater this problem, this research focuses on producing lightweight aggregate concrete using a high amount of such waste products as the mix ingredient. This research is expected to reduce a considerable amount of industrial solid waste dumped at the landfill apart from promoting green technology and sustainability. Developing green technology in building construction would minimize the environmental degradation, reduce greenhouse gas emissions and improve healthy life. This chapter discussed the essential concepts of lightweight concrete behaviour and also by-product from industries.

2.2 National Green Technology

The National Green Technology 2009 policy stems from four perspective pillars namely energy, economy, environment and societal. The first pillar seeks to attain energy independence and promote efficient utilization of energy. Energy is divided into two sectors viz. supply and consumption. Suhaida, Tan, & Leong (2013) reported that the government promotes the application of renewable energy (RE) and energy efficiency (EE) in buildings such as solar photovoltaic (PV), rainwater harvesting, phasing out of incandescent lights, and the application of green building index. The second pillar that is the economy aims to enhance the national economic development through the use of green technology. The third pillar is the environment, in which it aims to conserve and minimize the environmental impact through the reduction of the greenhouse emission, improvement of air as well as the quality of water.

Henceforth, more effort has been adopted to manage and utilize the water resources, wastewater treatment, solid waste and sanitary landfill. Other green building practices such as management, maintenance and the demolition of buildings were also adapted to support the effort. The last pillar which is societal aims to improve the quality of life for all population. The effort is made in order to make sure that more cities and communities appreciate and adopt green technology that will improve the quality of life. In relation to the third and fourth pillar, the present research aims to reduce amounts of oil palm shell and fly ash ending at the landfill that causes pollution to the environment. The success in developing new environmentally friendly building material is envisaged to provide a cleaner and healthier environment for the local communities.

2.3 Malaysia's Construction Industry and Environment

The construction sector is one of the most critical sectors that contributes towards the Malaysian economy and development. The Department of Statistic Malaysia (2016) reported that the construction industry value grew by up to 10.7% with a value worth RM 31.9 billion in the third quarter of 2016. Figure 0.1 shows the construction growth of Malaysia from 2014 to 2016. From the figure, the construction industry witnessed steady growth due to population expansion. These growing sectors will result in more raw materials needed to meet the global construction demand such as sand, aggregate and cement. Nonetheless, this growth has an undesirable effect associated with it namely the massive demand for the aforesaid natural resources that will inadvertently cause the depletion of such raw materials due to the construction activity. This problem leads to new initiatives to ensure that all demand can be fulfilled while ensuring lesser damage to the environment.

Figure 0.1 Construction growth from 2014 to 2016

Source: Department of Statistic Malaysia (2016).

2.3.1 Coarse Aggregate Depletion

It has been established that the aggregate demand and supply are positively correlated in Malaysia, the Philippines, Singapore and Thailand (Bashar, 2009). Malaysia is extremely fortunate to have several distributed natural aggregate resources, with almost every state carrying out its own quarry and aggregate production activities. In 2012, the construction sector in Malaysia recorded the most significant increase compared to other economic sectors, which accounted for 18.1% (CIDB, 2016). The increasing of construction sector will directly increase the demand for raw materials used in construction. The high demand for aggregate would lead to the continuous production of aggregate from quarries on a large scale which in turn, could deplete the aggregate supply. Thus, the construction industry needs to import the aggregate in order to support the demand for materials that in turn would fundamentally increase construction cost. Figure 0.2 illustrate aggregates production in Malaysia from 2008 to 2016.

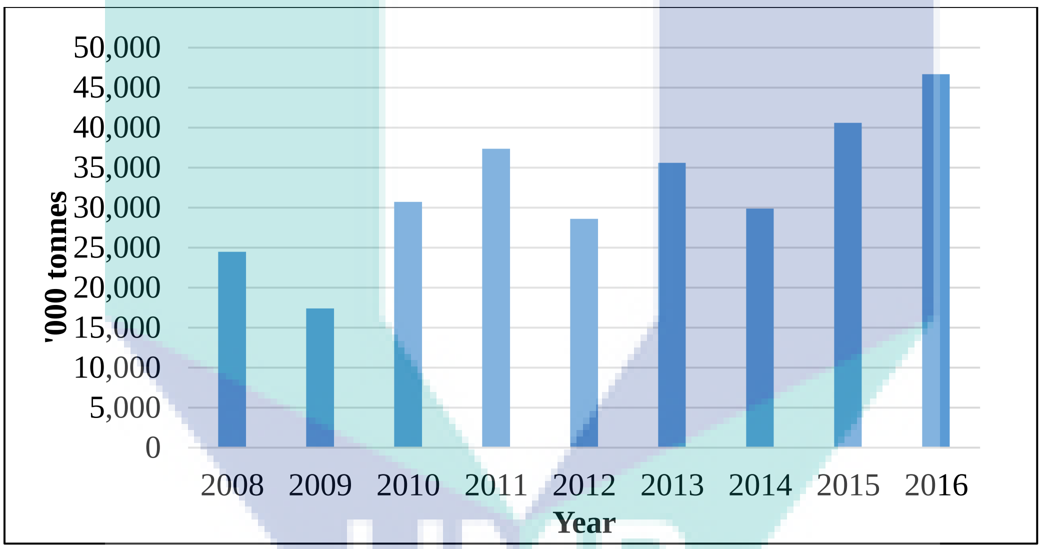

Figure 0.2 Malaysia production of sand and gravel from 2008 until 2016

Sources: Department of Mineral and Geoscience Malaysia (2017)

Table 0.1 shows the aggregate production in Malaysia and number of the quarry for every state. It is apparent that there is an increase in aggregate production from 2007 to 2010. In 2010, there are 101.809 tonnes produced by 298 quarries around Malaysia. Perak had the most number of quarries in 2010 with 57 quarries and produces 13.69 million tonnes of aggregates, while Johor has the second most number of quarries with 43 quarries and produces 26.704 million tonnes of aggregates. In contrast, Perlis and Melaka have the least number of quarries in Malaysia with 2 and 8 quarries, respectively. Although with the recorded growth of this industry, Malaysia has begun to import aggregate from another country. Table 0.2 shows the value and quantity of aggregates imported by Malaysia from other countries such as China, Vietnam, Hong Kong, Indonesia and Philippines from 2008 to 2010. Every year, Malaysia spent millions of ringgit to import aggregates from other countries to meet with the country's demand for aggregates. As a result, the overall cost of construction project increases due to the increasing price of aggregates. From the table, it is evident that the total amount of aggregate imported increased annually.

Table 0.1 Malaysia aggregate production by state (include limestone)

State	2007		2008		2009		2010	
	'000 tonnes	quarry	'000 tonnes	quarry	'000 tonnes	quarry	'000 tonnes	quarry
Selangor	25 283	35	10 998	16	19 643	33	21 612	32
Johor	5 009	31	11 666	34	15 501	35	26 704	43
Perak	14 126	55	17 717	56	13 612	58	13 691	57
Sarawak	6 275	42	8 149	36	8 029	40	9 478	39
P.Pinang	3 220	15	4 086	15	4 994	14	5 098	14
Kedah	2 813	18	3 418	18	4 009	18	4 165	18
Terengganu	5 767	15	5 020	16	4 007	17	3 988	15
Pahang	3 067	24	3 476	25	3 790	25	3 889	25
Melaka	1 446	7	1 935	10	3 353	10	4 139	8
N.Sembilan	3 979	16	3 002	14	3 324	16	3 783	16
Sabah	3 193	40	2 787	16	2 813	17	1 934	17
Kelantan	2 592	12	2 834	11	2 571	11	2 544	11
Perlis	904	2	792	2	852	2	784	2
Total	77 674	312	75 883	289	88 497	296	101809	298

Sources: Department of Mineral an Geoscience Malaysia (2010).

Table 0.2 Malaysia imports of aggregates by country

Mineral	2008		2009		2010	
	Quantity (tonnes)	Value (RM)	Quantity (tonnes)	Value (RM)	Quantity (tonnes)	Value (RM)
China	5397	3575000	63041	5377000	17 334	7459000
Vietnam	8099	2951000	8898	3178000	10 963	3336000
Hong Kong	123	82000	37	73000	16 900	2352000
Indonesia	1972	961000	2686	1304000	1 003 745	2140000
Philippines	10820	5171000	15204	8276000	12 159	5847000
Other	4572	5519000	4315	4830000	7 820	4781000
Total	30981	18259000	94181	23038000	1 068 941	25915000

Sources: Department of Statistic (2010)

Realizing this issue, the non-renewable aggregate should only be used for the production of concrete where needed, such as columns, beams and critical parts of the structure. The uses of lightweight aggregate concrete in the construction of structural building part where it is necessary is a smart approach to reduce high dependency on granite. By considering the use of lightweight aggregate (LWA) in lightweight aggregate concrete production, the granite demand can be reduced. In view of this issue, the present research looks into the potential of palm oil industry waste known as oil palm shell to be used as lightweight aggregate in lightweight aggregate concrete production by entirely eliminating the use of granite as coarse aggregate.

2.3.2 Fine Aggregate Depletion

Sand has by now become the most widely consumed natural resources on the planet after fresh water. Over the last two centuries, sand has become a vital commodity for our modern economies. Most construction buildings are made of concrete which is sand, cement, water and gravel. The growing construction industry in the world consumes a colossal quantity of sand. According to Rashad (2016), the worldwide consumption of natural sand as a fine aggregate in concrete production is very high, and several developing countries have met some limitations in the supply of natural sand to meet the increasing needs of infrastructural development in recent years. Many countries are also facing the scarcity of natural fine aggregate which is suitable for construction. Figure 0.3 shows the increasing value of sand imported for construction in the United Kingdom from 2009 to 2015. From the data, it is apparent that the import value for sand is increasing each year due to the insufficient amount of sand for construction in the United Kingdom. There is an evident increase in imported sand from 2010 to 2014 and 2014 to 2015 with 63% and 54%, respectively.

The continuous mining and use of natural sand would lead to the deterioration of river beds resulted in ecological imbalance. These activities cause destruction of habitat of aquatic wild life and lower the water quality. Moreover, as the sand supply began to decrease, the price increased due to insufficient supply. As suggested by Rashad (2016), there are countries affected by the issue of the depletion of natural sand for the use in construction industry. Thus, the shortage of resources of natural sand had opened the door for using by-products as fine aggregate in the production of concrete.

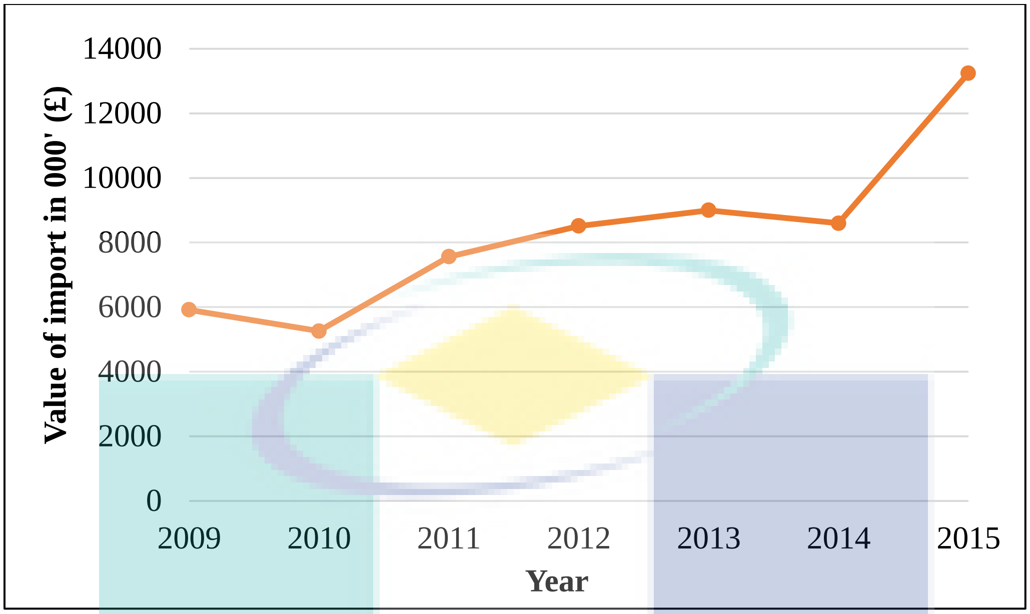

Figure 0.3 Value of sand imported for construction in the United Kingdom (UK) from 2009 to 2015 in thousand British pounds

Sources: https://www.statista.com/statistics/473275/construction-sand-import-uk/

2.4 Lightweight Concrete

2.4.1 Properties

Lightweight aggregate concrete is produced using cement, sand, lightweight aggregate, superplasticizer, and water. According to Neville (2011), lightweight aggregate concrete density varies between 300 to 1850 kg/m^3. Lightweight aggregate is high in porosity, which results in the decreasing density of concrete. The density of lightweight aggregate concrete is mainly affected by the type of aggregate used. If the texture of the aggregate is porous, more water required to fill the pores that will result in decreasing concrete workability and thus decrease its density (Hoff, 2002). On the other hand, the use of a lightweight aggregate with less porosity would result in concrete with higher density. Proper compaction will ease the placement and result in a denser concrete. This process significantly prevents honeycombing on the finished concrete thus preventing water ingress making it denser. The application of appropriate curing process is essential to ensure that cement undergoes improved hydration that is vital for the continuous development of strength and durability properties. This is primarily due to the production of C-S-

H gel that would increase the packing microstructure, refines the microstructure of concrete thus creating a much denser pore structure

According to Neville (2011), lightweight aggregate concrete strength begins at 0.3 MPa and can be increased up to 70 MPa. Such wide range of compressive strength is due to different type, texture and density of coarse aggregate used (Mehta and Monteiro, 1993). The strength of lightweight aggregate concrete is relatively lower than ordinary concrete due to its lower value of density as a result of porous aggregate used. However, lightweight aggregate concrete made from rotary kiln expanded shale, clay or slate and sintered expanded shale or clay provides the same compressive strength as normal weight aggregates with approximately the same cement content. Shafigh et al. (2014) managed to produce LWAC using waste from palm oil with strength around 30 to 40 MPa. The compressive strength of concrete with larger aggregate is lower than the concrete with the smaller size of aggregate due to it easily pack and lock to each other. Alengaram et al. (2011) remarked that the factors that influence the modulus of elasticity are aggregate stiffness, hardened cement matrix and aggregate bond in concrete. The modulus of elasticity of lightweight aggregate concrete differs from ordinary weight concrete due to the strength of lightweight aggregate used.

2.4.2 Application

Lightweight aggregate concrete (LWAC) is widely known as one of the materials used for the concrete in building construction. Lightweight aggregate concrete often called structural lightweight aggregate concrete with regard to the applications in buildings, bridges and offshore structures. The use of this concrete contributes to the reduction of load of the building that contributes to the reduction of the size of column, beam or foundation. This contributes to the cost reduction in the construction project. This material which is easier to be handled at construction owing to its lightness makes it more attractive to the builders. Number of formworks used in the construction also can be reduced as well. A large number of the lightweight concrete products has been used in building industry. LWAC can be divided into two types which are partial compacted LWAC and structural LWAC. Partial compacted LWAC usually used for precast concrete blocks, panels and walls. The structural LWAC can be used as normal concrete. Apart from low density, other desirable LWAC physical properties such as heat insulation, thermal acoustic application, void infilling, bridge approached for undulating prevention amongst others, has made LWAC become one of the most popular materials used in the industry. LWAC's good thermal efficiency contributes to the heating and cooling in buildings. It has also been used effectively in filling voids, walls, partitions, panels and many more. LWAC is also efficiently usable in high-rise buildings and bridges. Conclusively, architect, engineers and contractors are fond of using LWAC in construction nowadays due to its various advantages that provide maximum profit to the project.

2.4.3 Contribution

Lightweight aggregate concrete (LWAC) has gained popularity as an alternative to ordinary concrete for structural purposes. Amongst the advantages LWAC for structural purpose are it reduces self-weight that lead to the smaller size of footing, environmentally friendly, high strength, low expansibility, good heat insulation, sound dampening qualities, water and fire resistance, durable, stable volume, ease of use for construction, and low cost. Moreover, the weight reduction of the structure, reduces amount of construction materials used such as concrete and steel reinforcement, thus lower the cost of the construction. Structural lightweight concrete has obvious advantages such as higher strength/weight ratio, better tensile strain capacity, lower coefficient of thermal expansion, and superior heat and sound insulation due to air voids in the lightweight aggregate. In addition, the reduction in a dead load of a construction by the use of a lightweight aggregate in concrete could result in smaller size of structural element of the building. The use of structural lightweight concrete reduces the self-weight of a structure and permits larger precast units to be handled. There are also lightweight aggregate concrete (LWAC) which is made of artificial LWAs such as expanded clay, slate, shale, or blast furnace slag, is a type of environmentally-friendly material for the construction industry. The main specialities of lightweight concrete are its low density and thermal conductivity. Its advantages are the reduction of dead load, faster building rates in construction and lower haulage or handling costs.

2.5 Concrete Durability Properties

2.5.1 Sulphate Attack

Sulphates in the soil can be dissolved and cause damage to foundations, retaining walls, and other underground concrete structures when exposed to groundwater. Sulphate can attack concrete by reacting with hydrated compounds in the hardened cement paste. These reactions induce sufficient pressure that causes disintegration of concrete. The disintegration is due to calcium sulphate that attacks calcium aluminate hydrate, forming calcium sulfoaluminate which is known as ettringite. Ettringite will accommodate the void space then will cause expansion in concrete. According to Neville (2011), concrete that attacks by sulphate could have a whitish appearance. Concrete subjected to sulphate attack undergoes expansion, mass reduction and finally strength loss when the aggregate detached due to crack in concrete. The damage usually begins at edges and corners of concrete, followed by progressive cracking and spalling which turn the concrete into a soft state.

The rate of deterioration increases with the increase of sulphate concentration in the cement. Other factors that influence sulphate attack to concrete are type and concentration of sulphate, flow of groundwater and rate of reaction with hardened concrete. Chemical reactions that generally involved in the formation of expansive products in hardened concrete can lead to severe deterioration. The most effective way to prevent sulphate attack is by using cement with C_3A content. Other than that, good compacted concrete which is dense would exhibit higher resistance to sulphate attack. The use of pozzolana that converts leachable calcium hydroxide into C-S-H gel reduces the susceptibility of concrete to attack by sulphate.

2.5.2 Carbonation

Carbonation is a chemical phenomenon of reaction between carbon dioxide and calcium hydroxide to the concrete. Carbonation reduces the alkalinity of concrete and exposed the steel to corrosion problem. The degree of such damage depends mainly on the structure and connectivity of pores, which control the penetration of sulphates into the concrete. Several factors affect the pore structure including the concrete constituents, mixture proportions and the curing process. Concrete permeability, moisture content, environmental CO_2 content and relative humidity influence the carbonation rate of concrete. The carbonation of the concrete is the reaction of carbon dioxide with calcium hydroxide $Ca(OH)_2$ in the presence of moisture and its conversion into $CaCO_3$. It causes the alkalinity of the concrete to reduce which is important for corrosion protection of the steel reinforcement.

The carbonation process runs slowly but continuous inside concrete from the surface until inner concrete. The carbonated zone of concrete that change $Ca(OH)_2$ to $CaCO_3$ would remain colourless when phenolphthalein indicator is sprayed on the concrete surface. However, the zone with pH value more than 9.5 changed to pinkish purple in colour. Furthermore, carbonation in concrete significantly increased with low cement content, short curing period, low strength and high permeable paste. As carbon dioxide diffuses into the hardened concrete through pores, the most efficient way to prevent is to seal the concrete surface using coating or painting. This problem can be solved by producing more compact concrete with fewer voids. Other than that, applications of proper curing technique in terms of adequate and suitable curing period able to increase the denseness of the concrete thus increase its durability against carbonation. Utilization of water curing technique slows the carbonation process as compared to air cured concrete specimen.

2.5.3 Water Absorption

Water absorption of concrete is an indicator of the pore contained in the particular concrete which is correlated with a linear relationship. Higher water absorption of concrete could indicate more possibility of chemical penetration. Water absorption test could be used to measure the concrete's ability to absorb water. Most good concrete has absorption below 10% of their mass (Neville, 2011). There are few factors that influence the rate of absorption in concrete which is the volume of cement paste in the specimen, water to binder ratio and also the curing condition. Curing method gives huge influence to the concrete absorption. Improper curing such as curing in hot weather would make excessive heat loss during hydration. This would increase the absorption of the concrete due to high porosity. Furthermore, the rate of water absorption can be influenced by temperature and type of binder. Concrete with larger pores resulting from improper curing method and poor compaction would absorb larger amount of water compared to the one with lower quantity of pores. High water absorption would in turn, decrease the resistance of concrete to aggressive environments such as acid attack, sulphate attack and carbonation attack.

2.6 Industries in Malaysia, Waste Generation and Pollution

Over the years, industries in Malaysia such as palm oil industry and coal industry continue to grow along its growing population creating more job opportunities. The growing demand for palm oil products causes the production of palm oil continues to increase. Malaysia is one of largest palm oil producer in the world. The estimation made by (MPOB, 2014) shows that the demand for global palm oil would be 68 million tonnes in 2020 and will increase to 77 million tonnes on 2050. Being the second largest palm oil producing country in the world, Malaysia is also responsible for producing a large amount of palm oil waste. After the palm oil industry process, it produces lots of by-products such oil palm shell which dumped at the landfill without any profitable value and thus requires larger area for dumping site. It is estimated that 6.89 million tonnes of OPS are produced annually that are ended up as waste (Chong et al., 2013). The waste produced is dumped daily causing storage problems and affect the environment (Yew et al., 2014).

At the same time, the local coal industries also growing along with the increasing demand. Coal is one of Malaysia's current domestic energy mix under Malaysia's Five-Fuel Policy; There is seven coal power plant that is in operation in Malaysia. The electricity demand is increasing due to economic growth that leads to the increase in the production of coal-fired plants. Indirectly, it will generate more waste dumped at the landfill. Fly ash is one of the incombustible mineral residues produced from the combustion of pulverized coal in the boilers at thermal power plants. The huge volume of FA remained unutilized and dumped in the landfill (Alaka & Oyedele, 2016) and it has created a worldwide problem that is not limited to Malaysia. The stockpiling fly ash would leach out due to rainfall into the soil layer beneath it. Depending on the soil type, the leaching could be severe enough to enter shallow aquifers. Leachate which is full of toxic substances may contaminate the groundwater and soil. Substances from FA can leach into the soil, surface water and groundwater. Heavy metals lead to major health problems, and the contaminated water would harm the health of living things. Thus, it is seen that the utilization of fly ash in replacing the sand in OPS lightweight aggregate concrete mixture would help to reduce the amount of fly ash dumped at the dumping site.

2.7 Utilization of Industrial Wastes in Concrete Research

Realization on the importance of integrating industrial by-products in production of other materials has resulted in many researches in concrete material area. The abundantly available palm oil wastes have inspired researchers to produce environmental friendly concrete using these wastes. Past researchers (Mannan and Ganapathy, 2002; Alengaram et al., 2011 and Shafigh et al., 2011) agreed that OPS is suitable for substituting aggregates to produce lightweight concrete as it is light, natural in size, being hard and organic origin that will not give effect to the concrete. When the OPS is utilized in concrete, the density of concrete is about 1900 kg/m^3 which makes the concrete lightweight Teo et al. (2006). Since this lightweight concrete requires fine aggregates in its production, usually river sand is used as mixing ingredient. The range of fine aggregate used in previous research is around 650 to 1050 kg/m^3 (Islam et al., 2016). The huge amount of fine aggregate used in producing LWAC would lead towards depletion of natural lightweight fine aggregate. Thus, the utilization of locally available industrial waste material as partial sand replacement in OPS LWAC would assist towards the reduction of high natural sand consumption and at the same time promote towards greener building construction material.

At the same time, fly ash which is a type of industrial ash have also been used as mixing ingredient in concrete. Numerous researchers used fly ash (FA) as cementitious materials (Kayali & Sharfuddin Ahmed, 2013; Arezoumandi & Volz, 2013; Wang & Park, 2015; Shaikh and Supit, 2015; Teixeira, Mateus, Camoes, Braganca, & Branco, 2016; and Sto-Perez & Hwang, 2016). Previously, fly ash has been used in concrete at levels ranging from 15% to 25% by mass of the cementitious material component. The use of fly ash of more than this range would produce concrete with slow strength development which leads to low early-age strength. This industrial ash also has been used as partial sand replacement in concrete by previous researchers (Jain and Islam, 2013; Parvathi and Prakash, 2013; Thomas and Nair, 2015). However, it is worth noting that industrial waste ash such as fly ash has never been utilized as sand replacement in this lightweight concrete. The mechanical and durability performance of lightweight concrete containing industrial ash as partial sand replacement when subjected to different curing method is yet to be investigated.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses in detail the procedure carried out in conducting the experimental work and laboratory test to achieve the objectives of the present study. At the beginning of this chapter, the details of ingredient and preparation of material used for mixing is presented. A brief explanation of trial mix method used to produce lightweight concrete containing industrial waste ash is also included. The detailed method of mechanical properties testing conducted such as compressive strength, flexural strength test, splitting tensile strength test and modulus of elasticity were also discussed. Durability testing namely sulphate attack, carbonation and water absorption were also discussed in the last section of this chapter.

3.2 Mixing Ingredients

Six main ingredients namely ordinary Portland cement (OPC), oil palm shell, sand, fly ash (FA), water and superplasticizer were used to produce specimens for this experimental work.

3.2.1 Cement

ORANG KUAT Portland Cement brand was used throughout this experimental research. This type of cement complies with Type 1 Portland cement conforming to MS 522: Part 1 (2003) for Portland cement specification and suitable for structural concreting precast, brickmaking and all general purpose applications. Table 0.1 shows the chemical composition of OPC.

Table 0.1 Chemical composition of ordinary Portland cement

Composition	Percentage (%)
Silicon dioxide (SiO_2)	9.42
Aluminium oxide (Al_2O_3)	1.82
Iron oxide (Fe_2O_3)	3.09
Calcium oxide (CaO)	56.97
Magnesium oxide (MgO)	0.37
Potassium oxide (K_2O)	0.68
Sulphur trioxide (SO_3)	3.13
Loss of ignition (LOI)	3.2

3.2.2 Oil Palm Waste

Oil palm shell (OPS) was used to fully replace conventional coarse aggregate to produce lightweight concrete. Oil palm shell (OPS) were collected from a palm oil mill located in the state of Pahang. At the laboratory, the shells were washed using tap water before oven-dried at 110 ± 5°C for 24 hours. The physical properties of processed OPS are tabulated in Table 0.2.

Table 0.2 Properties

Physical Properties	OPS
Specific gravity (kg/m^3)	1.37
Water absorption (24 hours) (%)	12.47
Moisture content (%)	12.45
Aggregate abrasion value, Los Angeles (%)	7.6
Bulk density (kg/m^3)	568
Fineness modulus (FM)	6.53
Flakiness index (%)	38.63
Elongation index (%)	98.74
Aggregate impact value (%)	18.18
Aggregate crushing value (%)	14.84

3.2.3 Sand

River sand was used as fine aggregate in this study. It acts as filler to fill up all possible voids in order to produce denser concrete. The sand was protected from getting wet due to excessive moisture condition or rain before use. The specific gravity, fineness modulus and water absorption values of the sand are 2.68, 2.72 and 0.82, respectively.

3.2.4 Fly Ash

Fly ash (FA) was used as partial lightweight fine aggregate to produce lightweight aggregate concrete in this research. The FA was collected from a coal-fired plant located in Selangor, Malaysia. FA taken was stored in a clean and dry room to ensure its purity. Table 0.3 shows the chemical composition of FA. Following the standard ASTM C618 (2005), this FA we classified in Class F. The specific gravity for this FA is 2.3 while fineness modulus was 2.51.

Table 0.3 Chemical composition of Fly Ash

Chemical Composition	Percentage (%)
Silicon dioxide (SiO_2)	39.0
Aluminium oxide (Al_2O_3)	28.7
Iron Oxide (CaO)	20.3
Potassium Oxide (K_2O)	2.1
Iron Oxide (Fe_2O_3)	8.9
Copper (CuO)	0.1
Manganese (MnO)	0.1
Loss of Ignition	2.0

3.2.5 Water

In this experiment, tap water supplied by Pengurusan Air Pahang Berhad (PAIP) was used in the production of the concrete specimen. Water in concrete is needed to initiate the cohesive properties of the binder Portland cement through hydration process. Distilled water was used during the preparation of chemical solutions for research involving durability testing against the aggressive environment.

3.2.6 Superplasticizer

The superplasticizer used throughout this research is Sika Visco-Crete®-2199. SIKA ViscoCrete®-2199 meets the requirements of Type A water-reducing admixtures as stated in ASTM C494 (2005). Its chemical base is modified polycarboxylate and brownish in colour.

3.4 Trial Mix for Optimum Lightweight Concrete Mix

3.4.1 Trial Mix

In this research, the trial mix method was used to produce the best lightweight concrete mix. According to Shetty (1982), mix design methods applying to normal weight concrete are generally difficult to use with lightweight aggregate concrete. In this research, the minimum targeted compressive strength is 25 MPa and lower than 1850 kg/m^3 for dry density. According to ASTM 330 (2009), the benchmark strength for structural lightweight concrete is 20 MPa. For the first stage, plain OPS LWAC was prepared. It was used as a control specimen in which OPS act as coarse aggregate. After the control mix was established, FA was added in OPS LWAC which act as partial sand replacement. Various percentage of FA was used that is 10%, 20%, 30% and 40% by weight of sand while other mixing ingredients were kept fixed. The chosen OPS LWAC with FA as partial sand replacement mixes were tabulated in Table 3.4. Then, the samples were tested for mechanical properties and durability properties up to 9 months of curing age.

Table 3.4 Selected mix design.

Materials	Mass (kg)				
	PC	10%	20%	30%	40%
Ordinary Portland Cement	450	450	450	450	450
Oil Palm Shell (OPS)	310	310	310	310	310
Fly Ash (FA)	0	65	130	195	260
Sand	650	585	520	455	390
Water	225	225	225	225	225
Superplasticizer	4.5	4.5	4.5	4.5	4.5

3.4.2 Lightweight Concrete Production

In order to produce OPS LWAC, several steps of preparation were conducted. Firstly, the concrete mixer used for concrete mixing was ensured clean and free from any debris. Subsequently, all the ingredients such as oil palm shell (OPS), cement, sand, fly ash (FA), water and superplasticizer were weighed to the required amount accurately. All the materials were mix using mixer until the uniform mix was acquired. Then, the slump test was conducted. Upon the completion of mixing process , the mix was taken out, filled inside the mould and placed on the vibrating table for compaction process. After compaction, the mould was covered with wet gunny sack and then kept overnight before demoulded. After demoulded, the specimens were marked and subjected to the curing process.

3.5 Experimental Program

The mechanical properties of the specimens that are compressive strength, splitting tensile strength test, flexural strength and modulus of elasticity were investigated using cube (100 x 100 x 100 mm), cylinder (Ø150 x 300 mm height), prism (100 x 100 x 500 mm) and cylinder (Ø100 x 200 mm height) respectively. The durability testing involved in this research are sulphate resistance test, water absorption test and carbonation resistance. For sulphate resistance test and water absorption test, 100 x 100 x 100 mm cubes were used. Carbonation test was tested using beams (100 x 100 x 500 mm) and cured up to 9 months. All the specimens were cured under three types of curing process namely water curing, initial water curing and tropical air curing. Various curing method is used to determine the best curing effect towards OPS LWAC with FA. The detail explanation of the curing methods is listed in Table 3.5.

Table 0.5 Concrete curing process

Type of Curing	Explanation
Water curing	Specimen was immersed in water tank until the age of testing
Initial water curing	Specimen was immersed in water tank for 7 days then take out from water tank until the age of testing
Tropical air curing	Specimen was placed in concrete laboratory until the age of testing

3.6 Properties Measurement

3.6.1 Slump Test

Slump test is conducted to assess the effect of fly ash (FA) content as partial sand replacement on workability and consistency of fresh concrete. The test was conducted according to BS 12350: Part 2 (2000). Before conducting the test, the internal surface of the mould was cleaned thoroughly and freed from superfluous moisture. The mould was then placed on a smooth, horizontally levelled rigid and non-absorbent surface such as a rigid plate. During the filling process, the mould was held firmly in place by standing on the two-foot pieces provided in the slump cone as shown in **Error! Reference source not found.**. The mould was filled in three layers, each approximately one-third of the height. Each layer was rodded 25 times to ensure proper compaction. The third layer was finished off level with the top of the cone. The cone was carefully lifted up then the upturned slump cone was placed on the base to act as a reference. The difference in level between its top and the top of the concrete was measured and recorded to the nearest 5 mm .

3.6.2 Compressive Strength

Compressive strength test is conducted to determine the concrete strength of concrete cubes. This test was conducted to investigate the effect of fly ash content as partial sand replacement on OPS LWAC. The effect of curing methods on the strength performance of OPS LWAC with FA is investigated. The compressive strength of the specimens was tested according to BS EN 12390: Part 3 (2009). All the specimens were tested at 7, 28, 60, 90, 180 and 270 days of concrete age. During the compression test, concrete specimen surface is subjected to the compression load to determine its strength and obtaining the maximum load. Before testing, the machine surface was ensured clean to ensure no error happen while tested and the concrete was wiped. The samples were weighed to determine the wet density of the concrete. The width and the thickness of the cube were measured and used to key in the data for the compression test. The concrete sample was placed at the centre of the lower plate, and the load was applied. The maximum concrete strength was directly taken from the machine.

3.6.3 Flexural Strength Test

Flexural strength is the ability of a beam to resist failure in bending. The flexural strength of OPS LWAC for both control and the one containing fly ash (FA) was tested in accordance with BS EN12390: Part 5 (2009), by using prisms of 100 x 100 x 500 mm. The machine used for this testing is unit test machine as shown in **Error! Reference source not found.**. The specimens for flexural strength test consist of 54 plain OPS LWAC prisms and also 216 OPS LWAC prisms containing fly ash of various percentages. All the specimens were subjected using three different types of curing regimes namely water curing, initial water curing and air curing. The test was carried out at the age of 7, 28, 60, 90, 180 and 270 days. The prisms were tested out by using a flexural testing machine with centre point loading. After the prism split up, the maximum load read known as the breaking load was recorded. The value of flexural strength f_{cf} was calculated by using Equation 3.2 (BS EN 12390-5, 2009).

$$f_{cf} = \frac{\mathrm{F\ x\ l}}{d_1 \mathrm{\ x\ } d_2^2} \tag{3.2}$$

Where,

F	=	the breaking load (N)
d_1 and d_2	=	the lateral dimensions of the cross sections (mm)
l	=	distance between the supporting rollers (mm)

3.6.4 Splitting Tensile Strength Test

Splitting tensile strength test is conducted to determine the effect of FA content as partial sand replacement on the tensile strength of OPS LWAC. The splitting tensile strength of concrete samples was determined according to ASTM C496 (2004). In this research, a total of 270 number of cylinders (150 mm diameter x 300 mm height specimens) were made. Three types of curing were used that are water curing, initial water curing and air curing. All the specimens were tested at 7, 28, 60, 90, 180 and 270 days of concrete age. The concrete cylinder specimen was placed horizontally between loading surface of compression test machine as in **Error! Reference source not found.**. The compressive force was applied along the length of a cylindrical concrete specimen at a rate until failure occurs. The splitting tensile strength was obtained by using Equation 3.3.

$$T = \frac{2P}{\pi \, l \, d} \tag{3.3}$$

T= splitting tensile strength,

P = total applied load,

d = diameter

l = Length

3.6.5 Modulus of Elasticity

Modulus of elasticity also known as Young's modulus or tensile modulus. It used to determine concrete ability to maintain its original form when load and stretched. The test was done according to BS 1881-121 (1983) by means of a compressive machine shown in **Error! Reference source not found.**. In this research, 270 number of 100 mm diameter x 200 mm height cylinders specimens were made. Three types of curing were used that are water curing, initial water curing and air curing. All the specimens were tested at 7, 28, 60, 90, 180 and 270 days of concrete age. The surface of the specimens was attached with two strain gauges at the centre of the specimen with the distance of not less than 1/4 of the length of the specimen from the end. After that, it was placed axially at the centre of the machine before the testing commenced. The moulded concrete cylinder was subjected to a slowly increasing longitudinal compressive stress. The modulus of elasticity was calculated by the static modulus of elasticity in compression, E_c equation as shown in Equation 3.4 (BS 1881-121, 1983).

$$\frac{\Delta\sigma}{\Delta\varepsilon} = \frac{\sigma_a - \sigma_b}{\varepsilon_a - \varepsilon_b} \tag{3.4}$$

Where,

σ_a = upper loading stress (N/mm^2)

σ_b = basic stress (0.5 N/mm^2)

ε_a = mean strain under the upper loading stress

ε_b = mean strain under the basic stress

3.6.6 Sulphate Resistance Test

Sulphate resistance test was conducted in order to determine the durability performance of OPS LWAC containing FA as partial sand replacement performance towards sulphate attack. The sulphate solution was prepared according to ASTM C1012 (2015). The degree of sulphate attack was evaluated by measuring strength reduction and mass loss of samples of 100 x 100 x 100 mm concrete cubes. The samples prepared consisted of control specimen and OPS LWAC containing various FA content and cured for 28 days using three type of curing regime namely water curing, initial water curing and air curing. Then, six specimens from each mix were immersed in 5 % sodium sulphate (Na_2SO_4) solution for 9 months as in **Error! Reference source not found.**. Mass measurement and visual assessment of the concrete were conducted every week until the age of 9 months. The compressive strength test was conducted at the end of the testing date in order to determine the strength reduction after the lightweight aggregate concrete was immersed in a sulphate solution.

3.6.7 Carbonation Resistance

Carbonation test was conducted according to BS EN 14630 (2006). This test was conducted to determine the carbonation depth of OPS LWAC containing various percentage of FA. In this research, the concrete prism specimens were prepared, and all the specimens were cured using three types of curing regime up to 9 months. Before starting the carbonation test, the sample was split up, cleaned and brushed. Then, in order to determine its carbonated area and thickness, the indicator was sprayed on top of the concrete surface. The phenolphthalein indicator would remain colourless when sprayed on the carbonated area which shows that the concrete has lost its alkalinity with pH below 8.6. The depth of colourless region was measured using calliper which indicated the degree of carbon dioxide-induced. On the other hand, the indicator would change to pink colour when contacted with a non-carbonated area with pH was above 8.6.

3.6.8 Water Absorption Test

This test method determines the rate of absorption of water by OPS LWAC containing FA. The characterization of pores structure in concrete can be determined using water absorption testing according to BS 1881: Part 122 (2011). In this research, 100 mm x 100 mm x 100 mm cube specimens were made with various percentage of FA. All the specimens were cured for 28 days of curing age before subjected to testing.The specimens were dried after taken out from curing tank. After that, the specimens were cooled before weighted and recorded. These specimens were then oven- dried for 24 hours at the temperature 110°C until the mass became constant and again weighed. This weight was noted as dry weight (m_1). After that, the specimen was kept in water for 30 minutes and recorded as wet weight (m_2). Lastly, water absorption was calculated by following Equation 3.5.

$$\%\ of\ water\ absorption = \frac{m_2 - m_1}{m_1} \times 100 \tag{3.5}$$

Where,

m_1= weight of specimen after dried up

m_2= weight of specimen after immersed in water

CHAPTER 4

MECHANICAL AND DURABILITY PROPERTIES

4.1 Introduction

This chapter discussed the effect of POFA content towards dry density, mechanical and durability properties of oil palm shell lightweight concrete. The beginning of this chapter discusses the dry density of this type of concrete when subjected to different types of curing for 28 days. The mechanical and durability properties were discussed throughout this chapter. All samples were subjected to different types of curing regimes namely water curing, initial water curing air curing.

4.2 Fresh Properties

The effect of fly ash as sand replacement in all mixes of concrete on slump values was illustrated in 4.1. The workability of concrete reduces as more fly ash is added as partial sand replacement. The workability of control specimen and the one containing 10% fly ash is within the targeted range and can be categorize as true slump. Utilization of fly ash replacement of 20%, 30% and 40% resulted in significant loss of workability. The mix become more difficult to be mixed as larger quantity FA is integrated as partial sand replacement. Therefore, the suitable percentage of FA to be used to produce OPS LWAC with FA within the target workability is 10%. This result is in line with finding of other researcher (Parvati & Prakash, 2013 and Shaikh & Supit, 2015).

The decrease in slump values is mainly attributed to the cohesive and stiffer mix resulted by higher fly ash content. This occurred when the dosage of fly ash was increased further, a number of porous structure of fly ash will absorb part of the moisture so that the water needed for mixing will be reduced. As stated by Wang & Wu (2006), fly ash have a porous structure and a hydrophilic surface. Due to the porous spherical shape of fly ash, the ball bearing effect does not contribute toward enhancement of concrete workability although the fly ash particles are hard and round.

Apart from that, since fly ash particles are finer than river sand, the requirement of water increases at higher replacement levels which results in the lowering of adhesion of concrete matrix causing lower workability. This results in the-non homogeneity of the mix when 20% of fly ash was utilized in OPS LWAC. SEM images of sand and fly ash as indicated in Fig.. 4.2 clearly shows that fly ash particles are finer than river sand. Figure 4.3 illustrates the slump height with increasing fly ash replacement. In this research, use of FA of 10% is the optimum percentage of replacement which contribute towards the most workable mixes.

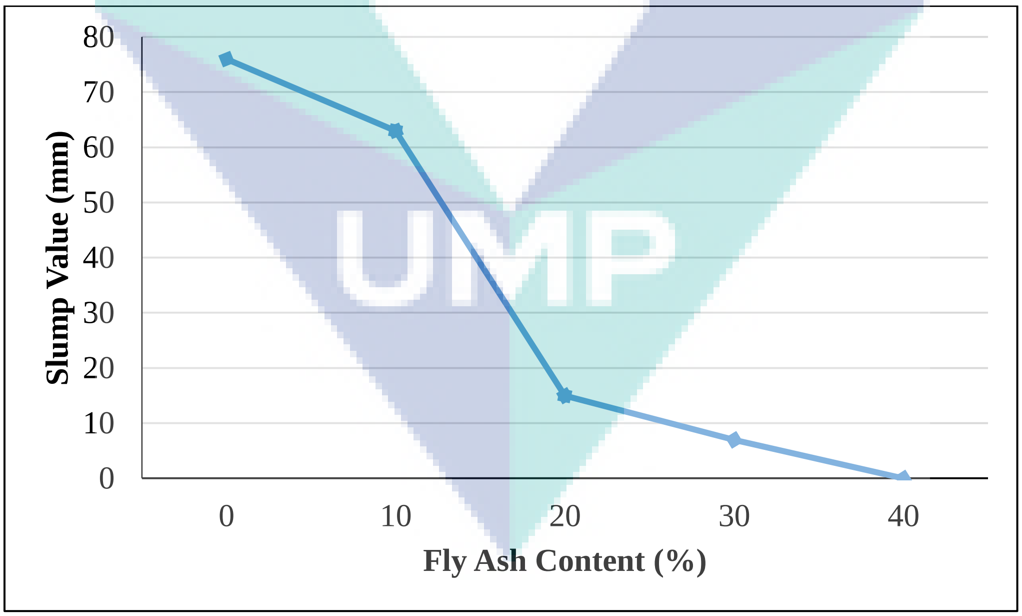

Figure 0.1 Workability of concrete mix with percentage of FA

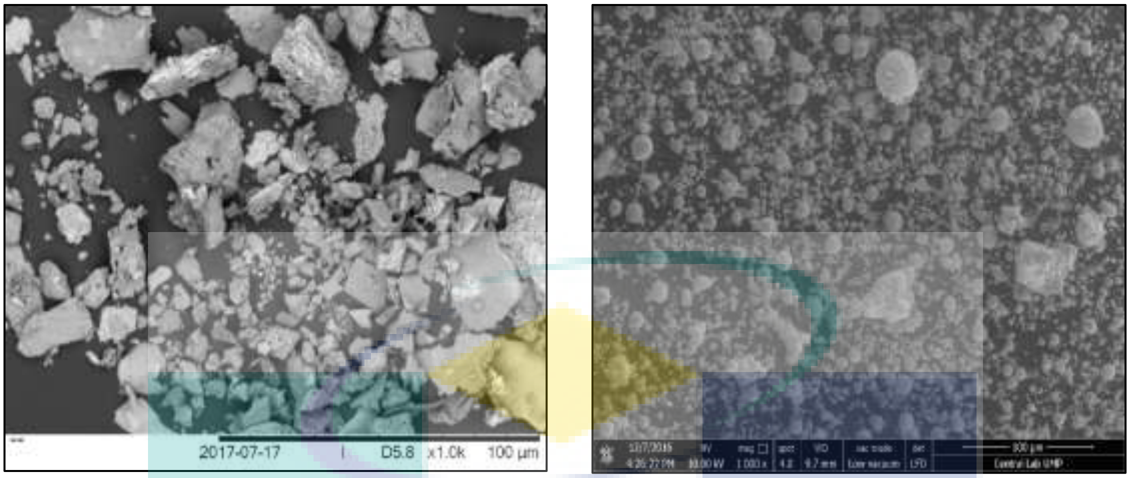

Figure 0.2 SEM of sand and fly ash under 1000x magnification

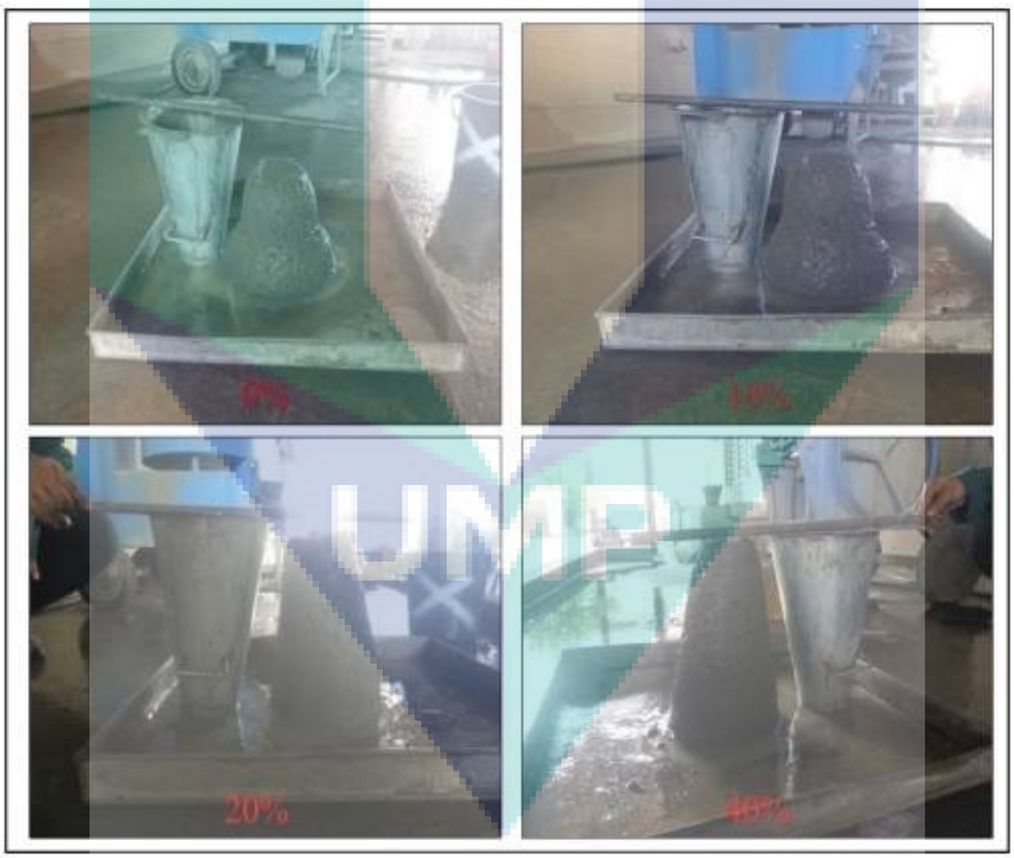

Figure 0.3 Slump for the replacement of sand by fly ash

4.3 Compressive Strength

The compressive strengths data for 7, 28, 60, 180 and 270 days of age of OPS LWAC with and without FA upon subjected to different curing regimes namely water curing, and initial water curing and air curing are show in Fig. 4.1,4.2 and 4.3. The curing types used influence the strength development of concrete specimen. From the data collected, the highest compressive strength value of OPS LWAC with FA were water curing specimens followed by 7days water curing + continuous air curing and lastly air curing. Water curing become the best curing because the continuous present of water were prevents excessive loss of moisture and allow controlling the evaporation of moisture from the concrete specimens surface. Also it helped in hydration process that would effect to concrete specimens strength.

On the other hand, specimens cured under air curing exhibits the lowest strength for all percentages of fly ash replacement. It is known that water is essential for hydration process in concrete and for pozzolanic reaction to take place. The absence of water interrupts the strength forming by calcium silicate hydrate gel producing weaker concrete than other types of curing regime. This situation is also reported by Muthusamy & Zamri (2016) when adopting different types of curing regime in oil palm shell lightweight aggregate concrete containing palm oil fuel ash. Thus, it can be concluded that continue water curing is the most suitable curing regime for OPS lightweight aggregate concrete produced by incorporating fly ash as partial sand replacement.

Between all the mixes, FA-10 produced the highest strength than other specimens (FA-0, FA-20, FA-30 and FA-40) when cured in water, air and subjected to initial water curing. Haneef, Kumari, Mukhopadhyay, & Jayakumar (2013) stated that compressive strength of concrete containing fly ash were influence by pozzolanic reaction in fly ash and curing period of the concrete. Through pozzolanic reaction, secondary C-S-H gel was produced improving the concrete pore structure thus becoming stronger. However, integration of higher volume of fly ash of more than this optimum amount (10% fly ash) would only decrease the overall strength significantly. Too much of fly ash will not generate a higher strength development since lower content of calcium hydroxide produced from hydration process. Fly ash particles which is porous produces stiffer mix when utilized of more than optimum content producing concrete with poor compaction and lower strength.

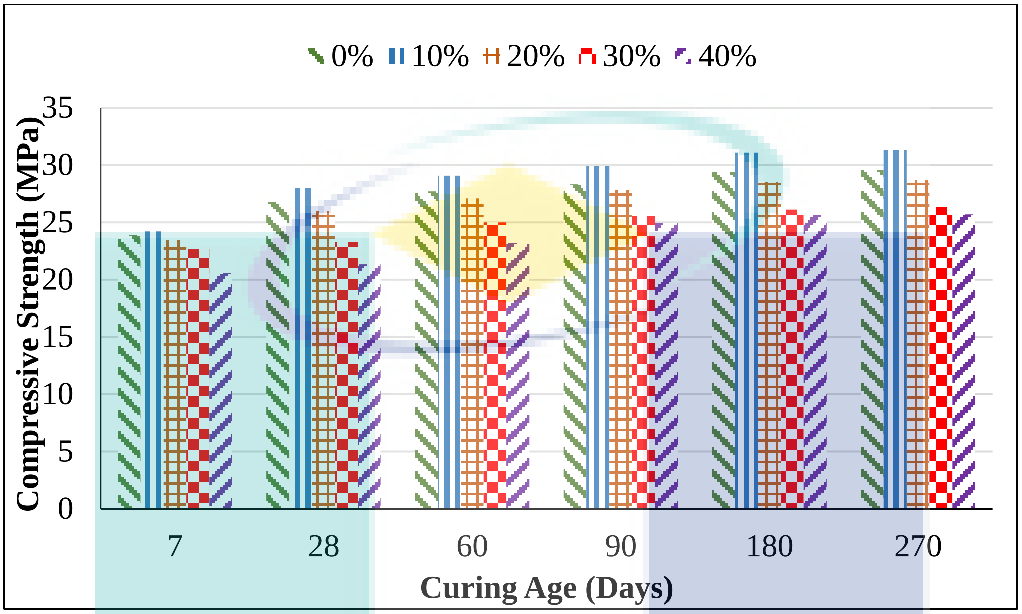

Figure 4.4 Compressive strength of water cured specimens

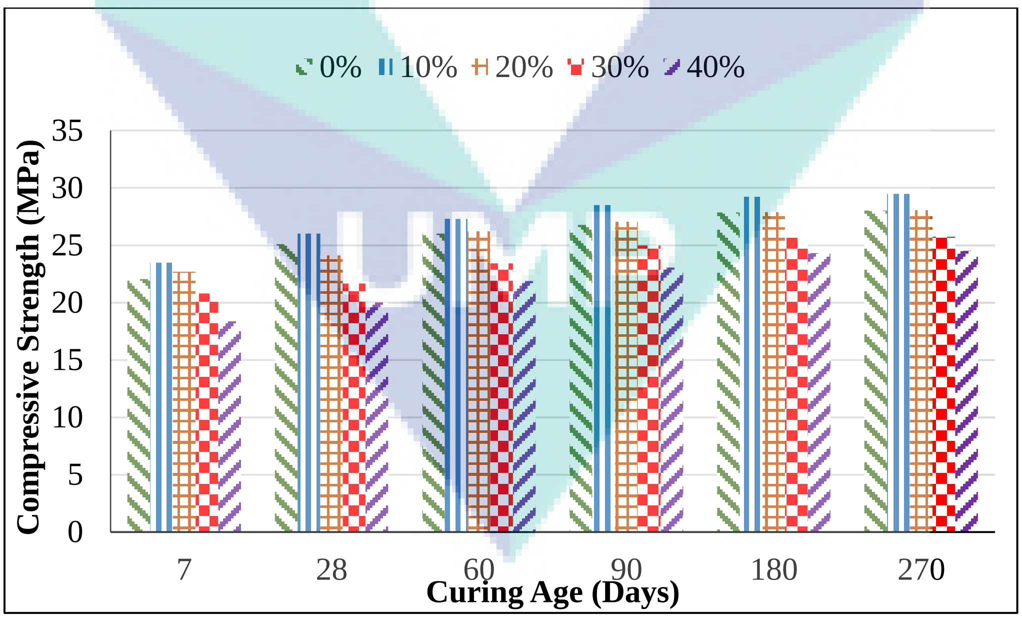

Figure 4.5 Compressive strength of initial water cured specimens

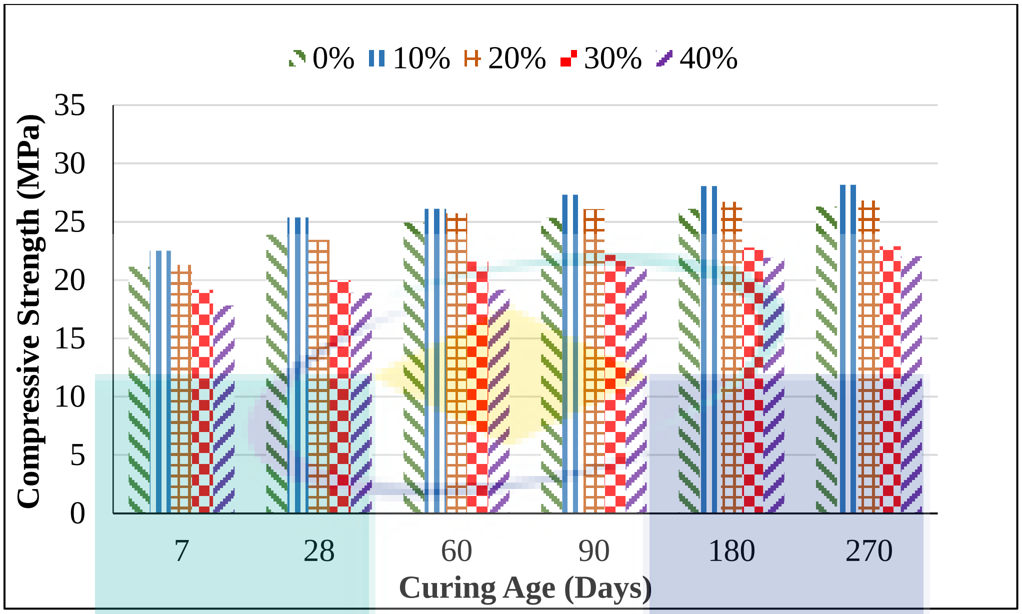

Figure 4.6 Compressive strength of air cured specimens

4.4 Flexural Strength

Figure 4.7 until 4.9 illustrates the flexural strength development of OPS LWAC containing various percentage of fly ash under different types of curing regime up to 1 years of curing age. Also, three types of curing regimes namely water curing, air curing and initial water curing were employed for flexural strength test investigation. As expected, the flexural strength development results shows similar trends as compressive strength results. All specimens with various percentage of FA exhibits strength increment from the age of 7 days until 270days. Specimens that were cured under water produces the highest value for flexural strength followed by initial water curing and lastly air curing. The presence of humidity and moisture to the concrete specimens has a significant effect on flexural strength of OPS LWAC with fly ash.

Others, specimens cure with air curing produces the weakest strength in terms of flexural strength. The strength of OPS LWAC containing fly ash were affected due to absence of water for hydration process. Air curing were produces the lowest flexural strength for both control and OPS LWAC with FA specimens and not recommended applied to this type of concrete. In past research (Conroy-Jones & Barr, 2004), expressed concrete cure by air exhibit lower strength that cure with water. The 28-day flexural strength loss of OPS LWAC with 10% FA as sand replacement under air curing and initial water curing was approximately 6.6% and 2.4% respectively, as compared to concrete subjected to full water curing condition. Thus, choosing an appropriate curing condition to the OPS LWAC specimens were influencing the flexural strength.

In the same way as compressive strength, FA-10 also produced the highest flexural strength than other specimens when cured in water, air and subjected to initial water curing. Fly ash which has pozzolanic properties contribute towards hydration process producing higher strength than control specimen. SiO_2 in fly ash will consume $Ca(OH)_2$ released during hydration process. The C-S-H gels produced would fill in the voids of concrete making it denser and stronger. Utilization of fly ash more than optimum amount is seen to produce weaker concrete than control specimen. Upadhyay, Srivastave, Herbert, & Mehta (2014) reported that strength of concrete increases with fly ash up to an optimum value, beyond which, strength values start decreasing with further addition of fly ash.

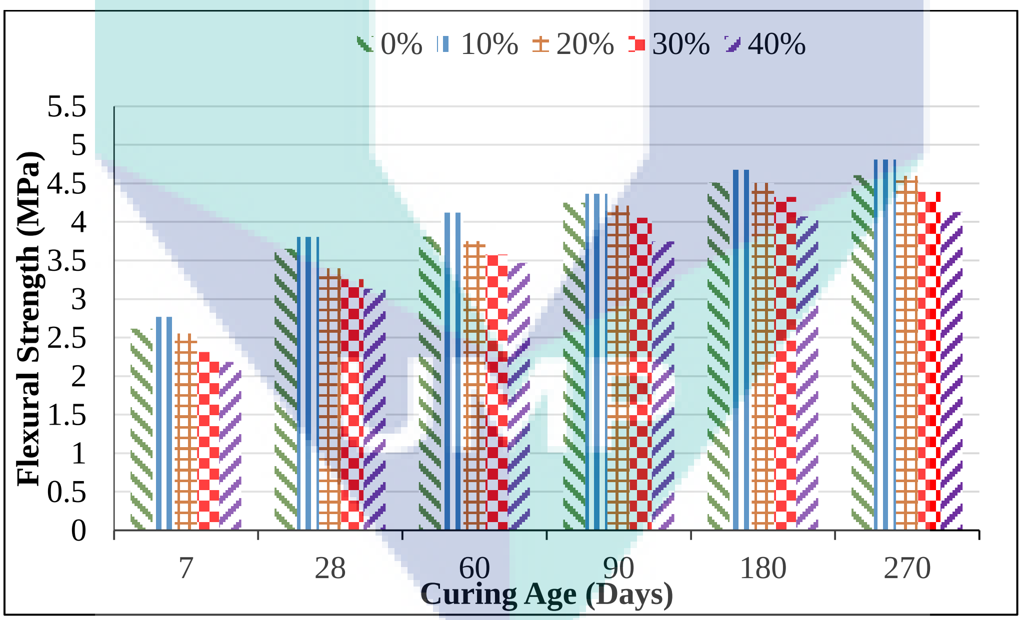

Figure 4.7 Flexural strength of water cured specimens

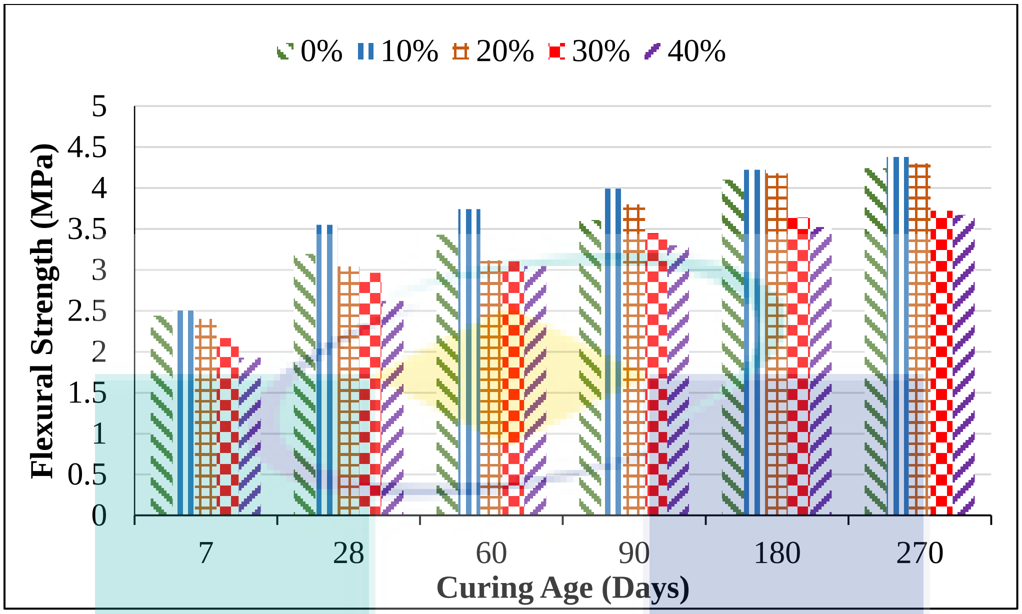

Figure 4.8 Flexural strength of initial water cured specimens

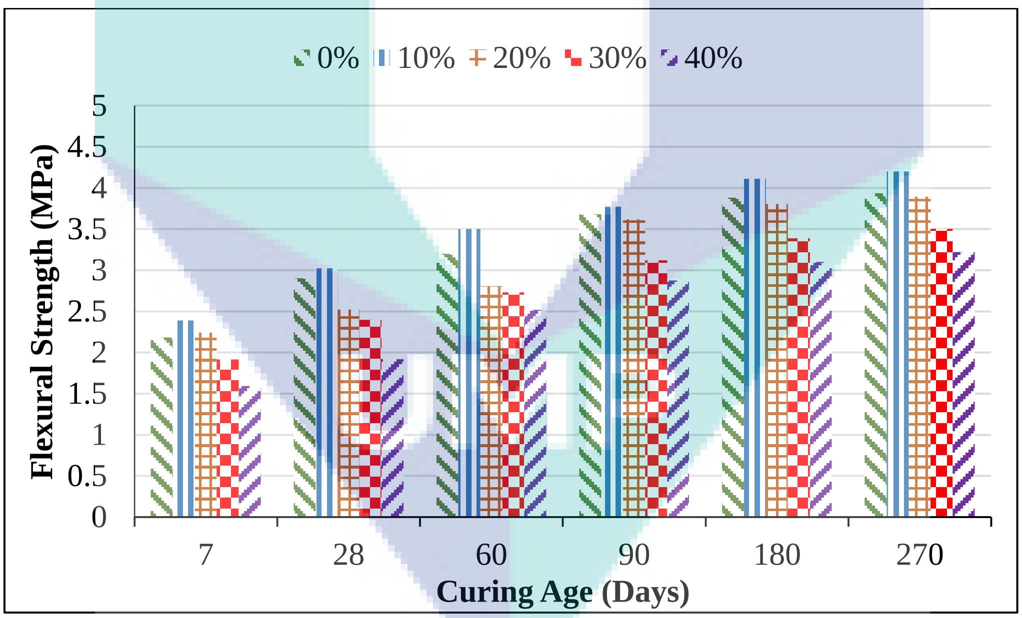

Figure 4.9 Flexural strength of air cured specimens

4.5 Modulus of Elasticity

Modulus of Elasticity (E) is a representation of the stiffness of a material that behaves elastically. Fig. 4.10 until 4.12 illustrates variation of modulus of elasticity at the age of 90 days for different fly ash percentages. From the table, it can be seen that there is increase in strength with the increase in fly ash up to 10% percentages. The maximum strength occurs at 10% fine aggregate replacement with fly ash. This may be attributed to the pozzolanic reaction for forming pozzolanic C–S–H gel. However, the strength becoming lesser with the addition of fly ash of more than 10%. This trend is more obvious between 30% and 40% replacement level. Siddique (2004) has stated that modulus of elasticity of concrete were start reduce with the use of large proportion of fly ash.

From the data, it can see the E value of OPS LWAC with and without FA content that cure with WC has the highest value followed by cure by initial water curing and AC. Concrete sample that cure in WC get the higher value because it have long time contact with water that help in concrete hydration. Other, concrete that cure with initial water curing just have 7days contact with water, thus the water on help in hydration at early age before it be left in air curing. As stated by Mo et al. (2016), concrete cure with water curing give higher MOE value due to continuous present of water and complete hydration in the concrete. According to Islam et al. (2016), modulus of elasticity value of air cure OPS LWAC were lower compare to water cure OPS Concrete due to weaker interfacial transition zone between paste and aggregate.

According to Alengaram et. al. (2011), the modulus of elasticity value of concrete were depend on the aggregate stiffness, hardened cement matrix, bond between OPS in concrete and OPS quality. All the modulus of elasticity value of OPS LWAC increases as curing age become larger. In this study, E value pattern were same as compressive strength pattern, which is OPS LWAC with 10% FA content was the highest and sample cure in water curing give the highest modulus of elasticity value than other curing. The range of modulus of elasticity value of OPS concrete were about 5 – 11 GPa with the compressive strength range of 24 – 37 MPa (Teo, Mannan, & Kurian, 2006a; Teo , Mannan, & Kurian, 2006b; Mannan & Ganapathy, 2002 and Alengaram, Jumaat, & Mahmud, 2008). From the data recorded, this study finding is inline with previous with past researchers for 10% FA replacement.

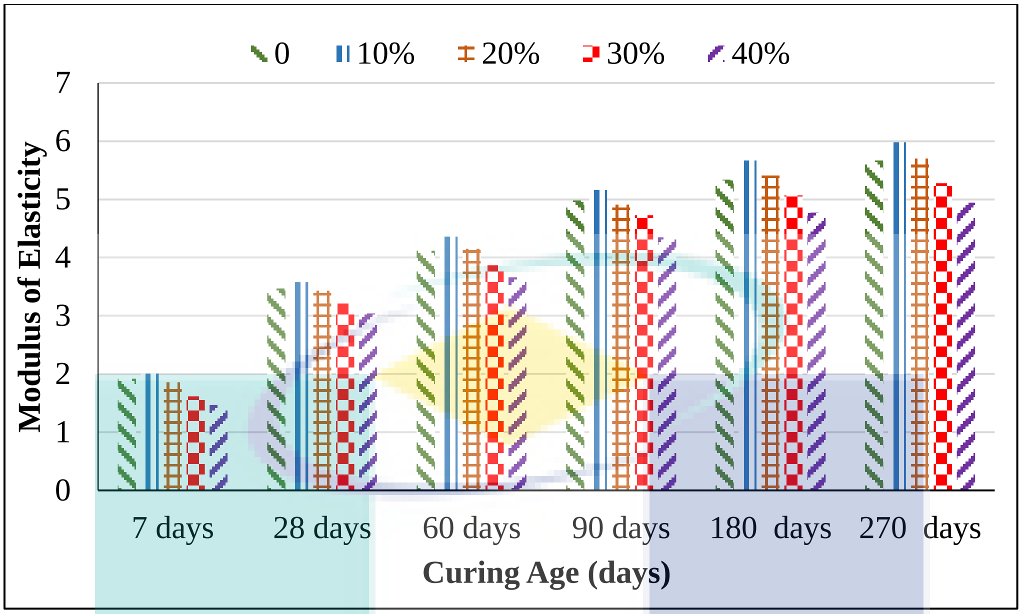

Figure 4.10 Modulus of elasticity of water cured specimens

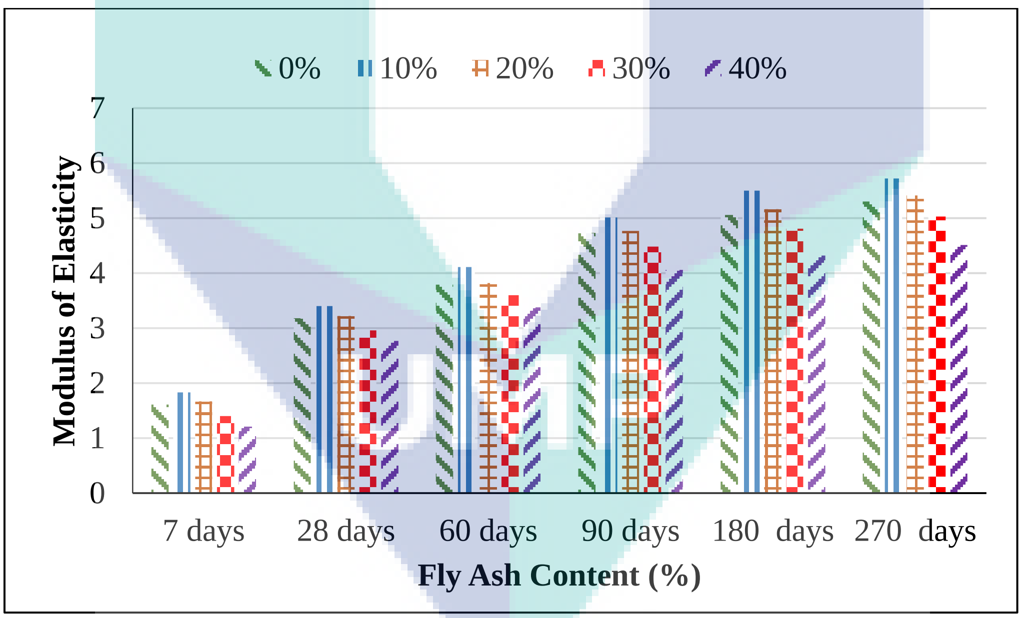

Figure 4.11 Modulus of elasticity of initial water cured specimens

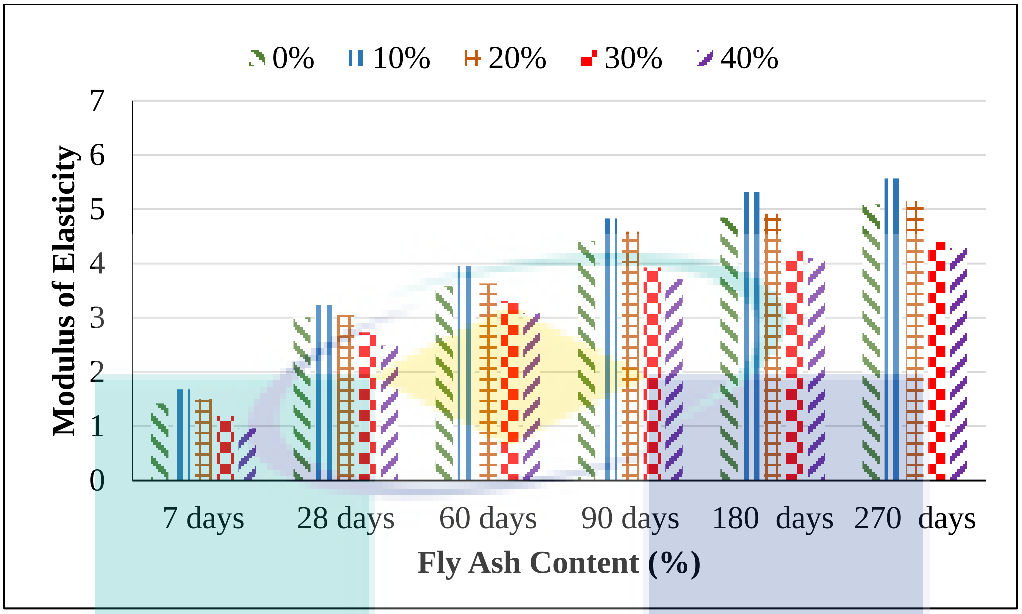

Figure 4.12 Modulus of elasticity of air cured specimens

4.6 Splitting Tensile Strength

There is a relationship between the compressive and splitting tensile strength of OPS concrete. It can be observed that the splitting tensile strength increases with the increasing of compressive strength. Previous studies showed that the 28-day splitting tensile strength of OPS concrete in water curing is in the range of 1.10–2.41 MPa (Mannan & Ganapathy, 2002; Abdullah, 1996; Alengaram et al., 2008). It can be seen that the splitting tensile strength of OPS LWAC in this study is in line with the previous study.

The development of splitting tensile strength of OPS LWAC under three types of curing is shown in the Fig, 4.13 until 4.15. Similar to compressive strength, the splitting tensile strength is dependent on the curing condition. In general, among the different curing regimes adopted, the lowest splitting tensile strengths were obtained under the AC condition, followed by 7WC+AC and the highest strength was for the OPS LWAC with FA content specimens under WC regime. As mentioned earlier, the lack of proper curing could have hampered the hydration process and consequently resulted in lower tensile strength gain for the OPS LWAC containing FA as partial sand replacement.

In terms of the effect of FA replacement towards splitting tensile strength of OPS LWAC, the result for every percentage is very close with slight decrease in splitting tensile strength when FA content added was increased. Result shows that FA replacement of 10% has the maximum splitting tensile strength, with strength quite close to control OPS LWAC and OPS LWAC with 20% FA but significantly higher than the both mixes. As the behaviour of concrete in splitting tensile strength test is similar to that of compressive strength tests, the change in splitting tensile strength of concrete may have direct relation to compressive strength. In other words, the higher the compressive strength, the higher the splitting tensile strength as well.

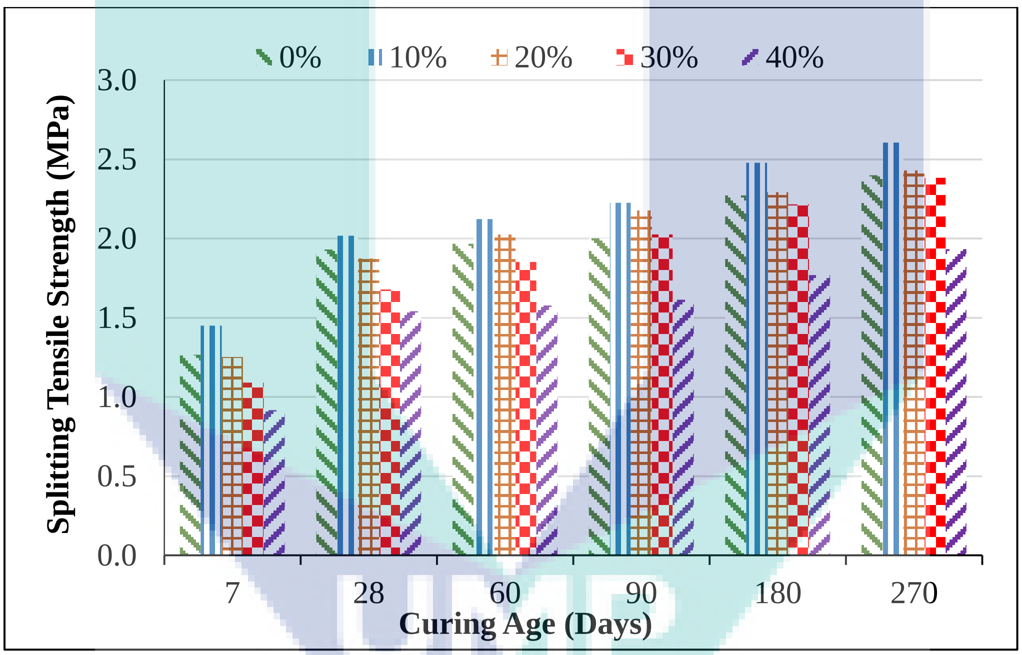

Figure 4.13 Splitting tensile strength of water cured specimens

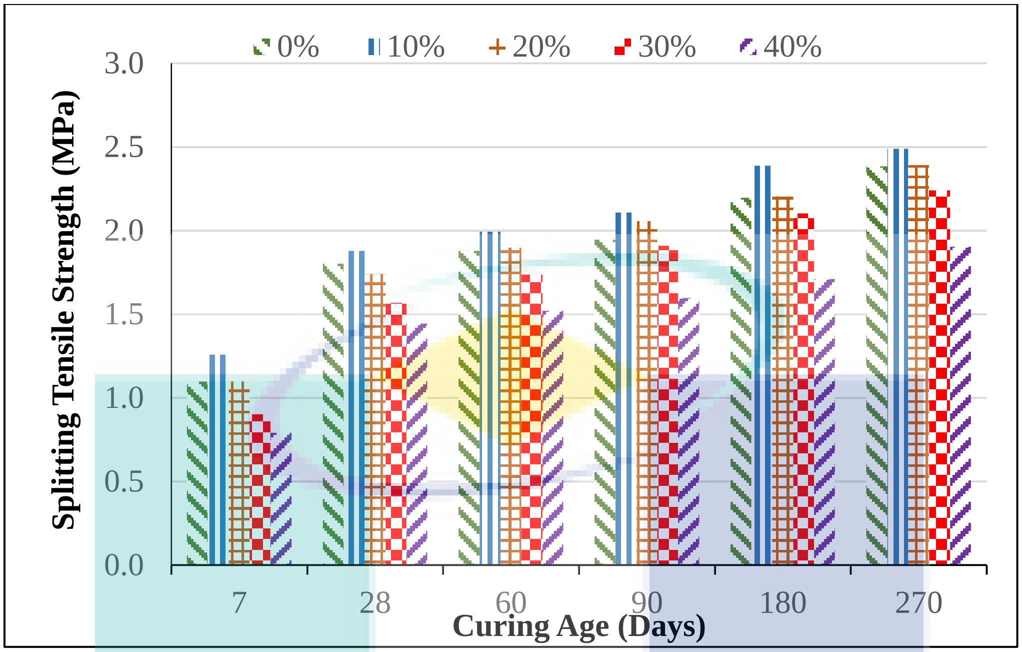

Figure 4.14 Splitting tensile strength of initial water cured specimens

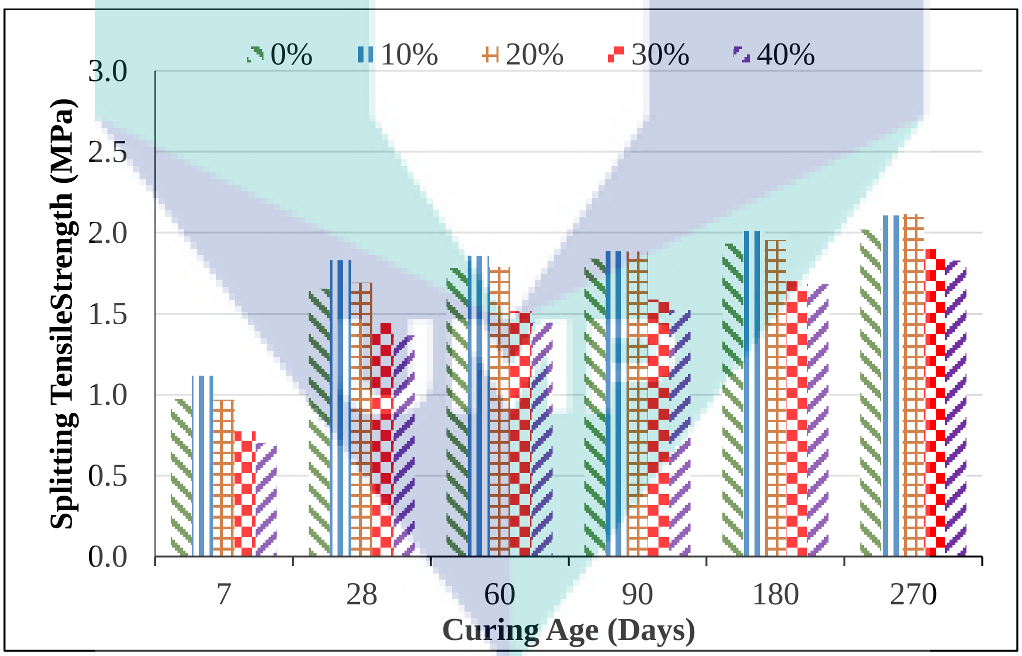

Figure 4.15 Splitting tensile strength of air cured specimens

4.7 Sulphate Resistance

The sulphate attack toward OPS LWAC containing various percentage of FA as compared to normal OPS LWAC in term of durability properties test were discussed in this section. As can be seen in Fig. 4.16, 4.17 and 4.18, the concrete mass for all specimens keep on increasing until the age of 17 weeks and there is no sign of deterioration for all specimens after a few weeks immersed in sulphate solution. The least mass change was denoted by 10% sand replacement by FA for all type of curing regime. Concrete containing pozzolan have better performance in sulphate solutions since the pozzolanic reactions reduce the quantity of calcium hydroxide and increase calcium silicate hydrate gel. However, the highest mass change was denoted by 40% FA when curing using water curing, air curing and initial water curing. This significant additional weight is caused by the ease of sulphate ion invasion into the concrete causing higher expansion than other types of samples. The higher expansion is due to 40% FA samples which has higher voids than other specimens.

At the early stage of sulphate immersion, no sign of deterioration is detected on both concrete specimens. After 20 weeks, the first sign attack appeared as the control OPS LWAC starts to show cracking at the edge and corners. It is known that damage due to sulphate attack usually starts at the edges and corners of the concrete. At this juncture, OPS LWAC with POFA did not show any change in shape and remained structurally intact without visible deterioration. After a few weeks, it is apparent that the degradation of the ordinary specimen became more extensive. Simultaneously, OPS LWAC with POFA started to show early signs of deterioration with fine cracking appearing at the edge of the concrete.

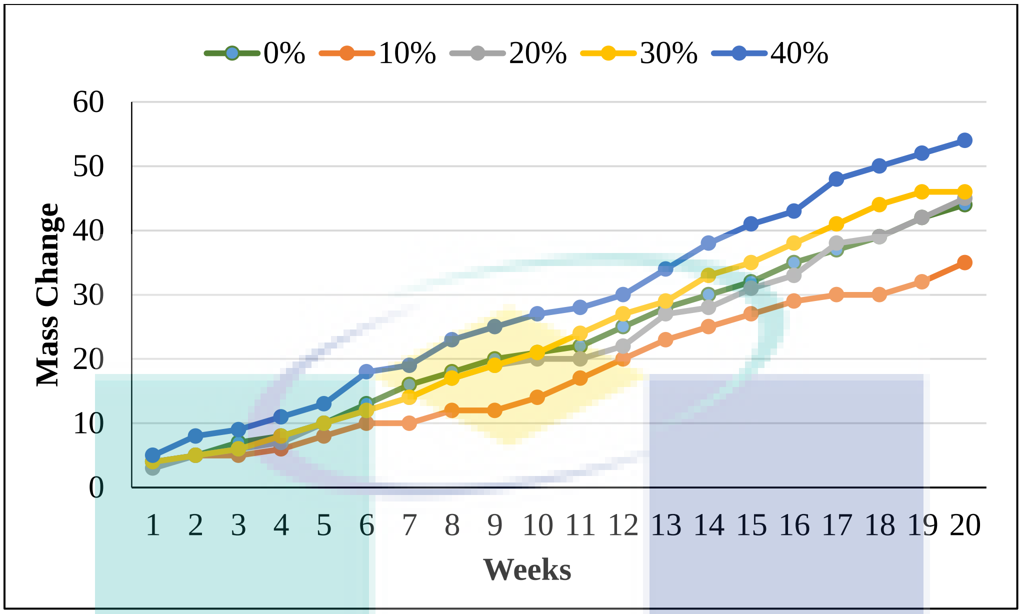

Figure 4.16 Mass change of water cured specimen

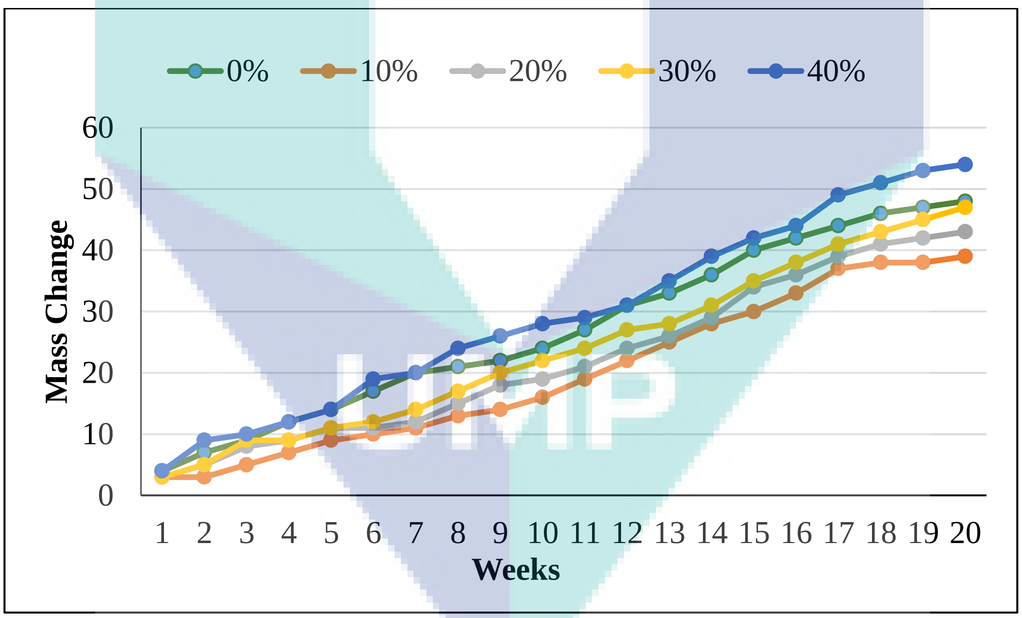

Figure 4.17 Mass change of initial water cured specimen

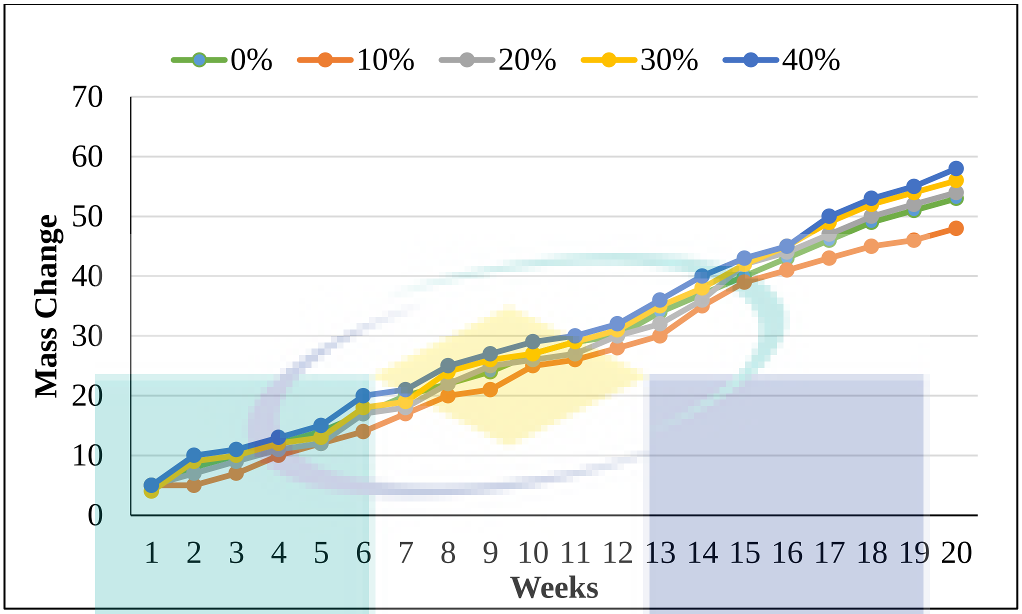

Figure 4.18 Mass change of air cured specimen

4.8 Carbonation

Concrete mixtures covering five different total sand replacement levels (0%, 10%, 20%, 30% and 40%) for OPS LWAC with various FA proportions, water, air cured and initial water for up to 180 days, were investigated in carbonation test. Carbonation testing in these research measures the carbonation depth of the concrete. The value of carbonation depth with age at all sand replacement levels under both water, air curing and initial water curing were compared with those of the control OPS LWAC.. Figure 4.19 until 4.20 illustrated the carbonation graph value due to period of time.

FA, a highly active pozzolan has been shown under normal curing condition, to increase strength and reduce concrete carbonation at optimal replacement. As been observed, there are no traces of carbonation for all OPS LWAC with FA as sand replacement up to 180 days. At 180 days, the carbonation starts to appear for all specimens when cured using air curing. However, the carbonation depth for FA replacement at 10% indicates the least effects amongst all. FA addition results in lower carbonation depth as the pozzolanic reaction and filling effect are beneficial in minimizing the pore size and volumes, thus reducing the carbonation rate. However, increasing FA percentage of more than 10% resulted in considerable increase in depth of carbonation. The rate of carbonation increases with an increase in CO2 concentration, especially for concrete specimens with higher FA inclusion when more than optimum amount. Higher FA content produces concrete with voids due to improper compaction thus ease the CO_2 transport through the pore system in hardened concrete. As a conclusion, the use of pozzolanic material but in optimum amount was beneficial in reducing carbonation.

The exposure conditions of curing regime have a significant influence to the carbonation depth of OPS LWAC. As expected, concrete cured continuously under water and initial cured showed no traces of carbonation than cure in air curing. The presence of water at all-time promotes the generation of larger amount of C-S-H gel which contributes to densification of concrete internal structure, making it more durable. Bai et al. (2002) suggests that water-curing reduces sorptivity, which reflects a finer pore structure that will inhibit ingress of aggressive elements into the pore system reducing carbonation. Moreover, the slow solubility of CO_2 in water (Taylor, 2014) assisted the water cured specimen to be free from carbonation effect during the period of this study.

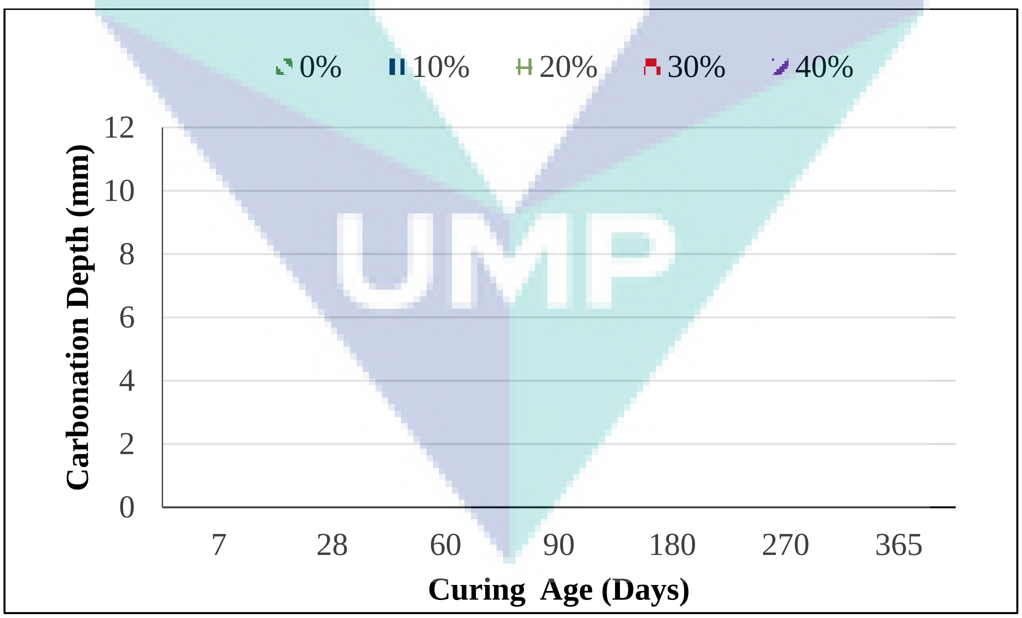

Figure 4.19 Carbonation depth of water cured specimens

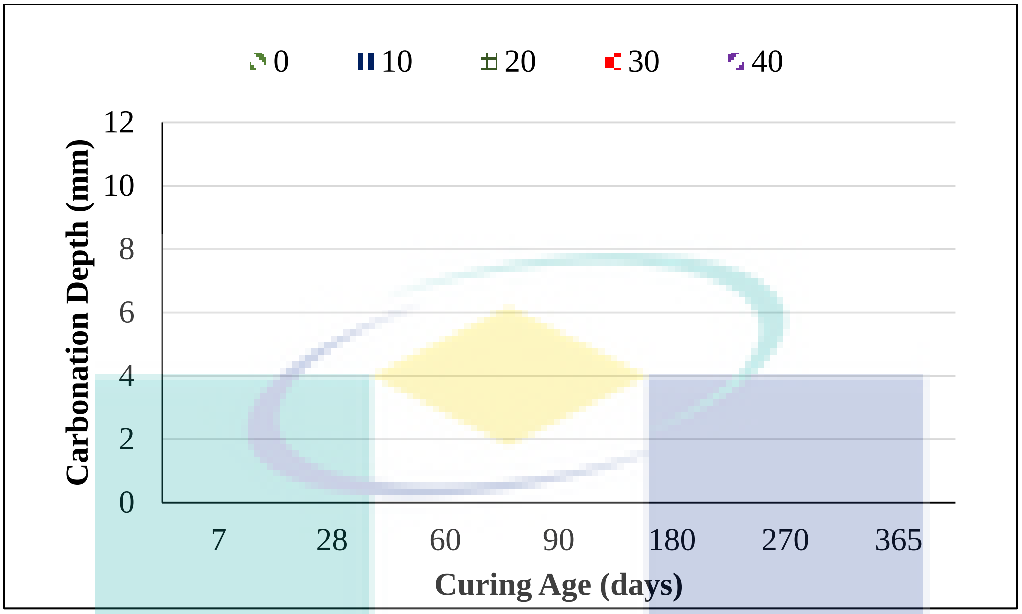

Figure 4.20 Carbonation depth of initial water cured specimens.

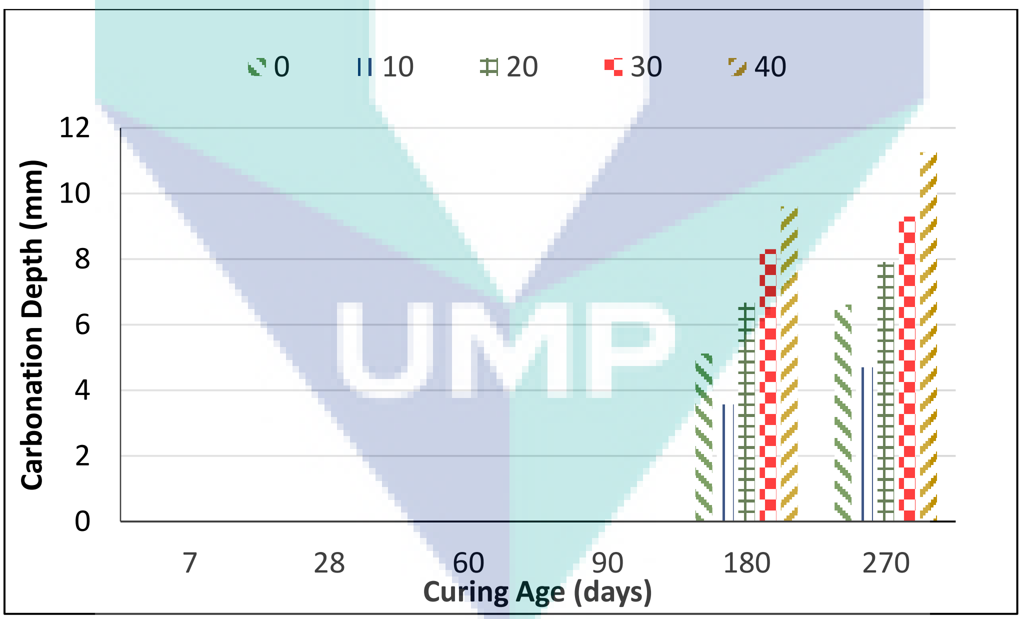

Figure 4.21 Carbonation depth of air cured specimens

4.9 Water Absorption

Water absorption of OPS LWAC are influence by present of FA and type of curing method and illustrated in Figure 4.22. It showed the water absorption value for every percentage and curing regime. By those influence, the concrete specimens were act in different rate of absorption. Bozkurt & Yazicioglu (2010) also indicated that the concrete absorption is also influenced by curing regimes. According to Neville (2011) the concrete water absorption of not more than 10 % is classified as high-quality concrete. It is worth mentioning that the water absorption value for both types of concretes in all curing conditions is within the range for high-quality concrete that is lower than 10%.

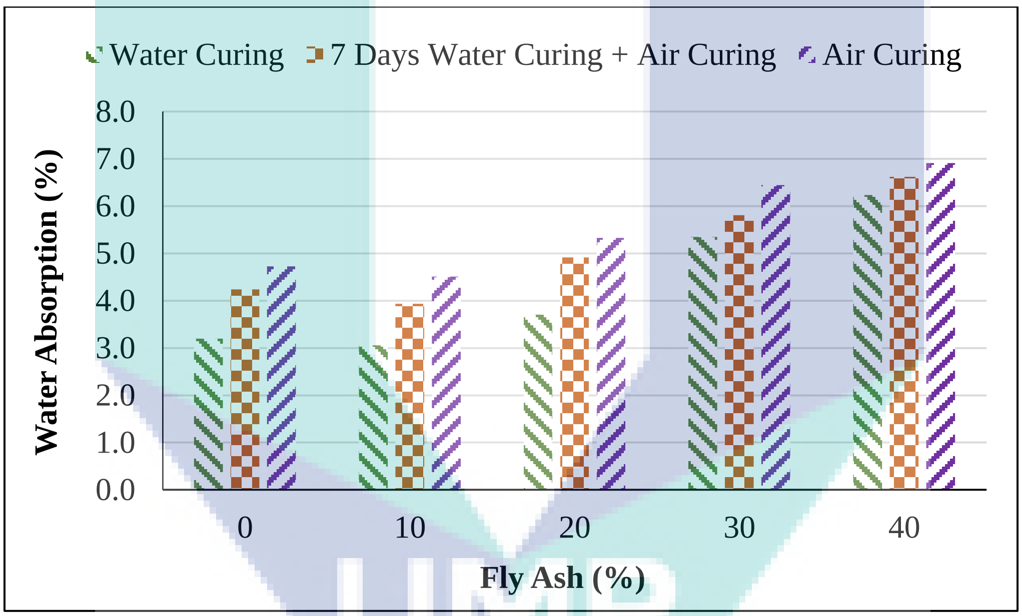

Figure 4.22 Water absorption of specimens subjected to different curing

Water absorption is an essential and important step for the definition of the durability, performance and lifetime of a concrete structure. Water absorption of OPS LWAC containing all percentages of fly ash under different curing regimes are presented in Figure 17. According to the results, water absorption in the range of 3.06 to 6.91 percent were obtained applying all curing conditions on OPS LWAC with fly ash specimens. All these concrete are in the range for high quality concrete as the water absorption is below 10% as stated by Neville (2011). This wide range in results demonstrates that different percentage of fly ash and curing regimes have different effects on water absorption of OPS LWAC.

From the figure, it shows that 10% sand replacement by fly ash contribute towards the lowest water absorption than other specimens including control specimen. The resistance towards water infiltration is due to the secondary calcium silicate hydrate gel that forms during pozzolanic reaction that fill in the voids inside OPS LWAC structure creating denser and higher impermeable concrete. The same result was obtained by Bradu & Florea (2015) which indicated that 10% fly ash produces the lowest water absorption result. Apart from that, too much fly ash replacement or more than optimum amount produces stiffer concrete which is hard to compact. This produces concrete with higher voids thus ease the water penetration into the concrete. Thus, the rate of water absorption are hardly influenced by the replacement level of fly ash.

OPS LWAC with fly ash cured in water resulted in the lowest water absorption compared with other curing conditions. With the presence of moisture, apart from promoting hydration process, fly ash reacts with calcium hydroxide ($Ca(OH)_2$ to form calcium silicate hydrate gel that refines the internal structure of concrete through pozzolanic reaction. Thus, a more compact concrete were resulted from water curing. Past researchers (Turk, Caliskan, & Yazicioglu, 2007; Bozkurt & Yazicioglu, 2010 and Abalaka & Okoli, 2013) also agreed that immersion samples in water provides the best curing regimes of all. Thus, it is essential to provide proper curing in order to produce a less permeable concrete with higher strength and greater resistance to physical or chemical attacks in aggressive environments.

Obviously, air curing caused the highest water absorption. This may be attributed to the higher porosity of the concrete preserved in air. Under this curing condition, the surface concrete rapidly loses its water for complete hydration process. In other words, hydration process discontinued due to evaporation of all remaining capillary water. This observation is in line with Zhang & Zong (2014) who stated that drier samples show higher water absorption than samples cured with the assistance of water. It is clearly found that lack of attention on choosing an appropriate curing condition can lead to a significant increase in water absorption of OPS LWAC with fly ash. On the other hand, initial water curing fall at the second best curing regime after water curing. Thus, it can be concluded that presence of moisture in curing conditions has significant effect on water absorption of OPS LWAC with fly ash.

4.10 Summary

The utilization of FA as partial sand replacement enhances the mechanical and durability properties of OPS LWAC through densification of concrete internal structure. Lightweight concrete containing 10% FA exhibit higher compressive strength, flexural strength, splitting tensile strength and modulus of elasticity value compared to control specimen at all curing age. FA in concrete resulted calcium hydroxide which can be transformed to be ettringite by sulphate ion leads to OPS LWAC with FA to experience lower mass change and larger strength deterioration value in comparison to control specimen. Lastly, carbonation and water absorption of OPS LWAC with FA exhibits favourable results upon subjected to water curing.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter concludes the overall experimental research findings obtained based on the objectives listed in Chapter One and analysis in chapter Five. Others, several suggestions and recommendations are made for improvement are also included in this chapter.

5.2 Conclusion

. Based on 28 days compressive strength data, 10% of sand replacement by FA get the highest value compare to the normal OPS LWAC and other various percentage of FA. Also, fulfil the criteria that been set for workability and density. This indicates that the optimum amount of FA replacement in OPS LWAC is 10%. Utilizing 10% of FA as sand replacement with water curing resulted the highest compressive strength, flexural strength, modulus of elasticity and tensile splitting strength than other mixes. Therefore, the continuous presence of water during curing period is vital for in providing better strength OPS LWAC development. Others, the concrete cure by air curing were not recommended due to unfavourable mechanical properties test results. It is because the shortages concrete contact with water was effect the reaction in concrete structure. Pozzolanic reaction due to 10% utilization of FA promotes the generation of secondary C-S-H gel that contributes towards the densification of concrete microstructure that in turn making it stiffer and consequently exhibiting higher modulus of elasticity value.The inclusion of 10% FA as partial cement replacement enhances the durability of OPS LWAC concrete other than mixes. Also, water curing and initial water curing were found to increase the susceptibility of FA concrete towards carbonation of OPS LWAC. OPS LWAC with 10% of FA with water curing exhibits lower water absorption than other mixes.

5.3 Recommendation for Further Research

From the analysis, discussion, and observation done during this research, there are a few recommendations and suggestions are made to further expand the research of OPS LWAC containing FA as a partial sand replacement:

1. The effect of FA content towards other mechanical properties of OPS LWAC is one of the areas that could be investigated.

2. The investigation on the properties of OPS LWAC with FA containing FA as partial cement replacement is also an area that could be explored.

3. The effect of FA content towards other durability properties of OPS LWAC is one of the huge are as that could be investigated such as acid attack and c

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