EFFECT OF DIFFERENT CURING METHODS ON SEWAGE SLUDGE ASH (SSA) CONCRETE

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EFFECT OF DIFFERENT CURING METHODS ON SEWAGE SLUDGE ASH (SSA) CONCRETE

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
B. Eng (Hons.) Civil Engineering

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Dedicated to my parents,

for their love and endless support,

helped make me who I am today

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ABSTRACT

The increase of sewage sludge produced from waste water treatment plant is increasing worldwide. Disposal of sewage sludge is a serious issue as disposing them to landfill for decomposition is not a solution to solve this problem that endangers the environment. Thus, the aim of this research is to determine the effect of different curing methods on sewage sludge ash concrete in order to promote the use of sewage sludge ash in construction industry by partially replacing cement. The sewage sludge is incinerated at 800 degree Celsius at 3 hours 30 minutes. 10% cement replacement is used in this research as it is the optimum replacement percentage. Slump test, UPV test, Compressive test and Flexural test are carried out to determine the fresh concrete and hardened concrete properties. Results shows that SSA beam cured in salt water exhibits higher flexural strength that SSA beam cured in plain water. The compressive strength of both control and SSA cubes are higher initially but ultimately deteriorates. SSA cubes cured in salt water possess highest ultrasonic velocity among all SSA and control specimens on 90 days of curing. The findings suggested that curing SSA concrete in salt water is viable as it provides more advantage than disadvantage, which will lead to reduced usage of cement that solves the problem of sewage sludge disposal.

ABSTRAK

Peningkatan sisa kumbahan yang dihasilkan daripada loji rawatan air sisa semakin meningkat di seluruh dunia. Pembuangan sisa kumbahan adalah masalah yang serius kerana melupuskan sisa kumbahan di tapak pelupusan untuk proses penguraian tidak boleh menyelesaikan masalah ini yang boleh membahayakan alam sekitar. Oleh itu, matlamat penyilidikan ini adalah untuk menentukan kesan kaedah pengawetan yang berbeza pada konkrit abu sisa kumbahan untuk menggalakkan penggunaan abu sisa kumbahan dalam industri pembinaan dengan menggantikan sebahagian simen dengan abu sisa kumbahan. Sisa kumbahan dibakar pada 800 darjah Celsius selama 3 jam 30 minit. Dalam kajian ini, abu sisa kumbahan akan digunakan untuk menggantikan 10% simen kerana ia adalah peratusan penggantian yang paling optimum. Ujian kemerosotan, ujian UPV, ujian mampatan dan ujian lenturan akan dijalankan untuk menentukan sifat konkrit segar dan konkrit keras. Hasil kajian menunjukkan bahawa rasuk SSA yang diawet dalam air garam memaparkan kekuatan lenturan yang lebih tinggi yang rasuk SSA yang diawet dalam air kosong. Kekuatan mampatan kiub kawalan dan SSA adalah lebih tinggi pada mulanya tetapi ia merosot pada akhirnya. Kiub SSA yang diawet dalam air garam mempunyai halaju ultrasonic yangn tertinggi di kalangan semua kiub SSA dan kawalan pada hari pengawetan yang ke 90. Hasil kajian mencadangkan bahawa mengawetkan konkrit SSA dalam air garam adalah berdaya maju kerana ia memberikan lebih kelebihan daripada kelemahan dan ini akan menyebabkan pengurangan penggunaan bahan-simen yang akan menyelesaikan masalah pelupusan sisa kumbahan.

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LIST OF SYMBOLS

%	Percentage
μm	Micrometer
°C	Celsius
$CaCO_3$	Calcium Carbonate
CO_2	Carbon Dioxide
C_3A	Tricalcium Aluminate
$CaCl_2$	Calcium Chloride
kg/cm	Kilogram per centimeter cubic
Kg	Kilogram
km/s	Kilometer per second
K_2SO_4	Potassium Sulphate
$MgCl_2$	Magnesium Chloride
mm	millimeter
MPa	Mega Pascal
NaCl	Sodium Chloride
N	Newton
w/c	Water to cement ratio

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
CAGR	Compound Annual Growth Rate
CEM	Certified Energy Manager
C & D	Construction and Demolition
EN	European Standard
IWK	Indah Water Konsortium
LHC	Low Heat Cement
MS	Malaysian Standard
OPC	Ordinary Portland Cement
POFA	Palm Oil Fuel Ash
RHA	Rice Husk Ash
RHC	Rapid Hardening Cement
SSA	Sewage Sludge Ash
SSAC	Sewage Sludge Ash Concrete
UPV	Ultrasonic Pulse Velocity
YTL	Yeoh Tiong Lay

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

It is found that Malaysia's population increased from 8.2 million in 1960 to 29.95 million in 2014, which shows growth of 271% (Trading Economics). The significant increase in population leads to the increment of waste production, especially sewage sludge (Azman et al., 2013). After undergoing a few treatments processes in sewage treatment plant, the wastewater is reduced into sewage sludge where most of it is used as soil improver in agriculture field. However, there is still a portion of sewage sludge sent to landfill for decomposition process to take place.

Cement is the main material in casting concrete, where it acts as binder for the coarse and fine aggregates. According to Research and Markets, the cement production index grew at a Compound Annual Growth Rate (CAGR) of 4.4% from 2009 to 2013 and the cement production index grew another 6.6% in 2014. As the demand for cement increases yearly, the price of cement also continues to soar. Various efforts have been done in conducting research to seek out alternatives to replace cement. Among the numerous research conducted, it is found that sewage sludge ash could partially replace cement as it contains a high content of silica which is chemical compound that is also present in cement. According to past research, sewage sludge is compatible with cement and could be used to partially replace cement due to its pozzolanic properties (Marta 2010; Jamshidi et al., 2011). Not only that, it is also found that sewage sludge acts a good binder element in cement due to its high presence of silicon oxide after it undergoes combustion process (Rafiu et al., 2012).

As Malaysia continues to prosper, the amount of resident in Malaysia also rises. High population means more waste are produced. Waste management using landfilling method may not be effectively relevant. In 2008, there are already 230 number of landfill area in Malaysia (Idrus et al., 2008). It is expected that Malaysia may face scarcity of landfill area should there more innovative action taken to solve the problem. Therefore it is important for the authorities to improve the current state of landfilling practice and the authorities also must be careful in meeting all of the regulatory requirements when a landfill sitting evaluation is performed because majority of the current landfills in Malaysia practices poor code of landfill. One way of managing the excessive solid waste produced is by reusing them as it does not only preserve the environment of Malaysia, it also helps to reduce CO_2 emission as in the process of cement product, CO_2 will be released as a by-product.

1.2 PROBLEM STATEMENT

Malaysia is currently facing a crisis where the solid waste produced is piling up and cause a major environmental problem which significantly reducing our environment capacity to sustain life. In 2010, it is recorded that Kuala Lumpur State Territory generates 2000 tons of municipal solid waste per day where averagely a person produce 1.2 kg of waste a day (Budhiarta et al., 2012). Due to the increasing development and population in Malaysia, the amount of waste generated continues to hike and less than 5% are being recycled. The poor standards of waste management in Malaysia such as outdated and poor documentation of waste generation rates and its composition causes less than 5% of waste produced are recycled. The waste generation rate is expected to increase from 1.2 to 1.4 kg/capita/day in 2025, with the total increase of 3 million tons/day after calculating the effect of economic development, degree of industrialization and public habits (Sharifah & Latifah, 2013).

Besides, the cement demand is increasing drastically around the world as reported by Market Watch where global the cement consumption increases by 7.7% in 2013 and the cement consumption rose by another 2.6% in 2014 to 4140 Mega tonnes due to the phenomenon of China, which contributed a lot in the consumption of cement which is 59% out of the 4140 Mega tonnes in 2014. This is a serious issue as cement is a non-renewable resource and it requires mining for limestone and shale which will endanger the ecosystem. Besides that, increasing cement demand means increasing production of cement which leads to the greenhouse effect phenomenon as production of cement releases greenhouse gas, which is CO^2 which is released during the production of clinker, a component of cement, in which calcium carbonate ($CaCO_3$) is heated in a rotary kiln to produce a series of complex chemical reactions (Gibbs et al., 2010).

1.3 OBJECTIVE

The main purpose of conducting this research is to discover the optimum curing method for concrete with partial replacement of SSA.

1. To investigate the effect of curing on SSA concrete
2. To compare the mechanical properties of SSA concrete by conducting Slump test, UPV, Compressive strength test and Flexural test

1.4 SCOPE OF STUDY

In this research, air dry curing, plain water immersion curing and salt water immersion curing are practiced in the concrete curing process. The sewage sludge used in this research is provided by Indah Water Konsortium. Sewage treatment plant located in Kuantan, Pahang whereas the salt water used is obtained from Teluk Cempedak in Pahang. As for the percentage of cement replacement by SSA, 10% replacement is chosen. The optimum temperature selected for incineration of sewage sludge is 800°C. The size of specimen is 100mm x 100mm for concrete cubes. The specimens are tested at the age of 3 days, 7 days, 28 days and 90 days. Tests to be carried out are compressive strength test, slump test, UPV test, 3-point flexural test.

1.5 RESEARCH SIGNIFICANT

Not all sewage sludge produced are reused and recycled as a quarter of sewage sludge produced are sent to landfill to be decomposed. This is not a wise method manage sewage sludge as it requires a large landfill area and takes a long time to be decomposed. This research is able to promote the use of SSA to replace cement in Malaysia. By reusing the sewage sludge ash as partial cement replacement material, it can not only reduce the negative impact on the environment but also reduce the cost for the project as sewage sludge can be obtained for free.

The significant of this study are:

1. Reduce space required for landfill and waste generated
2. Promote the application of sewage sludge in construction industry
3. To identify the effects of curing towards SSA concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter includes the review of past relevant literatures such as the study of SSA to be utilized in construction field and types of curing that deemed to be compatible with SSA. In this chapter, data and information from the past literature are outlined in order to facilitate the setting of scope of study in this research. Besides that, this chapter also shows the comparison between different types of curing that is applied to concrete cubes casted from OPC and SSA.

2.2 CONCRETE

Concrete is the most popular artificial material used in the construction industry. Concrete is a composite material where it is made up of cement, water and aggregate in a suitable mix proportion in order to serve different purposes. Concrete is widely used in construction industry as its raw materials are easily obtained, have durable characteristics, easily and readily prepared and can be fabricated in all sorts of conceivable shapes and dimensions. One of the main factors that caused the increase of concrete usage is the development of the country. Development of a country is important for a country to prosper, however problems will start occur, such as what we can see Hong Kong where the construction industry produces approximately 37 100 tonnes of construction and demolition waste (C & D waste) every day, which is around four times higher than that of municipal waste produced (Poon et al., 2004). To overcome this problem, recycling of C & D waste is practiced in Hong Kong where it can help to reduce C & D waste sent to landfill. This does not only helps to save cost, it also helps to preserve the environment.

Thus, various researches are done in order to search for materials that are compatible and possible to partially replace cement which is also environmental friendly. This new trend is also known as green technology and is currently widely practiced in all around the world and is no longer a new topic in research to preserve and conserve the environment.

2.2.1 Aggregate

It is well recognized that aggregate is one of the vital component in concrete which mainly contributes to the strength and durability of the concrete. Aggregates used in concrete are categorized into two main types, coarse and fine aggregate according to their size where aggregates retained on sieve no 4 with 4.75 mm opening is considered as coarse aggregate whereas aggregates passes sieve no 4 and retained on no 200 sieve with openings of 75 µm is classified as fine aggregate. Concrete is more workable when smooth and rounded aggregate is used instead of rough angular or elongated aggregate. Aggregate is an important matter in concrete that maximum properties and workability of concrete are directly affected with the properties of aggregate (Svylester & Iziengbe, 2015). Type and size of aggregate used strongly influences the strength of concrete casted. Currently, one of the problems in the construction industry is the durability of the concrete where freeze-thaw phenomena can cause concrete deterioration.

Moisture content of the aggregates can also influence the ultimate strength of the concrete as it might influence the water cement ratio. The four types of moisture conditions are Oven Dry, Air Dry, Saturated Surface Dry and Wet.

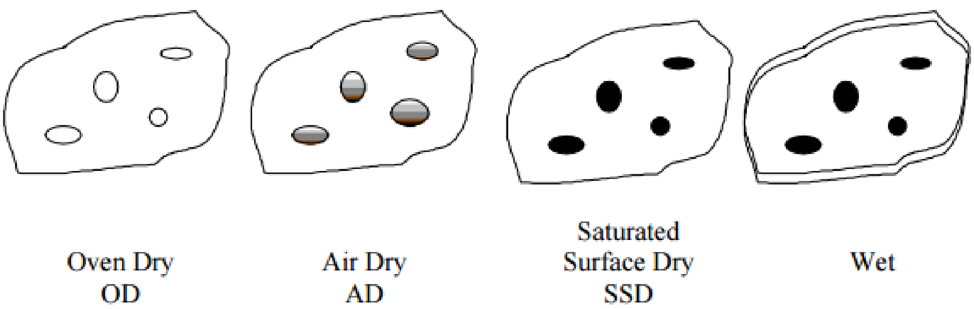

Figure 2.1: Moisture conditions of aggregate

Source: http://slideplayer.com/slide/4508729/

Sand used in construction must be clean and free from impurities as it might disrupt the chemical composition of concrete and might reduce the strength of concrete casted. Pit sand, river sand and sea sand are the three types of sand that is used in construction industry where each of them serves a different purpose due to their difference in size. Pit sand which is also known as coarse sand is about 4.75mm - 2mm in size where it can be obtained from deep pits and it is red-orange in color. As for river sand, it is considered finer quality sand compared to pit sand and can be procured from river streams. Lastly, sea sand is the finest sand among the three types of sand and can be obtained from sea shores. However, its use in construction industry is not recommended as sea sand contains salt which tends to absorb moisture from atmosphere is not a desirable condition for cement as it loses its action when it is mixed with sea sand. However, due to fast growing industry, the demand for river sand has increased tremendously which causes the deficiency of river sand as it is a non-renewable resource. To overcome this issue, sand is manufactured artificially where hard granite rocks are crushed. Manufactured sand can be easily available and it does not contain impurities that can affect the setting time of concrete which helps in maintain the strength of concrete. Sadly, there are workability issues as manufactured sand might be coarser and angular texture compared to river sand.

The four types of coarse aggregate mainly used in construction industry are sandstone, limestone, granite and slate. Sandstone is a clastic sedimentary rock which consists of mainly sand-sized minerals which is quite common and can be found throughout the world. Besides that, it also possesses a cementing material that binds the sand grains together. The geological properties of this sedimentary rock are fairly diverse such as quartzite, arkose, subarkose and greywacke aggregate that may produce a range of hardened concrete properties (Yılmaz & Tuğrul, 2012). As for limestone, it is also a sedimentary rock which is made up of calcite and aragonite which actually is calcium carbonate ($CaCO_3$) in a different crystal form. Limestone can be found quite easily as it occupies 10% of the total volume of all sedimentary rocks. Formation of limestone normally occurs in clear, warm, shallow marine waters. Application of limestone aggregate in concrete will improve the structural applications and concrete mix properties to attain economic viability (Jomaa, 2012). The strength and modulus of elasticity in concrete increases with the increase in fine limestone aggregate but the increment is relatively small (Carlos et al., 2010). Granite is the most common igneous rock that is found on earth's surface and it is phanertic and granular in texture. Granite is formed when molten rock is forced between other rocks in earth's crust where as it cools underground and forms large crystals. Granite is not the best material to be used as coarse aggregate as concrete containing crushed granite shows the least strength development at all ages (Abdullahi, 2012). Slate is the least popular among the four of them because it is a low grade metamorphic rock formed by alteration of shale or mudstone. The composition of slate depends on the degree of metamorphism where is it mainly composed of clay minerals or micas. Bashir et al., (2010) found out that the strength of no-fines bloated slate aggregate concrete is lower than the strength of normal weight concrete.

According to Chen et al. (2005), shape of coarse aggregate do influence the strength of asphalt concrete mixtures. There are four types of aggregate shape used in this research; blade, disk, rod and cubical. It is discovered that cubical aggregates has the best rutting resistance compared with other shapes. Using elongated aggregate in a mixture will cause the concrete to be prone to shear deformation. Results showed that cubical shaped aggregates possess the highest indirect tensile strength and resilient modulus compared to other aggregate with shape. Chen et al. (2005) concluded that cubical shaped aggregate produces the strongest asphalt concrete based on the results obtained.

Besides providing strength and durability characteristics to concrete, fine aggregate also takes the role of filling the empty spaces between the coarse aggregate. The use of very fine aggregate (aggregate powder) increases the strength of concrete more than expected by simply lowering the water/binder ratio due to improved interaction of paste and aggregate (Kronlöf, 1994). This can be explained where the fine materials interfere with the formation and orientation of large crystals at the paste-aggregate interface. Sadly, coarse aggregates are a non-renewable resource which requires quarrying that will hard and disturb the balance of the ecosystem.

2.2.2 Cement

Cement is a fine mineral powder made with very precise processes. When cement comes in contact with water, it transforms into a paste that binds and hardens when it is submerged in water. Due to its characteristics, it is very suitable to be used and is the main material in concrete mixing process. Cement is made by grinding together a mixture of limestone and clay, which is then heated at a temperature of 1450°C which then become a granular substance known as clinker (VICAT.com). There are four main components in cement, which are calcium, silicon, aluminium and iron. The behavior of concrete is mainly caused by the composition of cement. There are two categories of cement, hydraulic and non-hydraulic cement. Non-hydraulic cement such as slaked limes (calcium hydroxide mixed with water) hardens due to reaction carbonation in presence of the carbon dioxide naturally present in the air whereas hydraulic cement set and become adhesive in wet condition due to a chemical reaction between the dry ingredients and water (Scientific Era).

In the construction industry, the type of cement used depends on the condition and climate of the site. The most common type of concrete used is Ordinary Portland Cement (OPC) where it is composed of calcium, silica, alumina, iron, magnesium and sulphur (Amin & Ali, 2010). Rapid Hardening Cement (RHC), Low Heat Cement (LHC) and White Cement can be derived from OPC by tinkering its chemical composition. To produce RHC, lime content is added in OPC which quickens the hardening process. This causes the concrete to attain high strength in early days so that form work could be removed in early stage. As for LHC, it is manufactured the same way as OPC, except the content of tricalcium aluminate is reduced in order to reduce the heat produced during hydration. LHC is mainly used in massive concrete construction such as gravity dams because possess high final strength and sulfate corrosion resistance. White Cement is prepared from raw materials free from iron oxide. It is more costly compared to OPC and is used for architectural purposes (theconstructor.org)

2.3 ALTERNATIVE CEMENT REPLACEMENT MATERIAL

Various attempts have been done in searching alternatives for cement as cement is a nonrenewable resource. Based on past research, sewage sludge ash, fly ash and rice husk ash could be used to partially replace cement. Besides reducing cement used in casting concrete, reusing waste seems to be a great idea to preserve and conserve the environment.

2.3.1 Sewage Sludge as Partial Cement Replacement Material

Sewage Sludge Ash (SSA) is obtained when sewage sludge is combusted in an incinerator where it is in the form of silt with some sand-size materials. It is possible to use SSA to partially replace cement as SSA exhibits pozzolanic activity. Besides that, it is found out that SSA is comprised of high content of silica, which is quite similar with cement which enables SSA to partially replace cement. Moreover, reusing SSA in construction industry helps to preserve the environment as not all sewage sludge is used as agricultural fertilizer, there is still a portion of it sent to landfill to be decomposed.

Based on the research conducted by Yusuf et al. (2012), it is discovered that the optimum temperature for sewage sludge incineration is 800°C as increasing the temperature beyond this point might reduce the final strength of SSA concrete and the incineration yields 70% from the max weight as incineration will dewater the sewage sludge to dry solids. It is found that SSA can be incorporated into bricks and replace cement up to 30% as increasing the replacement percentage will only lower the quality and strength of bricks. Besides that, SSA is can also be used to replace cement in mortar as SSA is compatible with cements comprised high content of C_3A as binder in mortar where it is found that there is no decrease in mechanical properties when tested at 28th day. Moreover, by grinding the SSA particles into fine powder, it also increases the pozzolanic activity of SSA. Also, milled SSA requires less water for hydration and reduces the initial setting time of concrete from 2-4 hours to three hours and final setting time of concrete from 5-8 hours to four hours as the hydration rate of calcium silicate in OPC is slower than aluminium oxide in SSA.

Liew et al. (2004) had conducted a research on reusing sewage sludge in clay bricks and found that sewage sludge could replace up to 40% of clay in clay bricks but it is not recommended to use up to 40% as the compressive strength of clay bricks with 40% of SSA is only 2 MPa which is considerably low compared to the control brick that possess compressive strength of 16 MPa. Weight loss due to ignition also increases as the content of SSA present in clay brick increases as implementing SSA into clay bricks will increase its the surface roughness.

Based on the research done by Perez-Carrion et al. (2014), it is possible for SSA to partially replace cement in precast concrete blocks. The compressive strength of precast concrete block with 10% cement replacement by SSA shows the highest compressive strength, which is 5.85 MPa compared to 20% replacement and control block which are 4.25 MPa and 4.5 MPa respectively. As for water absorption rate, SSA precast concrete block with 10% replacement rate shows similar rate with the control block. Perez-Carrion et al (2014) concluded that SSA can replace up to 20% of cement in precast concrete block for reducing environmental impact on SSA.

2.3.2 Fly Ash as Partial Cement Replacement Material

Fly ash is a byproduct or residue left after burning pulverized coal fired generating plant. In 2003, about 2.5 billion tonnes of coal is burnt where only 650 million tonnes of fly ash is produced which gives a yield rate of 26% (Jagadesh, 2006). During the ignition process of pulverized coal, only carbon and volatile materials were burn off as some of the mineral impurities fuse in the suspension and float out of the combustion chamber in the gaseous state. The exhaust gases cools down and solidifies, it turns into a spherical glassy material which is known as fly ash.

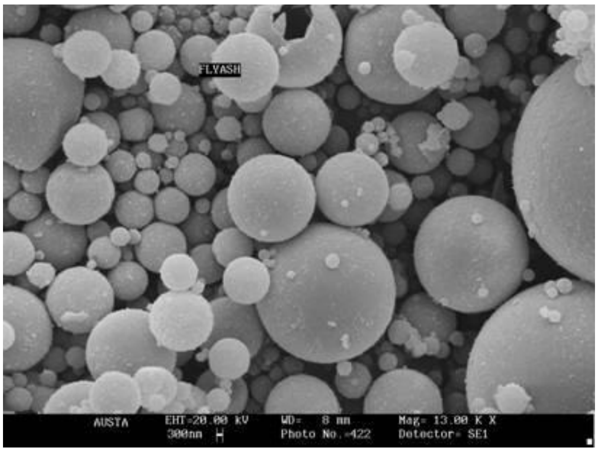

Figure 2.2: Micrograph of fly ash particles

Source: http://www.flyashaustralia.com.au/WhatIsFlyash.aspx

The size of fly ash particles varies and they resemble the Type 1 Portland cement but they are chemically different where they are made up of silica, alumina, iron and calcium. Bag filters or electrostatic precipitators are utilized in order to collect the fly ash from the exhaust gases. All types of fly ash exhibits cementitous properties as due to the presence of silica and they are pozzolan. However, it is not used to fully replace cement as the chemical reaction between fly ash and calcium hydroxide is considered slow compared to cement and water which will result in delayed hardening of the concrete. There are two types of fly ash that is widely used in the construction industry, class C and class F. Class C fly ash are by-product of subbituminous coal after ignition where it contains high amount of calcium and less than 2% content of carbon where it contains at least 50% of silica dioxide, aluminum oxide and iron oxide. Class C fly ashes will harden like cement when exposed to water. As for class F fly ash, they are obtained from ignition of anthracite coal where it possesses a minimum silica dioxide, aluminum oxide and iron oxide of 70%. Unlike class C fly ashes, most class F fly ashes does not harden when come in contact with water as they only react with the byproducts of cement hydration process. The performance properties of class C and class F fly ashes varies depending on their chemical and physical constitution. In these last few years, fly ash is widely used in U.S. where more than 50% of concrete casted contains fly ash. Fly ash is used to partially replace cement in concrete where the replacement percentage varies according to the type of fly ash used and desired final strength of concrete. Class F fly ash can only replace cement by 15% to a maximum of 25% which is considerably low compared to class C fly ash that can replace up to 40% cement content in concrete.

There are pros and cons in using fly ash to partially replace concrete. Usage of fly ash in concrete could produce a stronger concrete as fly ash will combine with lime particles which increases the strength of concrete over time. Concrete that contains fly ash becomes stronger and more durable compared to Ordinary Portland Cement mixtures as fly ash reacts with the byproduct of Portland Cement during hydration process, which is calcium hydroxide. Besides that, fly ash also increases concrete workability which makes it easier to place and vibrate in order to fill forms completely. This is due to the shape of fly ash, which is tiny spherical which provides greater workability compared to particles of Portland Cement which are solid and angular. Moreover, application of fly ash in concrete also reduces bleeding and segregation. Fly ash particles increase the cohesiveness of concrete which reduces the chance of segregation.

However, there are some downsides in using fly ash to partially replace cement. First of all, the quality of fly ash produced varies where poor quality fly ash could impose a negative effect on concrete. Fly ash is originally used to decrease the permeability of concrete. However poor quality fly ash might reverse it, instead of decreasing the permeability, it increases the permeability of concrete, creating more bleed channels that leads to bleeding failure. Concrete that possess high freeze-thaw durability has high amount of air entrained in it, whereas the presence of fly ash will reduce the freeze that durability as some fly ash contains high carbon content that absorbs air entraining particles, causing lesser amount of air entrained in the concrete that results in making the concrete prone to frost damage.

2.3.3 Palm Oil Fuel Ash as Partial Cement Replacement Material

During the process of palm oil production, solid waste such as fibers and shells of palm oil fruit are removed and reused as fuel in the boiler of palm oil mills where the solid waste turns into ashes after combustion at the temperature of 800°C to 1000°C which is also known as Palm Oil Fuel Ash (POFA). The yield rate of POFA is only 5% out of the total weight of solid waste combusted (Sata et al., 2004) POFA used to be a waste material is considered worthless and pollutes the environment before researches found out that it exhibits pozzolanic activity. Due to its high pozzolanic properties, it is possible to be used as a cement substitute material.

According to the research conducted by Deepak et al. (2014), 5% of cement replacement with POFA shows the highest compressive strength, which is 24.36MPa, 5.7% higher than the control block whereas the optimum percentage of cement replacement with POFA is 15% as it reaches compressive strength of 38.8MPa on the 28th day. Adding superplasticizer to POFA concrete will also increases the workability of the concrete where it also increases the slump value of concrete compared to the slump of OPC concrete. Moreover, the flexural and tensile strength of POFA concrete with 15% cement replacement is slightly higher than normal OPC concrete. Besides, reusing POFA as cement material in construction industry greatly helps the environment in reducing the area required for landfill for decomposition of these waste materials.

Chindaprasirt et al. (2007) had conducted a research to determine the strength and water permeability of concrete containing POFA. It is found that at 20% of cement replacement by POFA, the compressive strength of concrete is slightly lower than normal OPC concrete on the 28th day but the compressive strength of POFA concrete is higher on the 90th day. In Chindaprasirt et al. (2007)'s research, the optimum percentage cement replacement by POFA is 20% as they only did 20% and 40% replacement percentage. Both 20% and 40% of cement replacement by POFA shows a promising result in reducing the permeability on concrete on the 28th and 90th day where the permeability of POFA concrete is only 20% of the permeability of normal OPC concrete.

However, Sooraj (2013)'s research shows that implementing POFA in concrete will bring adverse effect to the concrete's strength. Sooraj (2013) conducted a research with 4 types of cement replacement percentage, which are 10%, 20%, 30% and 40%. Compressive strength of POFA concrete with 10% cement replacement shows the highest compressive strength among the 4 types of cement replacement percentage but it is still slightly lower than the control block by 1.26 MPa on the 28th day. However, POFA concrete with 10% cement replacement achieves a higher splitting tensile strength at 28th day, which is 2.69 MPa, 0.07 MPa higher than the normal OPC concrete. As for the flexural strength of concrete, POFA concrete with 20% cement replacement acquires the highest flexural strength, which is 6.12 MPa. Thus, Sooraj (2013) had concluded that the optimum percentage of cement to be replaced by POFA is 20% based on the results obtained.

Sata et al. (2004) had conducted a research regarding the utilization of POFA in High-Strength Concrete and found out that ground POFA with high fineness is suitable to be used to produce high-strength concrete as it is a highly reactive pozzolanic material. POFA used in this research are ground by ball mill until the particle size of POFA is reduced to 10μm. In this research, the optimum percentage of cement replacement by POFA is found to be 20% which is 91.5 MPa at 90th day, 4 MPa higher than the control block. Besides, increasing the percentage of cement replaced by POFA will reduce the peak temperature rise of concrete where 30% of cement replaced by POFA can reduce 15% of temperature rise compared to the normal OPC concrete.

To conclude, most of the past research showed that the optimum percentage cement replacement by POFA is 20% as any more or less that that will give a less desirable outcome.

2.3.4 Rice Husk Ash as Partial Cement Replacement Material

Rice husk is the outermost layer of paddy grain where it is separated from the brown rice during the milling process. Rice husk weighs around 20% of the weight of paddy and it is found that around in 2008, the global production rice husk is 132 million tons (Rice Knowledge Bank). Rice husk is usually burned in the open or sent to the landfill to be decomposed which is not a good idea because rice husk contains high content of silica (SIO_2) and up till now, it is still often considered as waste substance. Rice husk is suitable to be used as partial cement material due to its high pozzolanic activity and presence of silica after being incinerated in the furnace. According to Ganesan et al. (2008), the optimum temperature of incineration is 650 degree Celsius for 1 hour which changes the chemical composition of rice husk into an efficient pozzolanic material which is rich in amorphous silica content (87%) and it possess a relatively low lost on ignition value (2.1%). Utilizing RHA to partially replace cement can produce concrete with higher resistance to chloride due to its lower loss on ignition compared to OPC. However, the research conducted by Habeeb & Mahmud, (2010) shows that the loss on ignition is considered relatively high, which is 5.81% which is why application of RHA in construction industry is not practiced widely as there a lot unknown elements yet to be explored.

Habeeb & Mahmud, (2010) states that even thou grinding RHA into smaller average particle size slightly increased its specific surface area, it is not the main factor controlling its surface area. However, their research shows that replacing 10% of OPC with RHA that has been grinded for 360 minutes gives the optimum result, which is 51.8 MPa at 28th days, 12.4 MPa higher than the control. Also, their research states that the RHA could replace up to 20% content of cement without causing great drop in the concrete strength and concluded that increasing RHA fineness could greatly increases the strength of blended concrete. Research conducted by Zhang et al, (1996) proves that the concrete with partial replacement of cement by 10% of RHA has weak early strength but it somewhat had higher strength than the control block after 180 days. This is due to the effect of incorporating RHA which reduced the porosity and the $Ca(OH)_2$ quantity in the interfacial zone and which subsequently reduces the width of the interfacial zone between the aggregate and the cement paste after comparing it with the control Portland cement. Interfacial zone is a narrow region around the aggregate particles with more water and lesser cement particles where the increasing of the total volume of interfacial zone in a concrete will cause the decrease in concrete strength.

2.4 CONCRETE CURING

Concrete curing is one of the vital steps to produce a strong and durable concrete. It is the process of controlling the rate and extent of moisture loss from concrete in order to ensure an uninterrupted hydration of Portland cement after the concrete has been placed and ready to be set. Concrete will harden due to hydration process which is the chemical reaction between water and cement but it only occurs if water is present and the concrete's temperature must stay within suitable range to facilitate the hydration process. Thus, curing is important as it ensures the temperature of the concrete remain within suitable range which can directly affect the rate of hydration and eventually the compressive strength and durability of the concrete.

Besides that, curing also ensures shrinkage cracking doesn't occur because the temperature will be kept uniform. Concrete curing doesn't only improves the concrete strength, it also improve the durability of concrete, enhance its stability and improve the microstructure of the concrete. As for the duration of curing, it depends on the grade and type of cement, design concrete strength, shape and size of concrete casted, mix proportion and environmental and exposure conditions where the duration may vary from few days to a month.

2.4.1 Air Dry Method

Air dry curing is the simplest curing method among concrete curing, where the specimens are just left in an open area, sheltered from rain and in room temperature after being removed from the formwork.

Safiuddin et al. (2007) had conducted a research to determine the effect of different curing method on microsilicate concrete. It is found that air dry curing method shows the worst performance in terms of compressive strength, dynamic modulus of elasticity and UPV. Besides that, air dry curing method produces the highest initial surface absorption, which is unfavorable for concrete curing process. All of these are induced by the moisture movement in the specimens was extremely high and thus, fail to provide protection on early drying out of concrete. This results in incomplete hydration of cement and retarding the pozzolanic reaction.

In the research conducted by Akinwumi & Gbadamosi, (2014), concrete cured by air dry method shows significant increase in strength after 28 days of curing and on the 90th days of curing, concrete samples cured by air dry method achieves the highest compressive strength compared to those cured by different methods.

2.4.2 Immersion Curing using Plain Water

Immersion curing is one of water curing method where the concrete samples to be cured are fully immersed in plain water. This curing method is typically used for curing concrete test specimens. As concrete hydration only occurs with the presence of water, covering concrete with a layer of water helps to promote this process and control the moisture evaporation rate from the surface of the concrete. Besides, covering the concrete with a layer of water helps to cool down and maintain the temperature of concrete which helps a lot in preventing cracking due to thermal stresses.

According to Akinwumi & Gbadamosi, (2014), concrete cubes cured in water have similar compressive strength development with those cured by plastic sheet covering. Immersion curing should be limited to 28-day curing period as the increase in compressive strength was not significant after 28 days curing period. In Akinwumi & Gbadamosi, (2014)'s research, they discovered that upon 90th day of curing, concrete cubes cured by plain water immersion method shows the least compressive strength compared to other methods.

However, in the research conducted by James et al. (2007) it is found that immersion curing with water was the most effective method of curing. In their research, three types of curing method are use, namely sprinkling method, membrane method and immersion method. 16 samples of each curing method are cast to be tested on the 7th and 28th day to acquire more accurate compressive strength. On the 28th day of curing, concrete samples cured by immersion method shows the highest average compressive strength, 20.34 MPa, followed by sprinkling method, 18.38 MPa and then membrane method 17.42 MPa. This is due to water curing helps in improving the pore structure of concrete and lowers its porosity which results in greater degree of cement hydration reaction without loss of moisture from concrete samples. Strength properties of concrete are greatly influenced by the moisture movement in concrete where the higher moisture movement, the weaker the concrete. They have concluded that water curing method is the optimum curing method to be applied on normal concrete as water curing prevents loss of moisture from concrete which then boost the cement hydration process.

2.4.3 Immersion Curing using Salt Water

This is curing method is also considered as one of the water curing method, except salt water is used instead of plain water. (Wegian, 2010) had conducted a research to determine the effect of sea water for mixing and curing on structural concrete. They have discovered that concretes mixed and cured in concrete possess higher compressive, tensile, flexural and bond strengths compared to concrete mixed and cured in plain water on 7th and 14th day. However, the strengths concrete mixes mixed and cured in plain water increase gradually after 28 and 90 days. This might be due to crystallization of salt in seawater, causing concrete mixes mixed and cured in saltwater possess lower compressive strength compared to those mixed and cured in plain water. Thus, it is concluded that sea water is not suitable to be used to cure and mix plain concrete as it only increases the early strength but decreases the ultimate strength of concrete.

Another research had been done by Islam et al. (2012) to determine the suitability of sea water on curing and compressive strength of structural concrete. This research also found that sea water will affect the concrete strength negatively. However, concrete samples mixed using sea water and cured in plain water shows a decrease of 10% in compressive strength on the 180th day whereas concrete samples mixed with plain water and cured in sea water shows lesser loss of strength, which is only 6%. Based on the results of this research, sea water is not recommended to be used as mixed water as it causes strength deterioration of concrete.

2.5 MECHANICAL PROPERTIES OF CONCRETE

There are various types of test that could be conducted to measure the mechanical properties of concrete.

2.5.1 Compressive Strength Test

Compressive strength test is a destructive lab test where pressure is applied on concrete samples until the specimen fails in order to determine the maximum amount of compressive load the concrete sample can sustain where the samples are normally in form of cube or cylinder. For concrete cube test, the size of samples chosen depends on type of aggregate used, which is either 150mm x 150mm x 150mm or 100mm x100mm x 100mm. The specimens will normally be tested on the 7th and 28th day where an increasing load of 140$\mathrm{kg/cm^2}$ per minute will be applied on the specimen until the specimen fails.

According to Jamshidi et al. (2012) incorporating SSA into concrete where it partially replaces fine aggregate will slightly reduce the compressive strength according to the percentage of replacement. Results shows that concrete mixture with 5% and 10% of fine aggregate replacement by SSA shows only minor drop in strength, which is 41 MPa and 38 MPa respectively and it is considered favorable as the control block only possess 42 MPa on the 90th day of curing. As for SSA concrete with 20% of fine aggregate replacement shows about decrease in 20% of compressive strength but it is still acceptable as it possess compressive strength above 25 MPa for 28 days of curing.

2.5.2 UPV

An ultrasonic pulse velocity (UPV) test is a nondestructive that is carried out on site to determine the quality of the concrete. UPV test checks and detect the uniformity of concrete, cracks, cavities and defects based on the pulse velocity method. Besides, UPV test also allows user to assess the strength of the concrete qualitatively and its gradation in different location of structural members. In order to determine the strength and quality of the concrete, ultrasonic pulse is sent into the concrete and the time required for the ultrasonic pulse to pass the concrete is recorded where the higher the velocity, the higher the quality of concrete in terms of uniformity and homogeneity. There are 3 methods of sending and receiving ultrasonic pulses, direct transmission, semi-direct transmission and indirect transmission. Reinforcement bars in the concrete might slightly affect the time for the pulse to pass the concrete if the reinforcement bars runs in a direction at right angle to the pulse path and in condition where the amount of reinforcement bars is small compared to the path length.

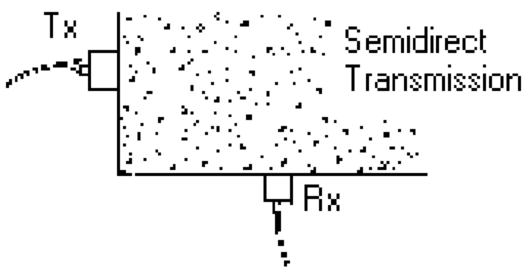

Figure 2.3: Semi-direct Transmission

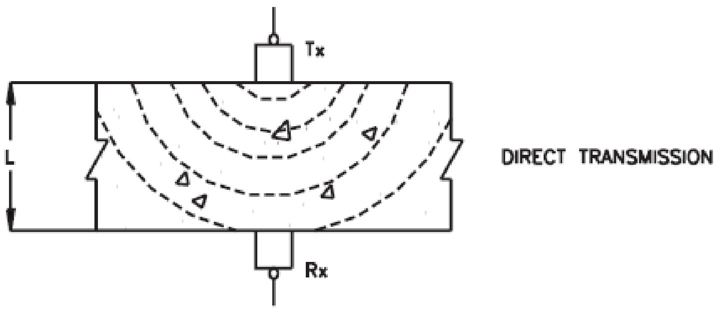

Figure 2.4: Direct transmission

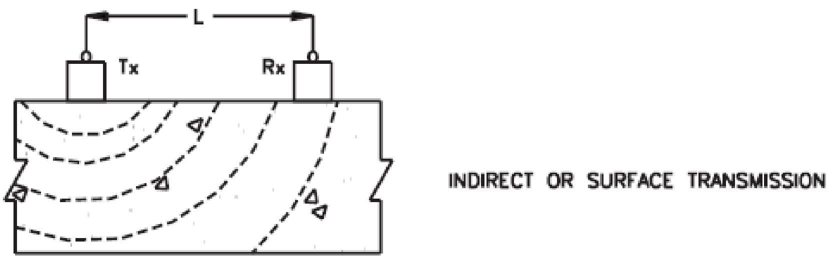

Figure 2.5: Indirect transmission

Source: https://www.researchgate.net/figure/236170126_fig2_Figure-2-Direct-a-Semi-direct-b-Indirect-surface-transmission-c

If the pulse velocity is more than 4.5 km/s, the concrete is in excellent condition. Good quality concrete has pulse velocity values ranging from 3.5 to 4.5 km/s. Concrete with pulse velocity ranging from 3 to 3.5 km/s is only considered satisfactory as there might be loss in concrete integrity. Concrete with pulse velocity less than 3km/s is considered of poor quality and confirmed loss of integrity. The UPV values and rebound numbers are used to determine the corrosion rate of concrete. The higher the UPV value and rebound number, the lower the corrosion rate and vice versa.

2.5.3 Three Point Flexural Test

Three point flexural test gauge the flexural strength of a beam where it measures the force required to bend a beam under three point loading conditions. By applying force in the middle of the beam, it produces compressions tress on the concave side of the beam and tensile stress on the convex side of the beam which results in forming an area of shear stress down the midline. Flexural strength of the sample can only be determined when the sample breaks in the outer surface within the 5.0% strain limit. There are three key analyses when conducting flexural test. Flexural modulus indicates a material’s stiffness where it assesses the slope of stress/strain curve. Flexural strength indicates the maximum force the sample could sustain before it breaks or deform. Yield point is where samples gives up where any further force applied to bend the sample will not results in and increase of the flexural force recorded.

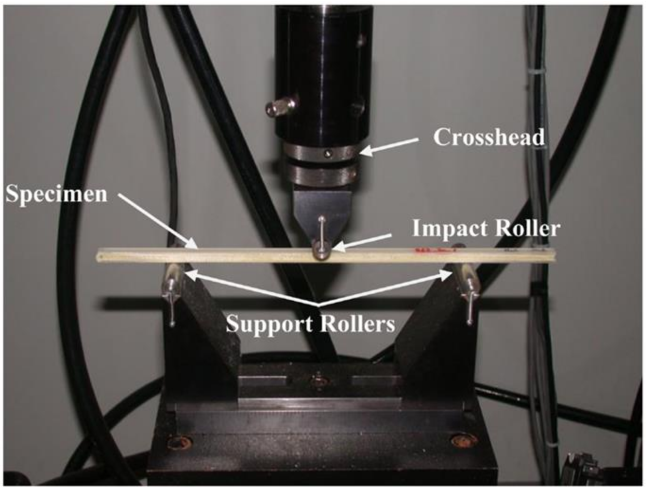

Figure 2.6: Three point flexural test

Source: http://journal.frontiersin.org/article/10.3389/fbioe.2013.00013/full

In the research conducted by Jamshidi et al. (2012), it is found that SSA concrete with partial sand replacement shows promising flexural strength up to 20% as SSA concrete with 20% sand replacement only shows 20% of flexural strength deterioration compared to the control specimen. Thus, Jamshidi et al. (2012) concluded that by implementing SSA into concrete as sand replacement not only contributes to reducing landfill required to dispose sewage sludge, it also reduces sand used in construction as sand is a non-renewable resource.

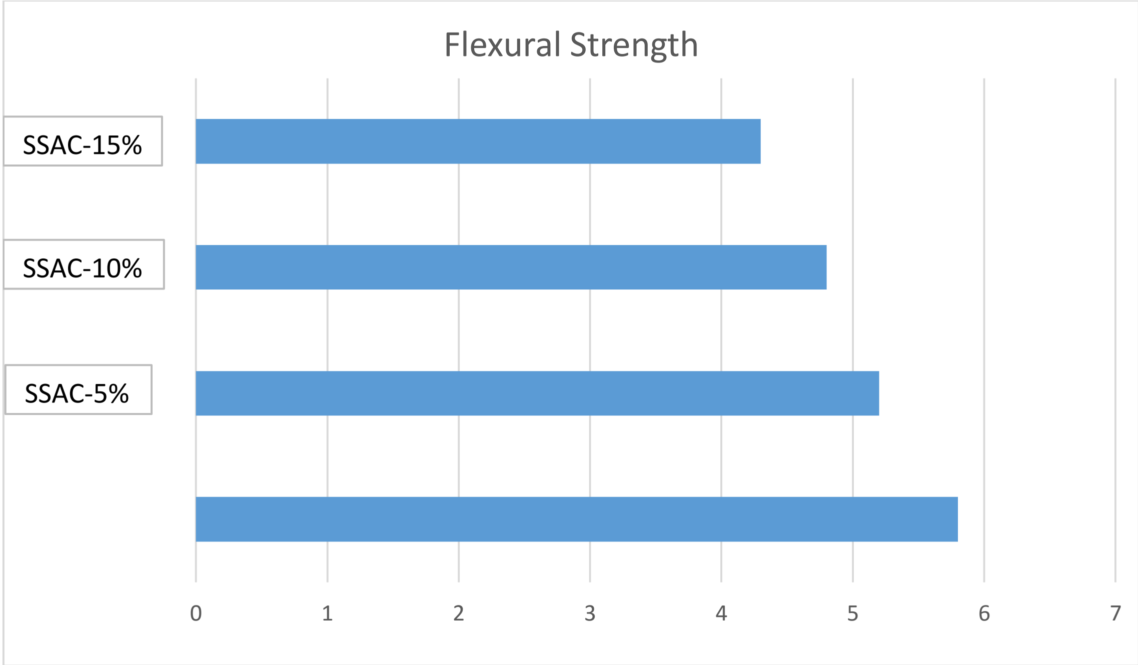

Figure 2.7: Flexural strength for SSAC of various percentages

Source: A.Jamshidi et al. (2010)

CHAPTER 3

RESEARCH METHDOLOGY

3.1 INTRODUCTION

This chapter reviews experiments and test to be conducted to determine the effect of curing on SSA concrete. In this research, data is collected through slump test, compression test, UPV test and Three point flexural test. Materials used and test conducted in this research complies the standard documentaries.

3.2 PREPARATION OF MATERIAL

The materials used in this research are Ordinary Portland Cement (OPC), river sand (fine aggregate), sand stone (coarse aggregate) sewage sludge ash (cement) and water. Sewage sludge ash will be used to partially replace cement. The ratio of concrete used is 1:2.25:2 which respectively to cement, fine aggregate and coarse aggregate. To maintain and control the quality of the specimens, the materials used for concrete mixing must be prepared with cautious and kept in a safe place.

3.2.1 OPC

Ordinary Portland Cement is selected to be used in the mixing of concrete in this research as adding other additives might diminish the effect of SSA and curing to the concrete, which makes it hard to determine the effectiveness of different curing used to cure the SSA concrete. YTL ORANG KUAT OPC is used in this research where it is certified to MS 522-1:2007 (EN197-1:2000), CEM I 42.5 N/ 52.5 N and MS 522: Part 1:2003. Besides, this type of OPC one of the common cement used in Malaysia which makes it easily available in the market. It is stored in a dry place in the laboratory as exposing it to water will cause it to harden due to hydration process.

3.2.2 Fine Aggregate

Fine aggregate provided and used in this research is river sand originated from Panching Kuantan. Other than filling the voids existing in the coarse aggregate, fine aggregate also reduces shrinkage and cracking of concrete. Besides, it also facilitates the hardening of concrete by allowing water to flow through its voids freely. Fine aggregates used in this project are sieved using sieve with 4.75mm opening before being used in concrete mix as only according to ASTM standard, fine aggregate are aggregates that pass through sieve with 4.75mm opening. Fine aggregates obtained are then kept in a safe and dry place to prevent accumulation of excess moisture and impurities.

Figure 3.1: Fine aggregate

3.2.3 Coarse Aggregate

In this research, sand stone is used as coarse aggregate as it is easily available and meet the requirements of this research. Coarse aggregates gives concrete its hard and solid properties after mixing with cement, sand and water. Also, it increases the durability and crushing strength of the concrete. Aggregates used in this research are sieved and those are retained on sieve no.4 with 4.75mm opening are considered coarse aggregated and kept in a dry place to prevent excess moisture content in it.

Figure 3.2: Coarse Aggregate

3.2.4 Sewage Sludge Ash

Sewage sludge used in this research is obtained from Indah Water Konsortium (IWK) sewage treatment plant located in Kuantan, Pahang where it collects sewage from nearby commercial and residential area which is categorized as domestic sludge. The sewage sludge collected is dried under the sun and only the top part is collected as the underneath portion consists of fine sand that filters the sewage sludge. The sewage sludge is collected into containers and stored in a dry place to prevent water from infiltrating the container. As excess moisture in sewage sludge will affect the incineration process, the sewage sludge collected is first oven dried at 105°C for 24 hours. To ease the handling of SSA after incineration, sewage sludge is placed in a clay pot before inserted into the furnace. The sewage sludge is incinerated at 800°C for 3 hours 30 minutes. Only the top portion of the SSA is collected and used in this research as the bottom part is not subjected to proper combustion which will reduce the strength of concrete drastically if used to replace cement. SSA collected is then grind into tiny particles similar to those of cement.

Figure 3.3: Grinded SSA

3.2.5 Water

In this research, the water to cement ratio used is 0.55 where the volume of water used is calculated in the concrete mix design. Water used in this research for concrete mixing purposes is supplied by the laboratory where it is free from impurities and heavy metal in order to prevent side reaction from occurring during the hydration process which might affect the strength of concrete.

3.3 CONCRETE MIX DESIGN

Universiti Malaysia PAHANG CONC	MAKMAL KONKRIT / TABLE 1 : CONCRETE MIX DESIGN FORM	Document No · CONC/2011/015; Issue No : 1; Revision No : 0; Effective Date : 10 Oktober 2011; Page No : 1 of 1

Stage		Item	Reference or Calculation	Value
1	1.1	Characteristic Strength	Specified	30 N/mm2 at 28 days; Proportion defective 10 %
	1.2	Standard Deviation (σ)	Table 1.1	5 N/mm2 or no data – N/mm2
	1.3	Margin (k x σ)	C1 or Specified	(k = 1.28) 1.28 x 5 = 6.40 N/mm2
	1.4	Target mean strength	C2	30 (Characteristic strength) + 6.40 (Margin) = 36.40 N/mm2
	1.5	Cement type	Specified	OPC / SRPC / RHPC
	1.6	Aggregate type : Coarse	Specified	Crushed / Uncrushed
		Aggregate type : Fine	Specified	Crushed Uncrushed
	1.7	Free-water/cement ration	Table 1.3 Figure 2	0.61
	1.8	Maximum free-water/cement ratio	Table 1.4	0.50 use the lower value
2	2.1	Slump	Specified	60 - 180 mm
		Vebe Time	Specified	0 - 3 s
	2.2	Maximum aggregate size	Specified	10mm / 20mm / 40mm
	2.3	Free - water content	Table 2.1	205 kg/m3
3	3.1	Cement Content	C3	205 (Free water content) / 0.5 (Free-water/cement ratio) = 410 kg/m3
	3.2	Maximum cement content	Specified	kg/m3
	3.3	Minimum cement content	Specified	Use 3.1 if < 3.2; Use 3.3 if > 3.1
	3.4	Modified free - water / cement ratio		
4	4.1	Relative density of aggregate (SSD)		2.4 known / assumed
	4.2	Concrete density	Figure 3	2410 kg/m3
	4.3	Total Aggregate Content	C4	2410 (Concrete Density) - 410 (Maximum Cement Content) - 205 (Free water Content) = 1795 kg/m3
5	5.1	Grading of fine aggregate (BS 822)	Percentage passing 600μm sieve	15-40 %
	5.2	Proportion of fine aggregate	Figure 4	45-47 %
	5.3	Fine aggregate content	C5	1795 (Total aggregate content) x 0.51 (Proportion of fine aggregate) = 913.45 kg/m3
	5.4	Coarse aggregate content	C5	1795 (Total aggregate content) - 915.45 (Fine aggregate content) = 879.55 kg/m3

Quantities	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg) (10mm / 20mm / 40mm)
per m3 (to nearest 5kg)				
per trial mix of _______ m3				

1 N/mm2 = 1MN/m2 = 1 Mpa
OPC = Ordinary Portland Cement
SRPC = Sulphate-resisting Portland Cement
RHPC = Rapid-hardening Portland Cement
Relative density = specified density = ratio between weight of sampel to weight of water
SSD = based on a saturated surface-dry basis

Figure 3.4: Concrete mix design

3.4 CASTING, MOULDING AND DEMOULDING

In this research, the specimens were casted in the size of 100mm x 100mm x 100mm according to BS 1881: Part 108: 1983. A total of 54 concrete cube specimens were casted where 27 of them act as control block and 24 concrete beam specimens were casted where half of the acts as control specimens. To produce specimens with smooth finishing, moulds used in this research are cleaned before being used. Equipments and machine used for mixing and casting are rinsed with water before the casting process starts in order to reduce water loss. Plasticizer is mixed in the water used for concrete mixing in the ratio of 1litre to 1metre cube of concrete. After concrete mix was poured into the moulds, they were compacted using the vibrator table to compact and reduce air voids in the specimens. The specimens were left in the laboratory for 24 hours before being removed from the mould and cured in different curing methods.

Figure 3.5: Concrete mixing

Figure 3.6: Beam casting

Figure 3.7: Beam compacting

Figure 3.8: Flexural beam

3.5 CURING

Curing methods used in this research are air dry curing, plain water immersion curing and salt water immersion curing. It is vital for the specimens to be cured as it helps to produce strong and durable concrete. The specimens are immersed in plain water and salt water and left to dry as shown in Figure 3.9. The duration of curing are 3 days, 7 days, 28 days and 90 days.

Figure 3.9: Salt water cured specimens

3.6 TEST PROCEDURES

3.6.1 Compressive Strength Test

This test was carried out in the UMP Faculty of Civil Engineering & Natural Resources concrete laboratory using the compression machine as shown in Figure 3.10 according to the BS standard (BS1881: Part 116:1983).

Figure 3.10: Compression test machine

In this test, axial load is applied on the SSA concrete specimens until the sample is deforms or fails. 3 types of SSA concrete specimens were tested using this test; specimens cured in plain water, salt water and specimens that undergo air dry curing. Specimens are tested on the 3, 7, 28 and 90 days of curing. In order to get an average result, 3 samples of each category were tested.

The compression test starts after the sample is placed in the middle of the machine with the valve closed. When the specimens reach its maximum strength and fails, the compression test stops automatically and results are shown on the screen of the machine.

3.6.2 UPV Test

Ultrasonic Pulse Velocity is conducted to check for strength and quality of the samples where ultrasonic pulse is channeled into the specimens and time for the pulse to travel through the specimen are collected in order to detect void and cracks in the specimen. The number of samples used to conduct this test is the same as compressive strength test, where 3 samples from each type of curing method are tested on 3 days, 7 days and 28 days of curing to obtain an average result. Direct transmission method is used to test the specimens. UPV machine used in this research is as shown in Figure 3.11.

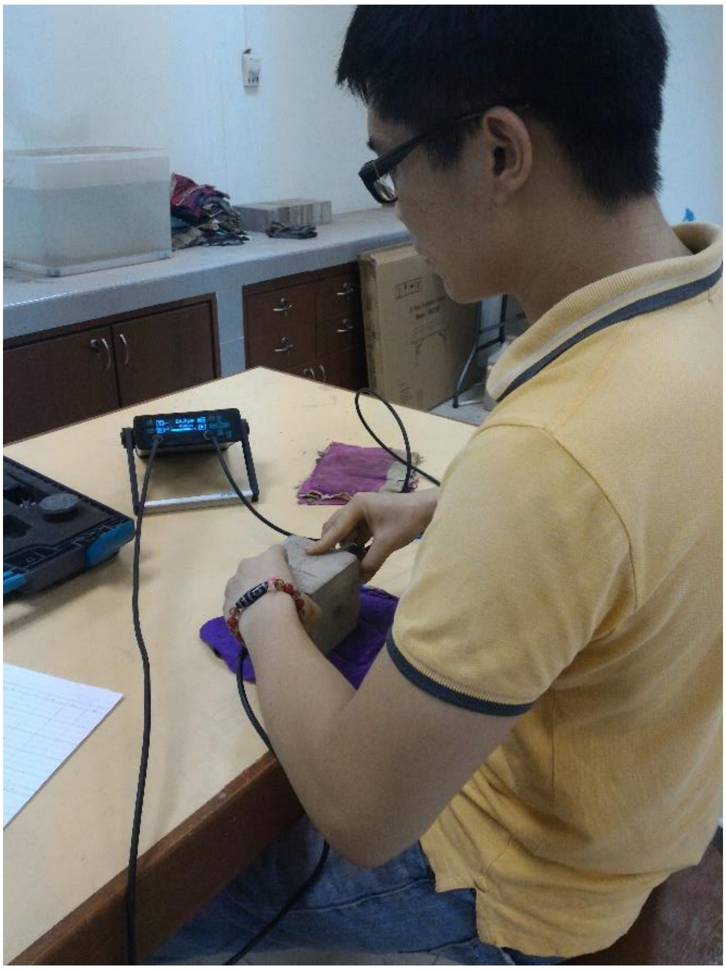

Figure 3.11: UPV test

3.6.3 Three Point Flexural Test

The purpose of conducting three point flexural test is to obtain the values of modulus of elasticity in bending, flexural stress and flexural strain of the material. This test was conducted in UMP concrete lab according to the ASTM standards. Flexural machine used in this research is as shown in Figure 3.12.

Figure 3.12: Flexural test machine

Specimens used are cured using 3 different type of curing method and were tested on 7 and 28 days of curing where 2 of each category are used to obtain an average value. The specimen was placed in the center of the machine where the load applying block was brought in contact with the upper surface of the specimen at the center line between the support blocks that holds the specimen in position. The machine is then started where it slowly increases the load applied to the center of the specimen until the specimen fails.

Figure 3.13: Failed flexural beam

3.6.4 Slump Test

Slump test is conducted to test fresh concrete for its workability. The main purpose of this test is to measure the consistency of fresh concrete in that particular batch. By consistency, it refers to the how easy can the concrete flows. Besides that, it can also be used to determine the degree of wetness of the concrete. Slump test in this study will be carried out according to BS 1881: Part 102: 1983. Before placing concrete in the apparatus, the slump cone, plate and tamping rod must first be cleaned and wetted to prevent moisture lost. The slump cone is placed on a steel plate and firmly secured by stepping on the side. The slump cone is filled in one-third of fresh concrete of its heigh and that particular layer was tampered uniformly with 25 strokes using tamping rod and this process repeated 3 times. After finish filling and tampering the concrete, the slump cone was lifted slowly in vertical direction. The height between the slump cone and fresh concrete was measured. There are 3 classifications of slump results: true slump, shear slump and collapse slump.

CHAPTER 4

RESULT AND DISUSSION

4.1 INTRODUCTION

This chapter studies the results obtained from the experimental testing that were conducted according to the method that has been discussed in the methodology which will determine the performance of SSA in different types of curing condition. The results obtained mainly focused on hardened properties of concrete such as UPV test, compressive test and three point flexural test. All the test regarding the specimens cured in different curing method are discussed in this chapter.

4.2 FRESH SSA CONCRETE PROPERTIES

Slump test is conducted to identify the fresh concrete properties for both batches of control and SSA concrete.

4.2.1 Slump Test

Concrete slump test is used to measure the consistency, uniformity and workability of fresh concrete in a specific batch of concrete. This test is widely practiced as it is easy to conduct and provides accurate result.

Table 4.1: Slump test result

Mix Type	Water to Cement Ratio	Slump Value (mm)	Slump Type
Control	0.55	50	True Slump
10% SSA	0.55	55	True Slump

The slump test is conducted according to BS EN 12350-2:2009 where slump value between 50-100mm is considered medium degree of workability. Concrete with 10% cement replacement by SSA provides a slump value higher than control by 5mm as shown in Table 4.1. According to (Jamshidi et al., 2012), SSA concrete with 10% cement replacement shows weaker capillary water absorption coefficient compared to control. SSA has weaker water absorption ability compared to OPC and thus, causing the fluidity of the concrete mix to increase which results in higher slump value.

4.3 HARDENED SSA CONCRETE PROPERTIES

4.3.1 Compressive Strength

Concrete cube specimens were cured in 3 different curing methods; air dry, plain water and salt water curing and tested at the ages of 3, 7, 28, 90 days to acquire the compressive strength value. 3 specimens of each curing method were tested at each age of curing in order to obtain the average result. Table 4.2 shows the summary of compressive strength results for the concrete cubes according to types of curing method practiced and graph denotes the relationship between compressive strength days of curing for control cubes.

Table 4.2: Summary of compressive strength for control cube

Days of Curing	Compressive Strength, MPa		
	Air Dry Curing	Plain Water Curing	Salt Water Curing
3	26.21	31.39	29.87
7	31.21	34.32	35.78
28	37.30	43.97	43.67
90	42.21	58.51	49.82

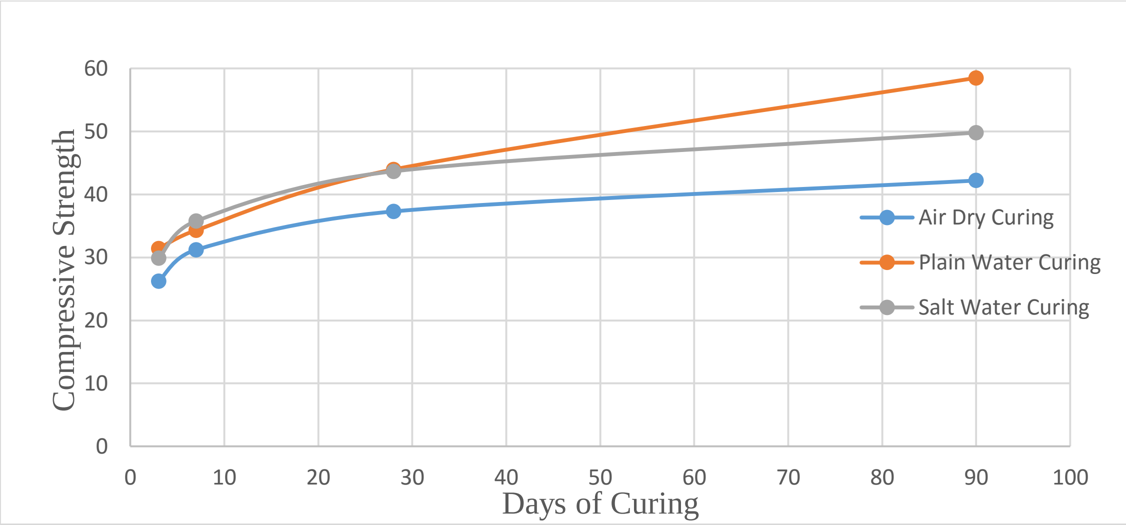

Figure 4.1: Compressive strength against days of curing for control cube

From Table 4.2, the compressive strength of control cube cured in plain water possess the highest compressive strength amongst the 3 types of curing, which is 31.39 MPa, followed by 29.87 MPa and 26.21 MPa for control cubes cured in salt water and air dry respectively. However, specimens cured in salt water has the highest compressive strength during the 7 days of curing, which is 35.78 MPa, 1.45 MPa higher than cubes cured in plain water and 4.57 MPa higher than cubes cured in air dry method. On a side note, specimens cured in salt water showed change in color; from dark grey to light grey whereas specimens cured in plain water and air dried show almost no change in visual characteristics as the change in color is due to salt deposition on the surface of the concrete cubes. On the 28 days of curing, specimens cured in salt water also showed promising results, which is 43.67 MPa. However, specimens cured in plain water showed a stronger compressive strength, 43.97 MPa whereas air dried specimens remains the lowest in term of compressive strength. According to Table 4.2, plain water cured specimens possess the highest compressive strength, 58.51 MPa, followed by 49.82 MPa and 42.21 MPa for salt water and air dried specimens respectively. According to (Islam et al., 2012) specimens cured in salt water affects the gain in strength when used for mixing and curing where it increases the early strength gaining of the concrete, which can be seen in Figure 4.1. From Figure 4.1, it can be seen that specimens cured in salt water shows increase in compressive strength during the early stages, which is from 7 days of curing until 28 days of curing. However, their ultimate strength decreases; at 90 days of the strength curing specimens cured with salt water is observed to decrease by 15%. Islam et al. (2012) states that specimens cured in salt water are penetrated by salt ions into the inner part of the specimen mass and influence the hydration process with the formation of expansive products and some leachable compounds which causes tiny cracks to appear deep in the specimens together with the leaching action of the newly formed compounds which will eventually leads to the decrease of concrete strength. As for the rapid gain of strength during the early stage, it can be explained by the effects of seas salts that contain components such as $N\mathrm{aCl}$ and $\mathrm{K_2}SO_4$ that causes a quick dissolution of cement compounds, especially tricalcium silicate in water that increases the hydration rate of concrete. The decrease of ultimate strength of specimens cured in salt water is due to the reactions of sea salts with hydrated cement matrix being expansive and leachable in nature, resulting in deterioration of concrete strength. For specimens cured by air dry method, the compressive strength on 90 days of curing shows 28% strength deterioration which is quite favorable as it is still higher than 25 MPa and can be used in construction industry. It simulates the condition where curing could be difficult, for example high rise buildings.

Table 4.3 shows the overall compressive strength for SSA concrete cubes with 10% cement replacement.

Table 4.3: Summary of compressive strength for SSA cube

Days of Curing	Compressive Strength (MPa)		
	Air Dry Curing	Plain Water Curing	Salt Water Curing
3	19.08	26.05	30.31
7	30.71	37.12	35.62
28	37.49	48.39	45.44
90	45.75	53.89	53.41

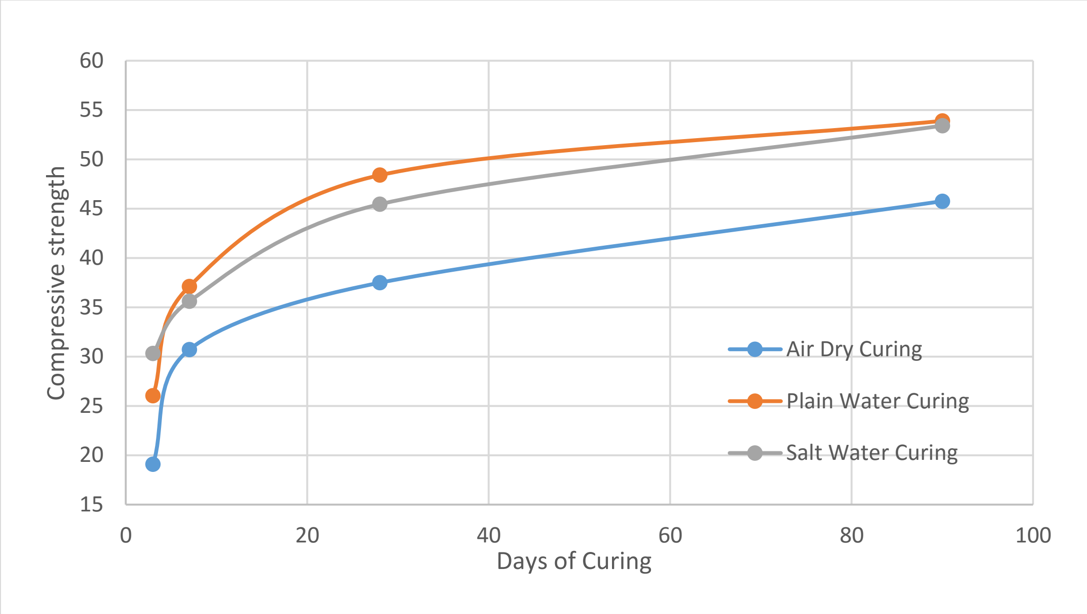

Figure 4.2: Compressive strength against days of curing for SSA cube

Table 4.3 denotes the summary for SSA specimens cured in different curing methods for 90 days of curing. According to Table 4.3, specimens cured in salt water possess the highest compressive strength, which is 30.31 MPa during the 3rd day of curing whereas specimens cured in plain water achieved the highest compressive strength amongst the 3 types of curing, which is 53.89 MPa. As for air dried SSA cubes, its compressive strength deteriorates for only 15% on the 90 days of curing.

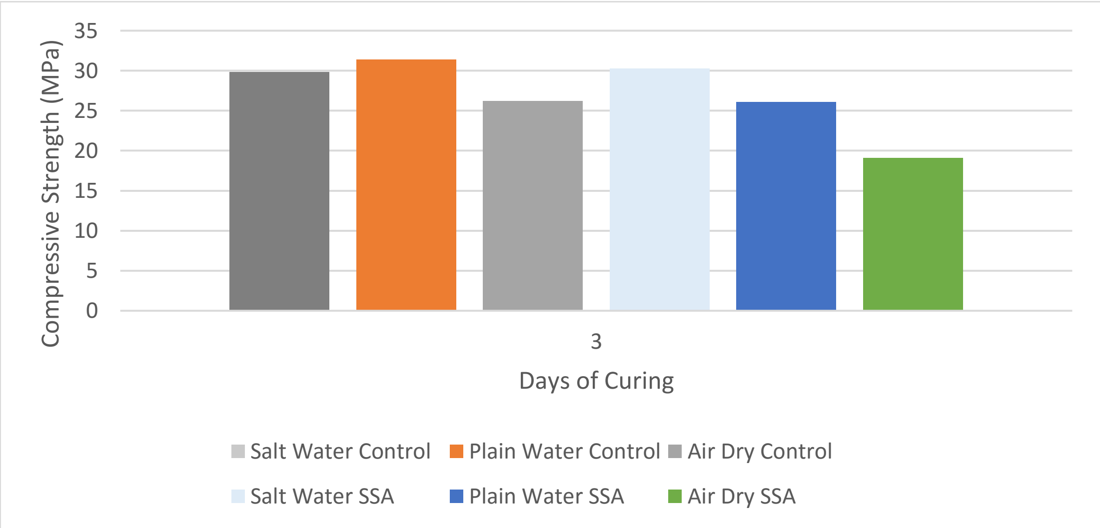

Figure 4.3: Compressive test for cube specimens on 3 days of curing

Figure 4.3 shows the comparison between control and SSA concrete cube specimens on 3 days of curing. It can be observed that control cubes cured in plain water exhibits then highest compressive strength for 3 days of curing, followed by SSA specimens cured in salt water. The boost in compressive strength can be explained by the components present in salt water such as $NaCl$ and K_2SO_4 that causes a quick dissolution of cement compounds according to (Islam et al., 2012). SSA specimens cured in plain water and air dried suffers a strength deterioration by 8& and 7% respectively. This might be due to the particles of SSA which is less reactive compared to cement particles which reacts vigorously with water in hydration process.

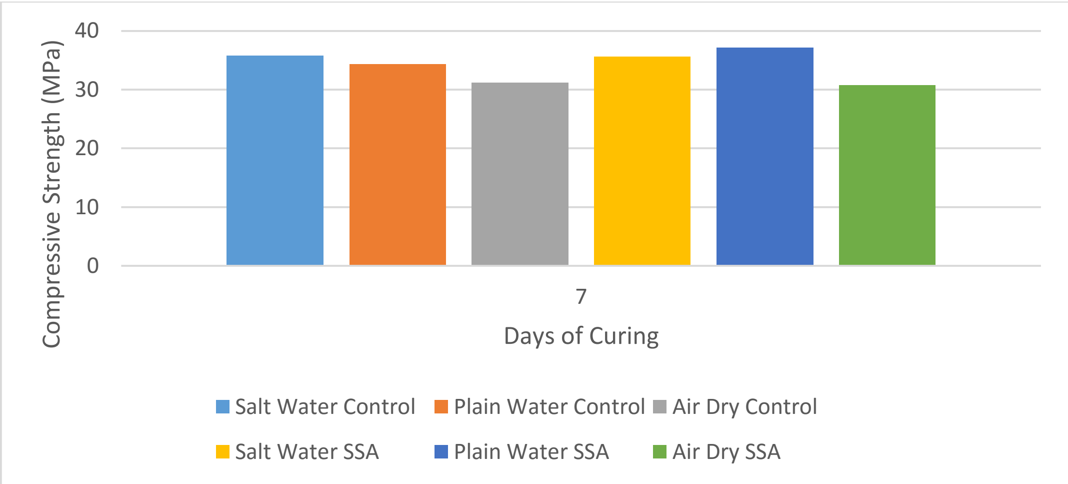

Figure 4.4: Compressive test for cube specimens on 7 days of curing

In Figure 4.4, it can be seen that SSA specimens cured in plain water exhibits the highest compressive strength during the 7 days of cuing, which is 37.12 MPa, followed by specimens cured in salt water. Specimens that are left air dried remains lowest in terms of compressive strength due to lack of water for the concrete to further undergo hydration process.

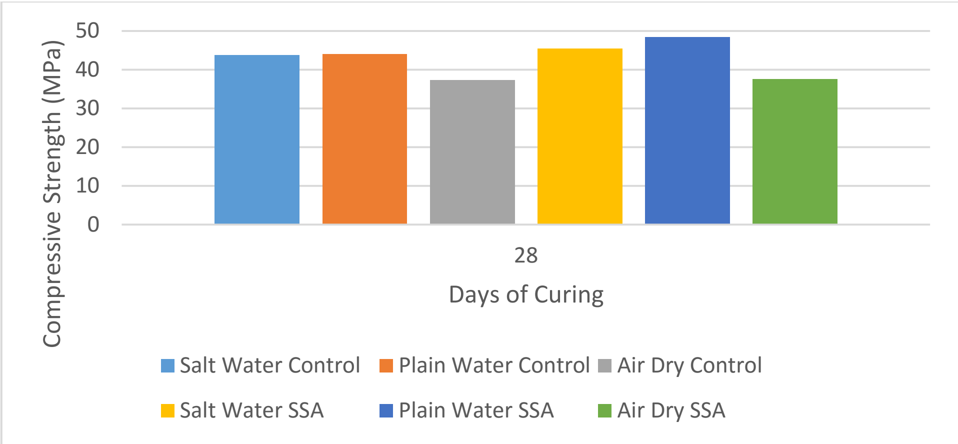

Figure 4.5: Compressive test for cube specimens on 28 days of curing

Summary of results obtained during 28 days of curing are shown in Figure 4.5, where SSA specimens cured in plain water remains the one with the highest compressive strength, 48.39 MPa. From Figure 4.5, it can be observed that all of the SSA cube specimens exhibits higher compressive strength on the 28 days of curing compared to control cube specimens. SSA specimens cured in salt water only show 6% strength deterioration, which is quite favorable. Besides that, SSA cube specimens that are air dried showed 23% strength deterioration, which is a lot but it still can be accepted as it still possess compressive strength that is quite high, 37.49 MPa. According to (Mbadike & Elinwa, 2011), the strength development of concrete depends on the percentage of chemical composition present in the concrete and the presence of chlorides and sulphates in salt water reduces the strength of concrete.

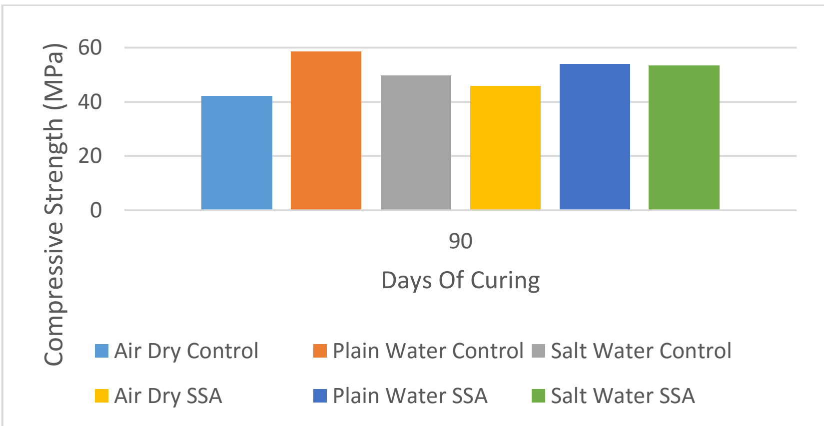

Figure 4.6: Compressive test for cube specimens on 90 days of curing

Figure 4.6 shows the summary of results for 90 days of curing where the final pattern of the results can be seen. It can be observed that only SSA specimens cured in salt water and air dried has higher compressive strength compared to those control specimens treated in the same curing method.

4.3.2 Three Point Flexural Test

Flexural beams with size 100mmx100mmx500mm are cured in salt water, plain water and left air dried. 2 specimens of each classification are tested on 7 and 28 days of curing to obtain an average reading. Table 4.3 shows the summary for results obtained from three point flexural test conducted

.

Table 4.4: Summary of flexural strength for control beam

Days of Curing	Flexural Strength, MPa		
	Air Dry	Plain Water	Salt Water
7	3.58	5.61	4.93
28	5.54	7.78	6.97

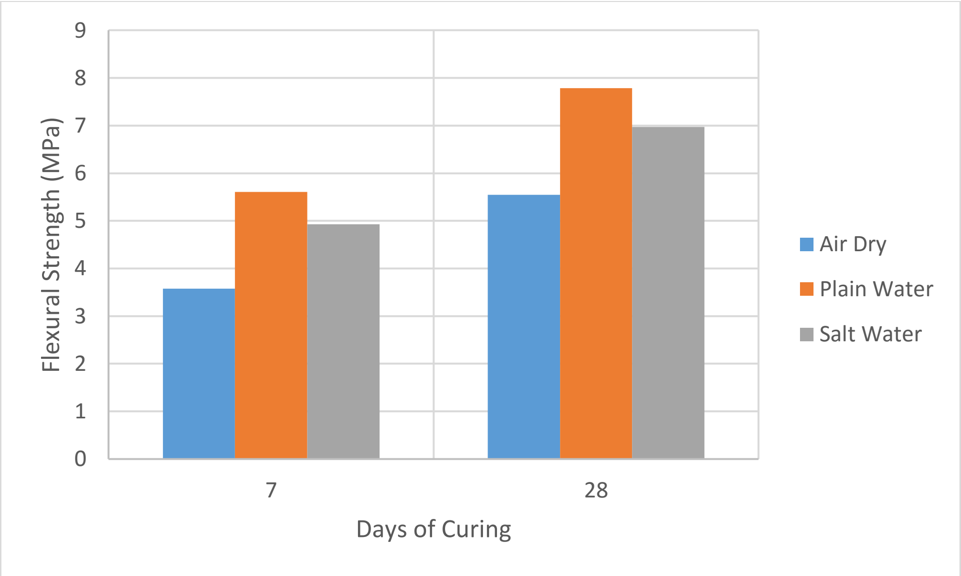

Figure 4.7: Flexural test result for control beam

During 7 and 28 days of curing, control beam cured in plain water exhibits the highest flexural strength among the 3 types of curing method, which is 5.61 MPa and 7.78 MPa respectively. The strength deterioration in specimens cured in salt water is not that significant as it suffers only 10% reduced strength compared to the specimens cured in plain water whereas control beams that are left air dried suffers 30% strength deterioration.

Table 4.5: Summary of flexural strength for SSA beam

Days of Curing	Flexural Strength, MPa		
	Air Dry	Plain Water	Salt Water
7	1.84	2.96	2.05
28	5.20	6.87	7.502

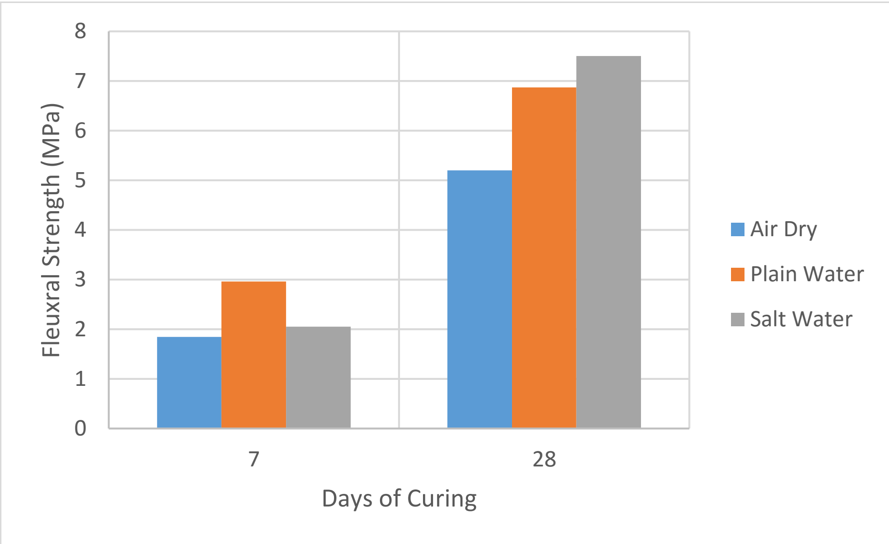

Figure 4.8: Flexural test for SSA beam

Initially, SSA beams cured in plain water possess the highest flexural strength, which is 2.96 MPa. However, SSA beam cured in salt water exhibits the highest flexural strength, which is 7.5 MPa, 1.09 times stronger than SSA beam cured in plain water during 28 days of curing. This is explained previously by (Islam et al., 2012) where salt components in salt water causes a quick dissolution of cement compounds to produce higher flexural strength.

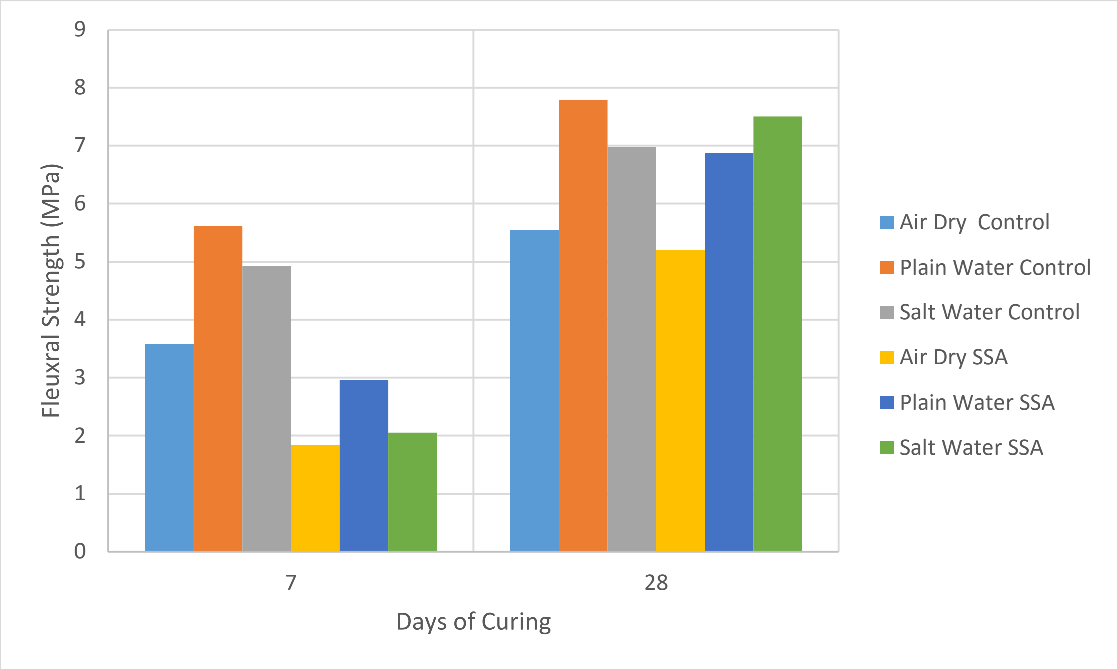

Figure 4.9: Comparison between flexural strength of SSA and control beam

From Figure 4.9, it can be seen that control beam cured in plain water exhibits the highest flexural strength on 7 and 28 days of curing. It can be observed that during the 7 days of curing, all of the SSA beams has considerably low flexural strength compared to the control specimens. However, the flexural strength of SSA beams manage to catch up with control beams on 28 days of curing where SSA beams cured in salt water shows a substantial increase in flexural strength, higher than control beams cured in salt water and only 4% strength deterioration as compared to control beam cured in plain water. According to (Wegian, 2010), concrete mixed and cured in seawater have higher compressive strength and bond strengths than concrete mixed and cured in fresh water in the early ages; 7 days of curing but the strength after 28 and 90 days for concrete mixes mixed and cured in fresh water increase in gradual manner.

4.3.3 UPV Test

UPV test are conducted on SSA and control cubes of each type of curing where 3 cubes are tested for each category to obtain an average value. For each concrete cube, 12 readings are taken where 3 readings are taken from 1 surface of the cube. Specimens are tested on 3, 7, 28 and 90 days of curing.

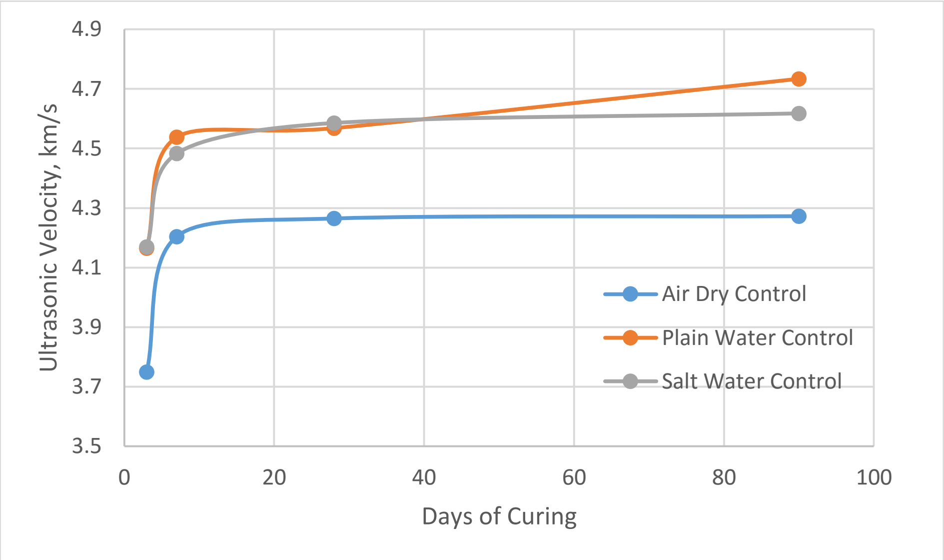

Figure 4.10: Ultrasonic velocity against days of curing

Figure 4.10 shows the results of UPV test for control cubes on 3, 7, 28 and 90 days of curing. Specimens cured in plain water shows the highest pulse velocity, which is 4.73 km/s, followed by salt water and air dried which are 4.61 km/s and 4.27 km/s respectively. Specimens cured in salt water and plain water are graded as excellent concrete quality as they possess pulse velocity above 4.5 km/s whereas specimens air dried falls in the category of good concrete quality with the pulse velocity of 4.27km/s. it can be observed that during 28 days of curing, specimens cured in salt water possess slightly higher pulse velocity than those cured in plain water but ultimately exhibits pulse velocity lower than those cured in plain water by 3%. According to Shoaei et al. (2014), a decrease in pulse velocity is observed for concrete exposed to sodium chloride and magnesium chloride.

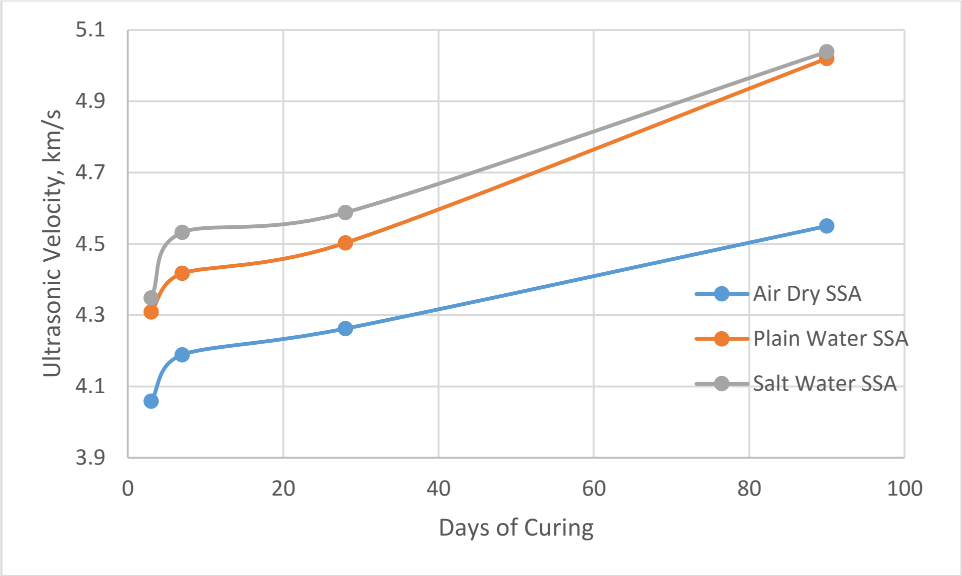

Figure 4.11: Ultrasonic Velocity against days of curing

Figure 4.11 shows the graph of pulse velocity against days of curing for SSA. SSA cubes cured in salt water exhibits the highest pulse velocity throughout the 90 days of curing which is 5.04km/s, followed specimens cured in plain water and air dried which are 5.02km/s and 4.55km/s respectively. By 28 days of curing, SSA cubes cured in salt water and plain water has already reached the category of excellent concrete quality whereas air dried SSA cubes are graded as excellent concrete by 90 days of curing. According to (Shoaei et al., 2014) $MgCl_2$ components in salt water showed positive effects in terms of compressive strength and ultrasonic velocity as $MgCl_2$ accelerates increasing of concrete strength by accelerating setting time of concrete if the amount present is a little. However, excess amount of $MgCl_2$ will be harmful to a certain degree for cement due to $CaCl_2$ condensation.

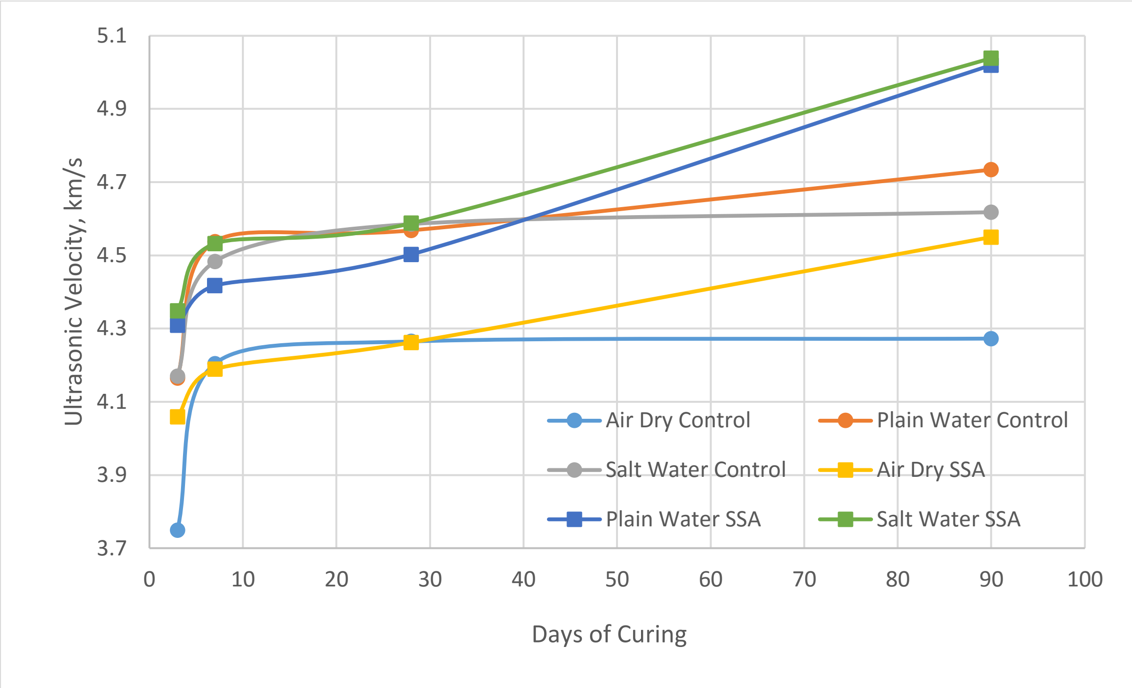

Figure 4.12: Comparison between ultrasonic velocity of SSA and control specimens

Figure 4.12 shows the comparison between SSA and control cubes. During 3 days of curing, SSA cubes cured in salt water exhibits the highest pulse velocity, followed by SSA cubes cured in plain water, control cubes cured in plain water and salt water, air dried SSA cubes and lastly air dried control cubes which have the lowest pulse velocity, 3.75 km/s. There is a significant rise in pulse velocity observed in salt water control cube and plain water control cube, rivaling SSA cubes cured in salt water. As for SSA cubes cured in plain water, the pulse velocity increases gradually in a slow pace. Air dried cubes remains the lowest throughout the 28 days of curing for both SSA and control cubes. On the 28 days of curing, specimens cured in salt water possess the highest pulse velocity, which is 4.59 km/s followed by 4.53 km/s for control cubes and SSA cubes respectively. As for the final results, which is during 90 days of curing, it can be observed that SSA specimens cured in plain water has higher pulse velocity compared to control specimens and the same thing occurs for specimens cured in salt water and air dried. SSA cubes cured in salt water has the highest ultrasonic pulse velocity, followed by SSA cubes cured in plain water, control cubes cured in plain water, control cubes cured in salt water, air dried SSA cubes and finally air dried control cubes. The rise in pulse velocity in all SSA specimens might be due to the composition of sewage sludge present in the concrete. Also, according to (Shoaei et al., 2014), concrete samples exposed to sodium chloride and magnesium chloride shows an increase in pulse velocity as these minerals covers the spaces of concrete, providing less voids in the specimen and higher ultrasonic pulse value.

CHAPTER 5

CONCLUSION AND RECCOMENDATIONS

5.1 INTRODUCTION

The aim of this research is to identify the effect of different types of curing on SSA concrete. Types of curing method practiced are plain water immersion, salt water immersion and air dry curing. Partial replacement of cement by SSA of 0% and 10% was practiced. The specimens are cured for 3, 7, 28 and 90 days before compression test, flexural test and UPV test are conducted on them.

5.2 CONCLUSION

Based on results obtained and discussed in Chapter 4, a few conclusions are drawn:

I. Control cube cured in plain water exhibits the highest compressive strength on 90 days of curing which is 58.51 MPa.

II. Control cube cured in salt water shows an increase in compressive strength in the early stages, where the ultimate strength decreases and suffers a 15% strength deterioration

III. Both air dried SSA and control cubes shows a substantial decrease in compressive strength but still practicable in construction industry as it achieves compressive strength above 25 MPa.

IV. SSA specimens cured in salt water and air dried exhibits compressive strength higher than the control specimens for 90 days of curing which shows that replacement of 10% cement by SSA is viable and can be practiced.

V. Replacing cement by SSA causes deterioration in flexural strength for specimens cured in plain water; however it is a boost for the flexural strength of SSA beams cured in salt water.

VI. Air drying concrete specimens is not an optimum choice as more voids are present, resulting in a lower ultrasonic pulse value.

VII. Curing SSA cubes in salt water proves to be more effective in increasing the ultrasonic velocity as the salt minerals covers the spaces of concrete, providing less voids in the specimen and higher ultrasonic pulse value

5.3 RECOMMENDATIONS

This research is focused on effect of different curing methods on the compressive and flexural strength of concrete and other properties such as voids ratio in concrete. Research on other performances such as water absorption level, heat absorption level and chemical composition are required to fully understand the effect in order for it to be applied effectively in the construction industry.

REFERENCES

Abdullahi, M. (2012). Effect of aggregate type on Compressive strength of concrete. *International Journal of Civil and Structural Engineering*, *2*(3), 791–800.

Amin, N.-, & Ali, K. (2010). Chemical Analysis and Comparison of Ordinary Portland Cement of Khyber Pakhtoon Khwa Pakistan. *Chemical Engineering Research Bulletin*, *14*(1), 45–49. http://doi.org/10.3329/cerb.v14i1.4320

Azman, E. T. M., Shaari, J., & How, V. K. (2013). Wastewater Production , Treatment , and Use in Malaysia, 2009–2014.

Barbosa, M. C., & Filho, R. D. T. (2004). Potentiality of Sewage Sludge Ash As Mineral Additive in Cement Mortar and High Performance. *International RILEM Conference on the Use of Recycle Materials in Buildings and Structures*, (2), 797–806.

Budhiarta, I., Siwar, C., & Basri, H. (2012). Advanced Science Information Technology Current Status of Municipal Solid Waste Generation in Malaysia. *International Journal on Advance Science Engineering Information Technology*, *2*(2), 16–21.

Carlos, A., Masumi, I., Hiroaki, M., Maki, M., & Takahisa, O. (2010). The effects of limestone aggregate on concrete properties. *Construction and Building Materials*, *24*(12), 2363–2368.

Chen, J. S., Chang, M. K., & Lin, K. Y. (2005). Influence of coarse aggregate shape on the strength of asphalt concrete mixtures. *Journal of the Eastern Asia Society for Transportation Studies*, *6*(4), 1062–1075.

Chindaprasirt, P., Homwuttiwong, S., & Jaturapitakkul, C. (2007). Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. *Construction and Building Materials*, *21*(7), 1492–1499.

Deepak, T. J., Elsayed, A., Hassan, N., N., C., Yun Tong, S., & B.M., M. (2014). Investigation on Properties of Concrete with Palm Oil Fuel Ash as Cement Replacement. *International Journal of Scientific and Research Publications*, *3*(1), 138–142.

Erdoğdu, K., & Türker, P. (1998). Effects of fly ash particle size on strength of portland cement fly ash mortars. *Cement and Concrete Research*, *28*(9), 1217–1222.

Ganesan, K., Rajagopal, K., & Thangavel, K. (2008). Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. *Construction and Building Materials, 22*(8), 1675–1683.

Gibbs, M. J., Soyka, P., & Conneely, D. (2000). CO2 Emissions from Cement Production. *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, 175–182.

Gutteridge, W. a., & Dalziel, J. a. (1990). Filler cement: The effect of the secondary component on the hydration of Portland cement. *Cement and Concrete Research*, *20*(6), 853–861.

Habeeb, G. A., & Mahmud, H. Bin. (2010). Study on properties of rice husk ash and its use as cement replacement material. *Materials Research*, *13*(2), 185–190.

Hughes, M. L., Tedesco, J. W., & Ross, C. A. (1993). Numerical Analysis of high strain rate splitting-tensile tests. *Computers & Structures*, *47*(4), 653–671.

Indian Standard. (1999). IS 5816:1999 Splitting Tensile Strength of Concrete.

Islam, M., Islam, S., & Islam, M. (2012). Suitability of sea water on curing and compressive strength of structural concrete. *Journal of Civil Engineering*, *40*(1), 37–45.

Ismail, S. (2013). The challenge of future landfill: A case study of Malaysia. *Journal of Toxicology and Environmental Health Sciences*, *5*(6), 86–96.

James, O., Ndoke, P., & Kolo, S. (2007). Effect Of Different Curing Methods On The Compressive Strength Of Concrete. *Pan*, (JANUARY 2007).

James, O., Ndoke, P., & Kolo, S. (2007b). Effect Of Different Curing Methods On The Compressive Strength Of Concrete. *Pan*.

Jamshidi, a., Jamshidi, M., Mehrdadi, N., Shasavandi, a., & Pacheco-Torgal, F. (2012). Mechanical Performance of Concrete with Partial Replacement of Sand by Sewage Sludge Ash from Incineration. *Materials Science Forum*, *730-732*, 462–467.

Johari, A., Alkali, H., Hashim, H., Ahmed, S. I., & Mat, R. (2014). Municipal Solid Waste Management and Potential Revenue from Recycling in Malaysia. *Modern Applied Science*, *8*(4), 37–49.

Jomaa, M. M. (2012). Using of Local Limestone as Aggregate in Concrete Mixture, *19*(1).

Journal, I., Civil, O. F., & Engineering, S. (2012). Mechanical properties of no-fines bloated slate aggregate concrete for construction application , experimental study, *3*(2), 302–312.

Kala, T. F. (2013). Effect of Granite Powder on Strength Properties of Concrete, *2*(12), 36–50.

Kewalramani, M. A., & Gupta, R. (2006). Concrete compressive strength prediction using ultrasonic pulse velocity through artificial neural networks. *Automation in Construction*, *15*(3), 374–379.

Khatri, R. P., Sirivivatnanon, V., & Gross, W. (1995). Effect of different supplementary cementitious materials on mechanical properties of high performance concrete. *Cement and Concrete Research*, *25*(1), 209–220.

Komloš, K., Popovics, S., Nürnbergerová, T., Babál, B., & Popovics, J. S. (1996). Ultrasonic pulse velocity test of concrete properties as specified in various standards. *Cement and Concrete Composites*, *18*(5), 357–364.

Kosior-kazberuk, M. (2011). Application of SSA as Partial Replacement of Aggregate in Concrete, *20*(2), 365–370.

Kozul, R., & Darwin, D. (1997). Effects of Aggregate Type, Size and Content on Concrete Strength and Fracture Energy, (43), 85.

Kroehong, W., Sinsiri, T., & Jaturapitakkul, C. (2011). Effect of palm oil fuel ash fineness on packing effect and pozzolanic reaction of blended cement paste. *Procedia Engineering*, *14*, 361–369.

Kronlöf, a. (1994). Effect of very fine aggregate on concrete strength. *Materials and Structures*, *27*, 15–25.

Kula, I., Olgun, a., Sevinc, V., & Erdogan, Y. (2002). An investigation on the use of tincal ore waste, fly ash, and coal bottom ash as Portland cement replacement materials. *Cement and Concrete Research*, *32*(2), 227–232.

Lanka, S. R. I. (2012). Influence of Fine Aggregate Types on the Performance Self Flowing Concrete, (2002), 251–258.

Liew, A. G., Idris, A., Samad, A. A., Wong, C. H. K., Jaafar, M. S., & Baki, A. M. (2004). Reusability of sewage sludge in clay bricks, 41–47.

Lin, Y., Zhou, S., Li, F., & Lin, Y. (2012). Utilization of municipal sewage sludge as additives for the production of eco-cement. *Journal of Hazardous Materials, 213-214*, 457–465.

Lo-shu, K., & Man-qing, S. (1980). several physico- mechanical properties of lightweight aggregate concrete, (December), 185–191.

Masirin, M. I. H. M., Ridzuan, M. B., Mustapha, S., & Don, R. A. @ M. (2008). An overview of landfill management and technologies : a malaysian case study at ampar tenang 1, 157–165.

Maximum, T., & Gravity, S. (2013). WSDOT FOP for AASHTO T 209 1, *209*(January), 1–10.

Mbadike, E. M., & Elinwa, A. U. (2011). EFFECT OF SALT WATER IN THE PRODUCTION, *30*(2).

Monteiro, P. (1907). Aggregates for Concrete. *Journal of the Franklin Institute*, *162*(69792).

Muthusamy, K., & Azzimah, Z. N. (2014). Exploratory Study of Palm Oil Fuel Ash as Partial Cement Replacement in Oil Palm Shell Lightweight Aggregate Concrete, *8*(2), 150–152.

Ni, H.-G., & Wang, J.-Z. (2000). Prediction of compressive strength of concrete by neural networks. *Cement and Concrete Research*, *30*(8), 1245–1250.

Osuji, S. O., & Inerhunwa, I. (2015). Determination of Optimum Characteristics of Binary Aggregate Mixtures, *7*(6), 68–76.

Poon, C. S., Shui, Z. H., & Lam, L. (2004). Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. *Construction and Building Materials*, *18*(6), 461–468.

Poon, C. S., Shui, Z. H., Lam, L., Fok, H., & Kou, S. C. (2004). Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete. *Cement and Concrete Research*, *34*(1), 31–36.

Portland Cement Association. (2002). Types and Causes of Concrete Deterioration. *PCA R&D Special N. 2617*, 1–16.

Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2004a). Utilization of Palm Oil Fuel Ash in High-Strength Concrete. *Journal of Materials in Civil Engineering*, *16*(December), 623–628.

Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2004b). Utilization of Palm Oil Fuel Ash in High-Strength Concrete. *Journal of Materials in Civil Engineering*, *16*(December), 623–628.

Shoaei, M., Gül, R., & Kotan, T. (2014). The Effect of MgCl 2 and NaCl Salts in Concrete, 147–151.

Smol, M., Kulczycka, J., Henclik, A., & Gorazda, K. (2015). The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy. *Journal of Cleaner Production*, *95*, 45–54.

Solanki, J., & Pitroda, J. (2013). Flexural Strength of Beams by Partial Replacement of Cement with Fly Ash and Hypo Sludge in Concrete. *International Journal of Engineering Science and Innovative Technology*, *2*(1), 173–179.

Sooraj VM. (2013). Effect of Palm Oil Fuel Ash (POFA) on Strength Properties of Concrete. *International Journal of Scientific and Research Publications*, *3*(6), 2250–3153.

Strength, C. (2014). Effects of Curing Condition and Curing Period on the Compressive Strength Development of Plain Concrete, *1*(2), 83–99.

Thomas, M. (2007). Optimizing the Use of Fly Ash in Concrete. *Portland Cement Association*, 24.

Udang, S., & Description, A. S. (2013). Study on the Characteristics and Utilization of Sewage Sludge at Indah Water Konsortium (IWK), *7*(8), 294–298.

Valls, S., Yague, A., & Vazquez, E. (2012). Valoration addition dry sludge sewage in concrete. *ISRN Chemical Engineering*.

Wastes, M., & Study, C. (2007). Incinerated sewage sludge ash (ISSA) in autoclaved aerated concrete (AAC), (October), 1–6.

Wegian, F. M. (2010). Effect of seawater for mixing and curing on structural concrete. *The IES Journal Part A: Civil & Structural Engineering*, *3*(4), 235–243.

Yagüe, a., Valls, S., Vázquez, E., & Albareda, F. (2005). Durability of concrete with addition of dry sludge from waste water treatment plants. *Cement and Concrete Research*, *35*(6), 1064–1073

Yılmaz, M., & Tuğrul, A. (2012). The effects of different sandstone aggregates on concrete strength. *Construction and Building Materials*, *35*, 294–303.

Yusuf, R. O., Noor, Z. Z., Moh', N. a., Moh', D. F., Din, D., & Abba, A. H. (2012). Use of sewage sludge ash (SSA) in the production of cement and concrete - a review. *International Journal of Global Environmental Issues*, *12*(2/3/4), 214.

Zarina, Y., Mustafa Al Bakri, a. M., Kamarudin, H., Nizar, I. K., & Rafiza, a. R. (2013). Review on the various ash from palm oil waste as geopolymer material. *Reviews on Advanced Materials Science*, *34*(1), 37–43.

Zhang, M. H., Lastra, R., & Malhotra, V. M. (1996). Rice-husk ash paste and concrete: Some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste. *Cement and Concrete Research*, *26*(6), 963–977.

APPENDIX A

CONCRETE MIX DESIGN

Universiti Malaysia PAHANG

CONC

MAKMAL KONKRIT

TABLE 1 : CONCRETE MIX DESIGN FORM

Document No : CONC/2011/015
Issue No : 1
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Page No : 1 of 1

Stage		Item	Reference or Calculation	Value
1	1.1	Characteristic Strength	Specified	30 N/mm2 at 28 days; Proportion defective 10 %
	1.2	Standard Deviation (σ)	Table 1.1	5 N/mm2 or no data – N/mm2
	1.3	Margin (k x σ)	C1 or Specified	(k = 1.28) 1.28 x 5 = 6.40 N/mm2
	1.4	Target mean strength	C2	30 (Characteristic strength) + 6.40 (Margin) = 36.40 N/mm2
	1.5	Cement type	Specified	OPC / SRPC / RHPC
	1.6	Aggregate type : Coarse	Specified	Crushed / Uncrushed
		Aggregate type : Fine	Specified	Crushed / Uncrushed
	1.7	Free-water/cement ration	Table 1.3 Figure 2	0.61
	1.8	Maximum free-water/cement ratio	Table 1.4	0.50 use the lower value
2	2.1	Slump	Specified	60 - 180 mm
		Vebe Time	Specified	0 - 3 s
	2.2	Maximum aggregate size	Specified	10mm / 20mm / 40mm
	2.3	Free - water content	Table 2.1	205 kg/m3
3	3.1	Cement Content	C3	205 (Free water content) / 0.5 (Free-water/cement ratio) = 410 kg/m3
	3.2	Maximum cement content	Specified	kg/m3
	3.3	Minimum cement content	Specified	Use 3.1 if < 3.2; Use 3.3 if > 3.1
	3.4	Modified free - water / cement ratio		
4	4.1	Relative density of aggregate (SSD)		2.4 known / assumed
	4.2	Concrete density	Figure 3	2410 kg/m3
	4.3	Total Aggregate Content	C4	2410 (Concrete Density) - 410 (Maximum Cement Content) - 205 (Free water Content) = 1795 kg/m3
5	5.1	Grading of fine aggregate (BS 822)	Percentage passing 600µm sieve	15-40 %
	5.2	Proportion of fine aggregate	Figure 4	45-47 %
	5.3	Fine aggregate content	C5	1795 (Total aggregate content) x 0.51 (Proportion of fine aggregate) = 915.45 kg/m3
	5.4	Coarse aggregate content	C5	1795 (Total aggregate content) - 915.45 (Fine aggregate content) = 879.55 kg/m3

Quantities	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg) (10mm / 20mm / 40mm)
per m3 (to nearest 5kg)				
per trial mix of ______ m3				

1 N/mm2 = 1MN/m2 = 1 Mpa
OPC = Ordinary Portland Cement
SRPC = Sulphate-resisting Portland Cement
RHPC = Rapid-hardening Portland Cement
Relative density = specified density = ratio between weight of sampel to weight of water
SSD = based on a saturated surface-dry basis

APPENDIX B

DATA FOR COMPRESSIVE TEST

CONTROL CUBE

Days of Curing	Air Dry Curing (MPa)			Plain Water Curing (MPa)			Salt Water Curing (MPa)		
3	26.43	25.66	26.55	31.03	31.56	31.57	32.22	29.79	27.59
7	31.78	30.41	31.46	34.20	32.01	34.43	36.81	35.55	34.99
28	36.95	37.30	37.659	43.95	42.92	45.04	44.49	42.08	44.45
90	42.85	41.87	41.897	55.04	61.24	59.24	47.85	50.62	50.98

SSA CUBE

Days of Curing	Air Dry Curing (MPa)			Plain Water Curing (MPa)			Salt Water Curing (MPa)		
3	18.06	18.12	21.06	22.14	26.59	29.40	30.64	30.52	29.76
7	31.19	29.38	31.55	40.10	34.46	36.80	40.44	33.22	33.20
28	34.51	39.67	38.28	52.57	45.14	47.45	40.94	48.54	46.84
90	42.69	45.75	48.81	55.17	54.02	52.50	54.74	53.86	51.63

APPENDIX C

DATA FOR FLEXURAL TEST

Control Beam

Days of Curing	Air Dry Curing (MPa)		Plain Water Curing (MPa)		Salt Water Curing (MPa)	
7	3.50	3.66	5.65	5.57	4.45	5.40
28	5.57	5.52	8.07	7.50	7.17	6.77

SSA Beam

Days of Curing	Air Dry Curing (MPa)		Plain Water Curing (MPa)		Salt Water Curing (MPa)	
7	1.80	1.88	3.27	2.65	2.23	1.88
28	4.94	5.46	6.91	6.83	6.28	8.73

APPENDIX D

DATA FOR UPV TEST CONTROL CUBE

Day 3

Air Dry Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	3731	3703	3891
	2nd	3484	3690	3690
	3rd	3623	3937	3745
2	1st	3610	3649	3773
	2nd	3759	3759	3703
	3rd	3952	3717	3649
3	1st	3546	3731	3731
	2nd	3731	3703	3921
	3rd	3759	3861	3921
4	1st	3690	3597	3816
	2nd	3731	3703	3921
	3rd	3759	3861	3921

Day 3

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4098	4219	4273
	2nd	4088	4273	4078
	3rd	4132	4201	4032
2	1st	4166	4048	4184
	2nd	4088	4000	4291
	3rd	4201	4098	4237
3	1st	4098	4255	4273
	2nd	4098	4149	4081
	3rd	4081	4201	4255
4	1st	4219	4219	4132
	2nd	4184	4273	4291
	3rd	4048	4098	4273

APPENDIX D

DATA FOR UPV TEST CONTROL CUBE

Day 3

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4048	4291	4098
	2nd	3937	4184	4329
	3rd	4115	4048	4385
2	1st	4048	4219	4356
	2nd	4201	4065	4166
	3rd	4237	4115	4115
3	1st	4132	4081	4291
	2nd	4115	4115	4184
	3rd	4081	3937	4464
4	1st	4219	4149	4310
	2nd	4291	4149	4310
	3rd	4098	4032	4201

Day 7

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	3984	4201	4132
	2nd	4016	4219	4219
	3rd	4081	4310	4149
2	1st	4237	4201	4132
	2nd	4219	4184	4132
	3rd	4201	4219	4184
3	1st	4166	4291	4255
	2nd	4219	4310	4237
	3rd	4166	4237	4464
4	1st	4329	4219	4310
	2nd	4098	4132	4184
	3rd	4237	4219	4255

APPENDIX D

DATA FOR UPV TEST CONTROL CUBE

Day 7

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4405	4807	4545
	2nd	4524	4484	4524
	3rd	4566	4608	4545
2	1st	4739	4464	4385
	2nd	4566	4504	4608
	3rd	4807	4504	4464
3	1st	4484	4464	4347
	2nd	4545	4608	4444
	3rd	4385	4464	4587
4	1st	4716	4651	4504
	2nd	4484	4504	4608
	3rd	4484	4524	4504

Day 7

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4587	4524	4444
	2nd	4651	4504	4273
	3rd	4926	4504	4484
2	1st	4504	4566	4366
	2nd	4444	4587	4524
	3rd	4366	4484	4291
3	1st	4444	4716	4608
	2nd	4524	4524	4366
	3rd	4504	4405	4629
4	1st	4484	4405	4566
	2nd	4366	4366	4310
	3rd	4424	4347	4366

APPENDIX D

DATA FOR UPV TEST CONTROL CUBE

Day 28

Air Dry Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4273	4219	4444
	2nd	4405	4184	4237
	3rd	4219	4237	4310
2	1st	4237	4329	4237
	2nd	4329	4115	4347
	3rd	4255	4149	4310
3	1st	4444	4219	4184
	2nd	4255	4219	4132
	3rd	4444	4347	4255
4	1st	4310	4166	4132
	2nd	4219	4237	4329
	3rd	4184	4219	4405

Day 28

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4464	4545	4629
	2nd	4444	4424	4484
	3rd	4524	4524	4524
2	1st	4761	4672	4504
	2nd	4672	4504	4545
	3rd	4830	4629	4366
3	1st	4651	4629	4524
	2nd	4694	4608	4672
	3rd	4716	4739	4405
4	1st	4694	4524	4504
	2nd	4587	4587	4424
	3rd	4545	4424	4484

APPENDIX D

DATA FOR UPV TEST CONTROL CUBE

Day 28

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4504	4608	4484
	2nd	4587	4504	4566
	3rd	4651	4608	4524
2	1st	4651	4504	4566
	2nd	4739	4651	4608
	3rd	4608	4484	4651
3	1st	4854	4608	4524
	2nd	4587	4651	4405
	3rd	4672	4629	4608
4	1st	4651	4484	4464
	2nd	4651	4830	4366
	3rd	4524	4464	4608

Day 90

Air Dry Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4237	4405	4184
	2nd	4291	4385	4184
	3rd	4237	4291	4329
2	1st	4464	4405	4255
	2nd	4329	4405	4201
	3rd	4255	4291	4201
3	1st	4149	4201	4310
	2nd	4201	4255	4132
	3rd	4255	4385	4464
4	1st	4201	4385	4329
	2nd	4149	4366	4273
	3rd	4291	4464	4329

APPENDIX D

DATA FOR UPV TEST CONTROL CUBE

Day 90

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4672	4739	4830
	2nd	4878	4672	4830
	3rd	4716	4739	4807
2	1st	4716	4716	4694
	2nd	4672	4716	4716
	3rd	4716	4566	4807
3	1st	4672	4830	4694
	2nd	4716	4629	4854
	3rd	4807	4651	4830
4	1st	4739	4694	4716
	2nd	4716	4716	4739
	3rd	4716	4739	4761

Day 90

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4545	4629	4761
	2nd	4524	4694	4651
	3rd	4587	4444	4566
2	1st	4587	4464	4694
	2nd	4716	4504	4545
	3rd	4566	4694	4587
3	1st	4807	4739	4545
	2nd	4566	4464	4464
	3rd	4587	4761	4807
4	1st	4672	4629	4672
	2nd	4587	4629	4672
	3rd	4629	4444	4807

APPENDIX E

DATA FOR UPV TEST SSA CUBE

Day 3

Air Dry Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4132	4065	3861
	2nd	4098	3968	4065
	3rd	4184	3937	3891
2	1st	4065	3968	4219
	2nd	4329	3891	4016
	3rd	4048	4081	4065
3	1st	4149	3968	4000
	2nd	4115	4166	3921
	3rd	4048	4065	4000
4	1st	4048	4065	4000
	2nd	4347	3984	4237
	3rd	4000	4000	4115

Day 3

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4424	4132	4629
	2nd	4366	4184	4385
	3rd	4255	4219	4273
2	1st	4255	4149	4424
	2nd	4255	4149	4424
	3rd	4219	4255	4255
3	1st	4255	4201	4310
	2nd	4504	4149	4310
	3rd	4347	4329	4329
4	1st	4424	4237	4347
	2nd	4273	4310	4329
	3rd	4464	4424	4329

APPENDIX E

DATA FOR UPV TEST SSA CUBE

Day 3

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4739	4329	4385
	2nd	4366	4310	4255
	3rd	4405	4310	4237
2	1st	4347	4219	4347
	2nd	4219	4184	4329
	3rd	4329	4255	4504
3	1st	4329	4255	4385
	2nd	4385	4237	4201
	3rd	4329	4424	4329
4	1st	4347	4291	4484
	2nd	4405	4504	4237
	3rd	4524	4444	4347

Day 7

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4149	4184	4115
	2nd	4166	4149	4048
	3rd	4201	4237	4166
2	1st	4219	4166	4219
	2nd	4132	4132	4081
	3rd	4524	4081	4166
3	1st	4276	4115	4166
	2nd	4219	4098	4149
	3rd	4237	4132	4424
4	1st	4132	4166	4219
	2nd	4201	4081	4329
	3rd	4405	4166	4149

APPENDIX E

DATA FOR UPV TEST SSA CUBE

Day 7

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4424	4273	4524
	2nd	4310	4329	4405
	3rd	4484	4347	4545
2	1st	4347	4464	4504
	2nd	4484	4405	4405
	3rd	4405	4524	4694
3	1st	4329	4366	4424
	2nd	4444	4347	4504
	3rd	4405	4405	4329
4	1st	4405	4347	4366
	2nd	4424	4273	4347
	3rd	4464	4329	4629

Day 7

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4608	4566	4366
	2nd	4716	4545	4405
	3rd	4716	4629	4716
2	1st	4608	4273	4608
	2nd	4608	4672	4405
	3rd	4366	4629	4608
3	1st	4545	4651	4587
	2nd	4464	4608	4444
	3rd	4291	4587	4608
4	1st	4464	4484	4484
	2nd	4545	4524	4464
	3rd	4385	4716	4255

APPENDIX E

DATA FOR UPV TEST SSA CUBE

Day 28

Air Dry Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4310	4201	4237
	2nd	4291	4385	4219
	3rd	4310	4132	4385
2	1st	4166	4201	4201
	2nd	4385	4385	4201
	3rd	4149	4310	4237
3	1st	4291	4184	4405
	2nd	4219	4310	4219
	3rd	4587	4115	4291
4	1st	4385	4273	4219
	2nd	4055	4310	4132
	3rd	4385	4132	4219

Day 28

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4424	4504	4504
	2nd	4329	4504	4484
	3rd	4608	4629	4385
2	1st	4484	4672	4506
	2nd	4716	4694	4524
	3rd	4504	4504	4424
3	1st	4424	4385	4504
	2nd	4587	4385	4484
	3rd	4329	4566	4405
4	1st	4484	4545	4694
	2nd	4405	4484	4484
	3rd	4366	4694	4464

APPENDIX E

DATA FOR UPV TEST SSA CUBE

Day 28

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4694	4672	4504
	2nd	4739	4608	4385
	3rd	4694	4651	4405
2	1st	4608	4484	4504
	2nd	4504	4504	4385
	3rd	4484	4405	4608
3	1st	4694	4504	4608
	2nd	4694	4608	4694
	3rd	4694	4608	4694
4	1st	4830	4694	4504
	2nd	4694	4484	4504
	3rd	4651	4672	4484

Day 90

Air Dry Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4524	4587	4524
	2nd	4504	4524	4524
	3rd	4566	4587	4424
2	1st	4424	4566	4524
	2nd	4784	4424	4524
	3rd	4587	4784	4424
3	1st	4424	4784	4566
	2nd	4761	4424	4424
	3rd	4587	4566	4784
4	1st	4464	4587	4784
	2nd	4587	4524	4424
	3rd	4385	4587	4424

APPENDIX E

DATA FOR UPV TEST SSA CUBE

Day 90

Plain Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	5181	4807	4950
	2nd	5263	5154	5263
	3rd	5154	5050	4830
2	1st	4830	5263	4784
	2nd	5128	5128	5128
	3rd	4926	4950	4784
3	1st	4926	5025	5000
	2nd	4875	5154	5128
	3rd	4875	5000	4901
4	1st	4926	4926	4901
	2nd	5050	5025	5263
	3rd	5128	5125	4901

Day 90

Salt Water Curing	Sample	1	2	3
Location	Reading	m/s	m/s	m/s
1	1st	4807	4901	5000
	2nd	5050	5181	5263
	3rd	4926	5025	5000
2	1st	4901	4926	5128
	2nd	5000	5263	5524
	3rd	4926	4901	5000
3	1st	4901	4950	5025
	2nd	4901	5263	5025
	3rd	5263	5025	5025
4	1st	4975	4878	4975
	2nd	5263	5076	5235
	3rd	4854	5000	5025

APPENDIX F

PHOTO OF EXPERIMENTAL WORKS

APPENDIX F
PHOTO OF EXPERIMENTAL WORKS