DURABILITY STUDIES OF SPENT MUSHROOM COMPOST ASH (SMCA) AS PARTIAL CEMENT REPLACEMENT IN CONCRETE

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ABSTRAK

Konkrit telah menjadi bahan binaan yang kompetitif kerana fleksibiliti besar dan ekonomi dalam memenuhi pelbagai permintaan. Di sebaliknya ialah keperluan untuk menampung kos yang semakin meningkat dan kekurangan simen. Sementara itu, cendawan telah dianggap sebagai salah satu komoditi yang bernilai tinggi di bawah Dasar Agro Makanan Negara Malaysia (2011-2020). Bahan buangan industri cendawan dijangka meningkat dengan pertumbuhan industri tersebut. Dari keseluruhan kompos cendawan habis guna yang dihasilkan di Malaysia, 69 % dibuang di tapak pelupusan. Di samping itu, Malaysia bergantung sebahagian besar kepada pembuangan terbuka dan tapak pelupusan, di mana kebanyakan tapak ini telah melebihi kapasiti operasi, seterusnya mengundang ancaman alam sekitar dan sosial yang serius. Oleh itu, adalah penting bagi industri untuk mencari alternatif pengurusan sisa kompos cendawan habis guna. Objektif penyelidikan ini adalah untuk mengkaji prestasi ketahanan konkrit dengan aplikasi abu kompos cendawan habis guna (SMCA) sebagai pengganti simen separa. Tahap penggantian 10 % simen oleh SMCA dipilih untuk campuran konkrit. Kekuatan minima 30 MPa dengan nisbah air-simen 0.45 telah digunakan. Specimen-specimen disediakan dan sembuh selama 28 hari sebelum diuji untuk penyerapan air, sorptivity, rintangan asid, rintangan sulfat dan rintangan klorida. Semua keputusan dibandingkan dengan konkrit normal. Ia menunjukkan prestasi konkrit SMCA lebih baik daripada konkrit biasa dalam penyerapan air dengan 0.003 % berbanding 0.012 % dan 0.005 mm/ √ min berbanding 0.138 mm/ √ min dalam sorptivity. Peratus perbezaan berat konkrit SMCA adalah juga lebih rendah daripada konkrit biasa dalam rintangan asid dan rintangan sulfat dengan masing-masing 0.06 % berbanding 0.13 % dan 0.04 % berbanding 0.19 %. Walau bagaimanapun, konkrit biasa adalah lebih tahan daripada konkrit SMCA dalam pendedahan klorida selama 28 hari dengan peratusan peningkatan berat 0.067 % berbanding 0.072 %. Keputusan menunjukkan reaksi pozzolanic dalam konkrit SMCA.

ABSTRACT

Concrete had become competitive building material due to its huge versatility and comparative economy in meeting wide range of demands. Added to this is the need to withstand the escalating cost and scarcity of cement. Meanwhile, mushrooms have been regarded as one of the high-value commodities under Malaysia's National Agro-Food Policy (2011-2020). With the growth of mushroom industry, mushroom industry waste are expected to increase. From the entire spent mushroom compost generated in Malaysia, 69 % is thrown in landfill sites. In addition, Malaysia largely depends on open dumping and landfills, where most of these sites have exceeded its operating capacity, leading to serious environmental and social threats. It is therefore vital for the industry to discover alternative waste management of the spent mushroom compost. The aim of this work is to study the durability performance concrete on the application of spent mushroom compost ash (SMCA) as partial cement replacement. Replacement level of 10 % Ordinary Portland Cement (OPC) by SMCA was chosen for the concrete mixes. Design strength of 30 MPa with water-cement ratio of 0.45 was used. The specimens are cast and cured for 28 days before being tested for water absorption, sorptivity, acid resistance, sulphate resistance and chloride resistance. All results are compared with normal concrete. It is demonstrated that SMCA concrete performed better than normal concrete in water absorption with 0.003 % vs. 0.012 % and 0.005 mm/ $\sqrt{}$ min vs. 0.138 mm/ $\sqrt{}$ min in sorptivity. The percentage weight changes of SMCA concrete are also lower than normal concrete in acid resistance and sulphate resistance with 0.06 % vs. 0.13 % and 0.04 % vs. 0.19 % respectively. However, normal concrete is more resistant than SMCA concrete in chloride exposure for 28 days with percentage weight gain of 0.067 % vs. 0.072 %. The results indicate pozzolanic reaction in the SMCA concrete.

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LIST OF SYMBOLS

g	gram
m	Meter
˚C	Degree Celcius
ha	hectare
mm	Millimetre
%	percent
kg	kilogram
µm	micometer
N/mm^2	Newton per millimeter square
N/(mm s)	Newton per millimetre second
MPa	Megapascal
N	Newton
mm^2	Millimetre square
h	Hour
mm/√min	Millimetre per minute square
g/cm^3	Gram per centimetre square
cm^2	Centimetre square
min	Minute
±	Plus minus
pH	Potential of hydrogen

LIST OF ABBREVIATIONS

Al_2O_3	Aluminium Oxide
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
BRE	Building Research Establishment
$CaCl_2$	Calcium Chloride
$Ca(OH)_2$	Calcium Hydroxide
Ca^{2+}	Calcium Ion
CaO	Calcium Oxide
CEN/TR	European Committee for Standardization Technical Report
CS	Calcium Sulphate
C-S-H	Calcium-Silicate-Hydrate
C_3A	Tricalcium Aluminate
C_2S	Dicalcium Silicate
C_3S	Tricalcium Silicate
DOA	Department of Agriculture
EN	European Standards
$Fe(OH)_2$	Iron (II) Hydroxide
H^+	Hydrogen Ion
HA	Mono-proton Acid
H_2O	Water
H_2S	Hydrogen Sulphide
MSW	Municipal Solid Waste
Na_2SO_4	Sodium Sulphate
OPC	Ordinary Portland Cement
PFA	Pulverized Fuel Ash
SiO_2	Silicon dioxide
$Si(OH)_4$	Silicic Acid
SMC	Spent Mushroom Compost
SMCA	Spent Mushroom Compost Ash
SO_4^{2-}	Sulphate Anion
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia has throughout the years undergo blooming in population, urbanization and industrialization. Consequently, immense quantities of waste has been produced by this rapid development (Badgie et al., 2012). The research for and the supply of an economical management method of these wastes has become a growing concern due to increasing amount of waste generated (Al Ansari, 2012).

Waste is any substance which is disposed after primary use, or it is worthless, defective and of no use. It may not be valueless but once it is thrown away, it is consider a waste. Every year, government has disbursed considerable amount of money on the collection and disposal of waste but its management system is insufficient and costly. According to Hajkowicz et al. (2005), waste management approach commonly entails prevention, reduce, reuse, recycling, energy recovery and disposal. Waste prevention, as the preferred option, is followed by reduce, reuse, recycling, recovery and as a last option, safe disposal.

Bahoria et al. (2013) stated that reuse of bulky waste is believed as the best environmental option for curbing disposal problem. Presently, waste products such as fly ash, blast furnace slag and palm oil fuel ash had been utilized in the construction field. The application of waste products in construction not only cost-effective but also lower the amount of waste.

On the other hand, spent mushroom compost (SMC) is mushroom industrial waste released after the harvest of one full crop of mushroom which further usage bring little or no profit. The mushroom industry has encountered difficulties in retaining and discarding the SMC. The indisputable solution is to research new utilization of SMC (Phan & Sabaratnam, 2012).

1.2 Background of Study

Concrete is the single most widely used material in the world and the key ingredient used in it is cement. Production of cement has a huge impact on environment and therefore many researches had been done to seek materials that may fully or partially replacing cement. There are researches that were done about the potential of SMC from mushroom industry to be used as part of the construction material. In a study carried out by Pang (2007), spent mushroom compost has the capability to be cost-effectively reused into concrete as fine aggregate. The quantity of SMC that can be applied should be modified to meet desired strength of concrete. The concrete consist of SMC is expected to be utilized in the manufacture of concrete curbs, sidewalks, retaining walls, and other non-structural infrastructures. In addition, there was an enhancement in early age strength of sample mixes by adding spent mushroom compost ash (SMC) into Ordinary Portland Cement and pulverised fuel ash paste as has been studied by Russell et al. (2005). From the XRD analysis, SMC ash had activated pulverised fuel ash in which pulverised fuel ash alumina paste reacted with sulphate phases to produce ettringite.

1.3 Problem Statement

Portland cement is produced by manufacturers at around 5 billion tons each year (Mason, 2015). For each ton of cement manufactured, the process will emits almost one ton of carbon dioxide into the atmosphere which accounts for approximately 7 percent of the world’s carbon dioxide emissions. According to Meyer (2009), cement industry not only produces carbon dioxide that causes greenhouse effect but also has other impact on environment. There are huge quantities of natural resources needed to produce cement and the production process is very energy intensive. Furthermore, production of concrete need great amount of water and would causes pollution of air, water and sound.

In Malaysia, the total worth of mushroom yield expand from RM79 million in 2011 to RM110 million in 2014. Increasing number of growers, size of farm and productivity contribute to the massive increased of production value (Department of Agriculture Malaysia, 2015). Around 800 g of SMC will be available for every 200 g of mushroom harvested. An average farm disposes roughly 24 tons of SMC each month.

Ahlawat and Sagar (2007) stated that SMC is ready to further react with new set of microorganisms. The disposed pile of SMC will become anaerobic and released foul-smelling. Moreover, leachate from SMC can also cause problems if not properly handled. As Guo & Chorover (2006) carried out their study on movement and retention of SMC leachate solutes in subsurface soil columns, groundwater may be seriously impacted if weathering of SMC is performed in fields with shallow water table of less than 3 m or in coarse subsoil. If hindered by compact surfaces without a trench or barrier around, SMC leachate may spread via runoff resulting surface water contamination.

1.4 Objectives

The objectives of the study are:

i. To determine the suitability of spent mushroom compost ash as partial cement replacement in concrete.
ii. To study the durability of spent mushroom compost ash in the perspective of water absorption, sorptivity, acid resistance, sulphate resistance and chloride penetration.

1.5 Scope of Work

The scope of work of the research is to achieve the objective presented. A preliminary analysis will be done to choose the optimum replacement percentage of spent mushroom compost ash (SMCA) based on previous similar research results. Only SMC treated using microwave burning is used in the research. The SMC was oven-dried for 24 hours at 105 ˚C prior to microwave burning. Samples will be prepared by mixing cement, coarse aggregate, fine aggregate, SMC and fixed amount of water. The concrete specimens will undergo water curing for 28 days before they were taken for testing.

Slump test is used to determine the workability of the concrete are complying to BS 1881: Part 102. All the size of specimens is 100 mm x 100 mm x 100 mm with 3 cubes used for each of the compressive test, water absorption, sorptivity, acid resistance, sulphate resistance and chloride penetration. Test for acid resistance, sulphate resistance and chloride penetration were done after samples were immersed in 5 % solutions of hydrochloric acid, sodium sulphate and sodium chloride respectively. After 90 days of acid and sulphate immersion, and 28 days of chloride immersion, mass change and compressive strength of the concrete were determined and compared with the controlled samples.

1.6 Research Significance

Growth of construction in Malaysia is strong and shows no sign of setback anytime soon (The Business Year, 2016). Naturally, when the construction industry undergoes solid growth, this will leads to an increase in demand for cement. Success in integrating SMC in construction sector would decrease the environmental impact by reducing use of energy, emissions of carbon dioxide and dust, and the use of natural raw materials.

Commonly, SMC are sent to landfill or openly burnt by mushroom farmers as they could not be used again for next cultivation due to possible contamination (Jamaludin et al., 2012). The possible application of SMC in concrete may reduce the environmental problems that raised from the disposal of mushroom waste. Other than that, reducing cement content by utilizing SMC in building materials can also reduce the construction cost while minimizing mushroom industrial waste.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete has boundless opportunities for inventive utilization, design and construction techniques. Concrete had become competitive building material due to its huge versatility and comparative economy in meeting wide range of demands. With the development of technology and growing field of applications of concrete and mortars, the strength, workability, durability and other natures of the typical concrete need refinements to make it more fit in different situations. Added to this is the need to withstand the escalating cost and scarcity of cement (Sashidhar & Rao, 2010).

Concerning with the issues mentioned above, studies have been done to partially replace cement in the concrete. Most of the materials involved in cement partial replacement consist of agricultural wastes and industrial wastes. Some of the examples of the materials from agricultural wastes are palm oil fuel ash, rice husk ash, sugarcane bagasse ash and coconut shell. Meanwhile, ground granulated blast furnace slag, fly ash and sawdust from industrial wastes are also being applied in concrete production.

In addition, moisture resistance is one of the main worries in building design and construction. Impeding water penetration into structures is important to prevent damage to the materials of the building. Other than that, chemicals invasion can also causing troubles if concrete are not properly designed. Therefore, materials, design and workmanship are all significant to the performance of concrete in preventing water intrusion, moisture damage and chemical invasion.

2.2 Malaysia Mushroom Industry

Mushrooms have been regarded as one of the high-value commodities under Malaysia's National Agro-Food Policy (2011-2020). In the policy, government decided to expand mushroom production areas from 78 hectares in 2010 to 340 hectares in 2020 due to high prospects of this commodity. Another plan that has also been developed in the policy is to increase the total productivity from 190 tonnes/ha in 2010 to 193 tonnes/ha by the year 2020 (Zaffrie et al., 2014). According to the Industrial Crops Statistics Malaysia from Department of Agriculture (DOA, 2015), the production of mushroom in Malaysia had increased about 977 tonnes from the year 2012 to 2015 since the implementation of National Agro-Food Policy (2011-2020). Figure 2.1 presents the Malaysia mushroom production from 2012 to 2015.

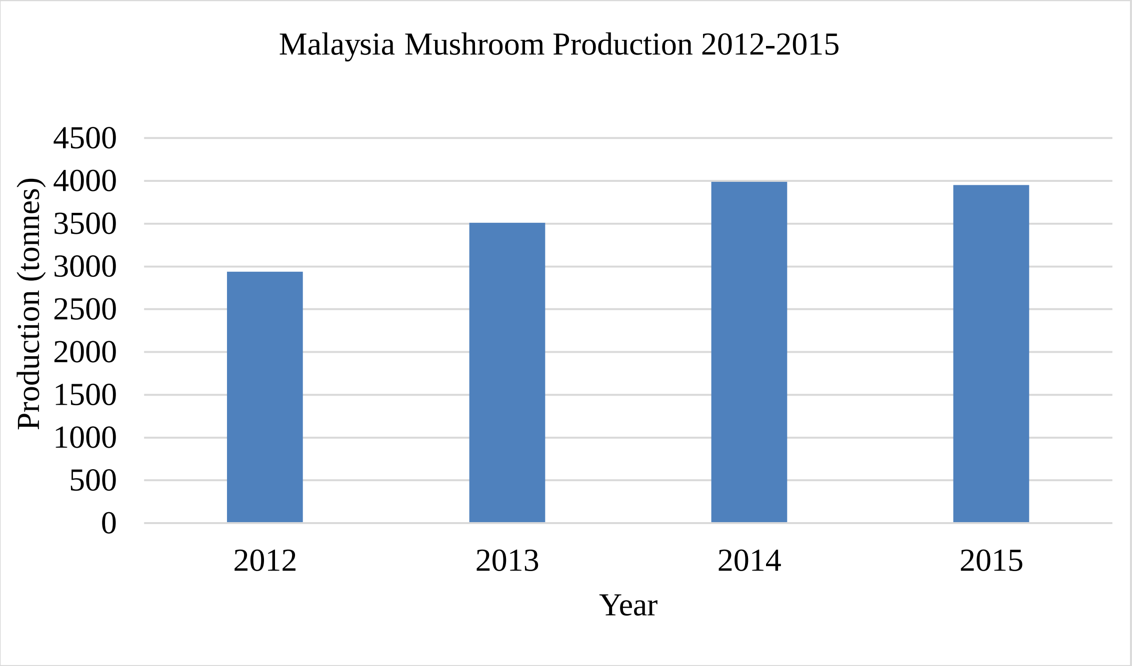

Figure 2.1 Malaysia Mushroom Production 2012-2015
Source: Department of Agriculture, Malaysia (2015)

2.3 Waste from Mushroom Industry

With the growth of mushroom industry, mushroom industry waste are expected to increase. Yielding of 1 kg mushroom will roughly produce 5 kg of spent mushroom compost (SMC) (Sample et al., 2001). Spent mushroom compost (SMC) is the soil-like material left after harvest of mushrooms. Sometimes, this material is also known as spent mushroom substrate. The appearance of fresh SMC is similar to peat, with a light brown colour and a light, fibrous texture. It contain quite high level of nutrients like potassium, nitrogen, calcium, phosphorus and small quantity of silicon and iron. In Malaysia, the mushroom compost was produced from raw materials of rubber saw dust, rice bran and hydrated lime in ratio of 100 kg: 10 kg: 1 kg respectively (Abd Rasib et al., 2015). After a few cycles of mushroom growth, SMC will be burnt openly as it could not be used again for subsequent cultivation to preserve mushroom quality (Jamaludin et al., 2012). Burying, landfilling and composting with animal manure are also other ways to dispose SMC.

In Malaysia, about 8424 metric tons of mushrooms based on 324 g intake of mushroom per person generates an estimated value of 42120 metric tons of spent mushroom composts (Jamaludin et al., 2012). This amount is predicted to grow due to possible shift of consumers to healthier lifestyle and increased demand in organic foods. From the entire SMC generated in Malaysia, 69 % is thrown in landfill sites, 28 % is used in agricultural land and remaining 3 % is incinerated (Singh et al., 2010). It is therefore vital for the industry to discover alternative waste management of the SMC.

In the past few years, the possibility of using SMC in construction was studied. Russell et al. (2005) stated that SMC ash may be used as a chemical activator for pulverised fuel ash (PFA) blended cement systems. The strength development with 20 % SMC shows a clear increase in strength from days 7 to 28 compared to mix with 100 % Ordinary Portland cement (OPC). Introduction of SMC increases the strength of mix 40 % OPC + 40 % PFA + 20 % SMC by 25 % at 7 days and almost 30 % at 28 days compared to the mix with 50 % OPC and 50 % PFA. In a study by Pang (2007), SMC has the capability to be economically utilized in concrete as fine aggregate. At least up to 20 % of fine aggregate can be substituted by SMC without making the concrete strength falling below the required 21 MPa. Another viable way to reuse this residue generated by mushroom industry is by using as an additive to develop better insulation bricks (Velasco et al., 2014).

2.4 Waste Issue in Malaysia

Municipal solid waste (MSW) is a category of diverse waste, generated from different sources such as residential, commercial, municipal services and agriculture. At present, landfilling is the main waste disposal method (80 % usage) and it is still expected to account for 65 % of waste in 2020 (Waste Management Policy of Malaysia 10th Plan, 2010 to 2020). Malaysia largely depends on open dumping and landfills, where most of these sites have exceeded its operating capacity, leading to serious environmental and social threats (Manaf et al., 2009). However, landfills are not sustainable solutions due to land scarcity, rising costs and other constraints (Johari et al., 2014). According to SWCorp (2014), solid waste of 33,000 tons generated per day are already exceeding the expected solid waste that will be generated by 2020 which is 30,000 tons per day. This high generation rate is associated with rapid economic growth, urbanization and changing lifestyles in the recent past. In addition, former Urban Wellbeing, Housing and Local Government Datuk Abdul Rahman Dahlan when still in position, had highlighted about the scarcity of landfill area in Malaysia (The Sun Daily, 2016).

2.5 Cement

ASTM C 150 defines Portland cement as hydraulic cement produced by pulverizing clinkers containing hydraulic calcium silicates, normally involving one or more of the forms of calcium sulphate as an interground addition. Hydraulic cements not only harden by reacting with water but also form a water-resistant product. Table 2.1 has listed the types of cement according to ASTM C 150, Standard Specification for Portland Cement.

Table 2.1 Types of Cement

Types of Portland Cement	Characteristics
Type I	For use when the special properties specified for any other type are not required. No limits are imposed on any of the four principal compounds.
Type IA	Air-entraining cement for the same uses as Type I, where air-entrainment is required.
Type II	Used especially when moderate sulphate resistance or moderate heat of hydration is desired. This limits the tricalcium aluminate, C_3A content of the cement to maximum 8 %,

Table 2.1 continued.

Types of Portland Cement	Characteristics
Type IIA	Air-entraining cement for the same uses as Type II, where air-entrainment is desired.
Type III	For use when high early strength is desired. It limits the C_3A content of the cement to maximum 15 %.
Type IIIA	Air-entraining cement for the same use as Type III, where air-entrainment is desired.
Type IV	For use when a low heat of hydration is desired. It requires maximum limits of 35 % and 7 % on C_3S and C_3A, respectively, and a minimum of 40 % C_2S in the cement.
Type V	For use when high sulphate resistance is desired. It has a maximum limit of 5 % on C_3A which applies when the sulphate expansion test is not required.

Adapted from: ASTM C 150, Standard Specification for Portland Cement.

2.6 Aggregates

Generally, concrete aggregates are natural mineral aggregates which comprised of sand, gravel, and crushed rock. Aggregates can be classified into coarse aggregate and fine aggregate according to particle size. Coarse aggregate is particles larger than 4.75 mm while fine aggregate is particles smaller than 4.75 mm; typically ranging from 75 µm to 4.75 mm. The particle shape and surface texture of an aggregate affect the properties of freshly mixed concrete more than the properties of hardened concrete (Kosmatka and Wilson, 2016). Rough-textured, angular and elongated particles require more water to produce workable concrete than the smooth, rounded and compact aggregates. However, rough and angular particles increase the bond between cement paste and aggregates due to interlocking effect. Usage of reactive aggregates should be avoided to prevent alkali-aggregate reactivity such as alkali-silica reaction. The alkali-silica reaction will develops a gel that swells as it attracts water from the surrounding cement paste. Consequently, the gels can generate pressure, causing expansion, and cracking of the aggregate and surrounding paste.

2.7 Mixing Water for Concrete

Almost any natural water that is drinkable and has no strong taste or odour can be used as mixing water for making concrete. Water of questionable suitability can be used for making concrete if mortar cubes (ASTM C 109) made with it have 7-day strengths equal to at least 90 % of companion specimens made with drinkable or distilled water. Too much impurity in mixing water not only may influence setting time and concrete strength, but also may give rise to efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability.

2.8 Durability Characteristics

According to ACI Committee 201, durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Concrete that is durable will maintains its initial form, grade and serviceability when subject to exposure. Durability plays important roles in the life-cycle cost and ecological aspect. Increasingly, restoration and replacement expenditure of structures emerging from material failures have become a large fraction of the overall construction budget. Conservation of natural resources can be done by making the materials durable and therefore longer lasting.

2.8.1 Water Absorption

Water is known to be the cause of many types of physical processes of degradation. The deterioration rate is influenced by the type of concentration of ions in water and the chemical constitution of the solid. Water molecules are small enough to penetrate fine pores and are capable to dissolve more substances than other liquid. Hence, many ions and gases that can cause chemical decomposition of solid materials are present in water. Besides, hydrostatic pressure accumulated by differential vapour pressures can initiate high internal stresses inside moist solid.

Udoeyo et al. (2006) had investigated the water absorption properties of concrete with wood waste ash as a partial cement replacement material. Concrete mixes with wood waste ash content ranging between 5 % and 30 % at increments of 5 % were mixed for water absorption tests. With the addition in level of cement substitution from 5 % to 30 %, the water absorption of concrete with wood waste ash as partial cement replacement was noticed to rise from 0.14 % to 1.05 %. However, concrete mix produced still satisfy the acceptable values of water absorption below 10 % for most construction material at levels of cement replacement by wood waste ash up to 30 %.

2.8.2 Sorptivity

Sorptivity or capillary suction, is the transfer of liquids in porous solids because of surface tension acting in capillaries and is a function of the viscosity, density and surface tension of the liquid and also the pore structure (radius, tortuosity and continuity of capillaries) of the porous solid (Pitroda & Umrigar, 2013). Sorptivity can be used to determine the intake of water by unsaturated and hardened concrete. In hydrated cement paste, the coefficient of permeability would controlled by the size and continuity of the pores at any point during the hydration process. The cement paste will have high capillary porosity when the water/cement ratio is high and the degree of hydration is low. It will has comparatively huge quantity of big and well-connected pores, thus high coefficient of permeability. As hydration continues, most of the pores will become smaller and lose their interconnections, so reducing permeability.

Pitroda & Umrigar (2013) stated in their study that pores in concrete result from the incomplete compaction are voids of larger size which can cause low strength in concrete. Permeability tests measures the reaction of concrete to pressure, which is seldom the driving force of fluids assess to concrete. Therefore, sorptivity test is needed to measure the rate of absorption of water by capillary suction of unsaturated concrete. As has been proven by Abalaka & Okoli (2013), water cured specimens had better compact microstructure than uncured specimens. Moreover, higher water-cement ratio mixes has larger sorptivity value than the mixes with lower water-cement ratio.

2.8.3 Acid Attack

Acid can be separated into two types which is weak acid and strong acid. Strong acids have lower pH value than weak acids. Examples of weak acids are acetic acid, carbonic acid, carbolic acid, lactic acid, phosphoric acid and tannic acid. Meanwhile, strong acids are hydrochloric acid, sulphuric acid, sulphurous acid, nitric acid, hydrofluoric acid and hydrobromic acid. Highly alkaline Portland cement is susceptible to attack by strong acids.

The disintegration of calcium hydroxide caused by acid attack progresses in two phases. The first phase being the acid reaction with calcium hydroxide in the cement paste. The second phase being the acid reaction with the calcium silicate hydrate. According to Gay et al. (2016), the first and faster dissolving constituent is calcium hydroxide which is also known as Portlandite with chemical reaction written as follows:

$$Ca(OH)_2 + 2H^+ \rightarrow Ca^{2+} + 2H_2O \tag{2.1}$$

Then, hydration product such as calcium silicate hydrate will undergoes decomposition with the general formula of HA for mono-proton acid with following process:

$$x\text{CaO} \cdot y\text{SiO}_2 \cdot n\text{H}_2\text{O} + 2x\text{HA} \rightarrow x\text{CaA}_2 + y\text{Si(OH)}_4 + (x + n - 2y)\text{H}_2\text{O} \tag{2.2}$$

The severity of the acid attack is notably dependent on solubility of the calcium salt of acid and stability of the corroded layer. A possible result of the chemical effects of acidic attack is gradual degradation of engineering properties of cementing materials. In the beginning, deterioration of concrete surface occurs with the crushing and dropping of surface material. If acidic attack continued, strength degradation of concrete will slowly occurs. It is caused by the decomposition of hydration products and the subsequent leaching of the decomposition products (Zivica et al., 2012). Previous research by Udoeyo & Dashibil (2002) shown that mass loss of the concrete specimens with 15 % total binder weight of wood ash is less noticeable control concrete specimens with only ordinary Portland cement (OPC) as binder. The test was done to study the resistance of concrete with wood waste ash as partial cement replacement against acid attack. Hardened concrete cubes casted were immersed in a 20 % concentrated nitric acid solution for ten weeks.

2.8.4 Sulphate Attack

The crucial agents for sulphate attack are sulphate anions (SO_4^{2-}). Sulphate anions are carried into concrete in different concentrations in water, together with cations which are commonly calcium, magnesium and sodium. These alkali sulphates are present in groundwater with higher concentrations of sulphate. Ammonium sulphate is often present in agricultural soil and waters. Decompose of organic matter in swamps, shallow lakes, mining pits, and sewer pipes frequently give rise to the formation of hydrogen sulphide (H_2S), which can be transformed into sulphuric acid by bacterial action. Therefore, damaging concentrations of sulphate are easily found in natural and industrial environments.

Mehta and Monteiro (2001) stated that calcium hydroxide and alumina-bearing phases of hydrated Portland cement are susceptible to attack by sulphate ions. Under hydration, Portland cements with more than 5 percent of tricalcium aluminate, $3CaO \cdot Al_2O_3$ (abbreviated, C_3A) will contain most of the alumina in the form of monosulfate hydrate, $3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 18H_2O$ (abbreviated, $C_3A \cdot CS \cdot H_{18}$). If the C_3A content of the cement is more than 8 percent, monosulfate hydrate will be in the form of $3CaO \cdot Al_2O_3 \cdot CaO \cdot H_2O \cdot 18H_2O$ (abbreviated, $C_3A \cdot CH \cdot H_{18}$). When the cement paste with the presence of calcium hydroxide comes in contact with sulphate ions, both the alumina-containing hydrates are converted to the high-sulphate form of $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$ (ettringite, $C_3A \cdot 3CS \cdot H_{32}$) as follows:

$$C_3A \cdot CS \cdot H_{18} + 2CH + 2S + 12H \rightarrow C_3A \cdot 3CS \cdot H_{32} \qquad (2.3)$$

$$C_3A \cdot CH \cdot H_{18} + 2CH + 3S + 11H \rightarrow C_3A \cdot 3CS \cdot H_{32} \qquad (2.4)$$

The formation of ettringite can be deleteriously expansive. This is because it has a solid volume greater than the original constituents as it grows to myriad acicular (needle-shaped) crystals. Consequently, this will induce high internal stresses in the concrete. Once the stress exceeds the tensile strength of the concrete, cracking and spalling will occur (BRE Construction Division, 2005).

Reddy et al. (2013) had investigated the resistance of supplementary cementing materials in concrete to sulphate attacks by measuring the variation of compressive strength. Supplementary cementing materials used in the research are fly ash, silica fume and metakaoline. Concrete cubes were immersed in 5 % sodium sulphate solution for 90 days to test for the changes of compressive strength. All the supplementary cementing materials concretes performed better than normal concrete with only cement as binder.

2.8.5 Chloride Attack

Chloride by itself is generally thought as not deleterious to concrete. However, chlorides can make alterations to the products of cement hydration and cause other forms of concrete deterioration (Alexander et al., 2013). Chlorides can be present in concrete by contamination or ingress from surroundings. Contamination occurred when aggregates with impurities, sea water or admixture containing chlorides have been incorporated in the concrete mix. On the other hand, ingress of chlorides is caused by the de-icing salts, sea water in contact with concrete and also air-borne salts. Chlorides can be deposited on the surface of concrete in the form of fine air-borne droplets of sea water. They are raised from the sea by turbulence and carried by wind (Neville, 2011). Chlorides penetrate into concrete by transport of water containing the chlorides, as well as by diffusion of the ions in the water. Salt is hygroscopic, which means salt attracts and retains water. When salts are incorporated to concrete, they draw up to 10 % more water into the pore structure of the concrete. This process reduces the space for expansion in the pore structure and consequently induces more pressure inside the concrete when it freezes. As a result, concrete surface will cracks and spalls.

Chloride attack present major risk to reinforced concrete especially for structures in marine environments. It can cause corrosion of steel reinforcement. According to Ahmad (2003), corrosion of steel in concrete can be initiated with the availability of oxygen, moisture and free chloride ions . Moisture satisfies the electrolytic requirement of the corrosion cell while oxygen will reacts with moisture to form hydroxide ions, OH^- which lead to formation of rust component iron(II) hydroxide, $Fe(OH)_2$. Chloride in concrete can be available in the forms of chemically bound that incorporated in the products of hydration of cement; physically bound that adsorbed on the surface of the gel pores; and free chloride within the pore solution of concrete. It is the free chlorides that are present for reaction with steel. When chloride content increased, it will reduces the concrete alkalinity. With the resent of moisture and oxygen, chloride ions destroy the oxide layer forms on the steel and corrosion starts to occur.

John et al. (2012) had studied chloride attack of fly ash concrete by determining the weight loss of specimens. Cubes of 100 mm were immersed in 3 % hydrochloric acid for 28 and 90 days. The results obtained shown that weight reduction for 50 % partial cement replacement fly ash concrete is less than the normal concrete. Karthika (2016) also investigated the chloride attack on the concrete weight changes with different percentage of nano silica replacing the cement. Cubes of 100 mm were immersed in 5 % sodium chloride in water for 28 days. The durability of concrete containing 2 % nano silica exhibits better resistance against sulphate attack with lesser weight changes compared to the normal concrete.

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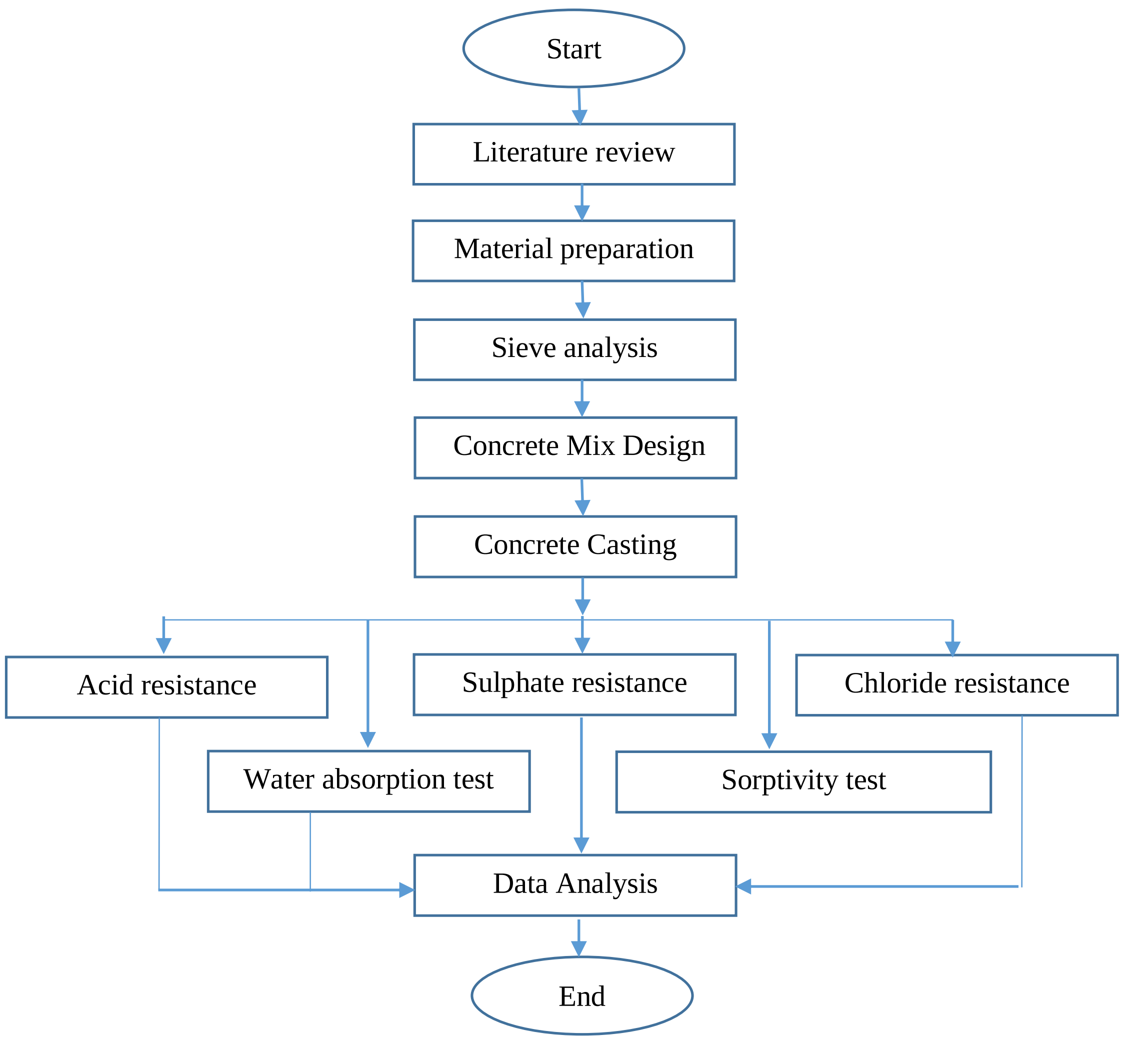
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the properties of the materials and procedure of experimental works to study the durability of concrete with spent mushroom compost as partial cement replacement. Tests were conducted to examine water absorption, permeability, acid resistance, sulphate resistance and chloride resistance.



3.2 Materials and Properties

The material used in this research is water, coarse aggregate, fine aggregate, Ordinary Portland Cement and spent mushroom compost. Spent mushroom compost will be used as partial replacement of cement in the concrete.

3.2.1 Cement

ASTM C 150 defines Portland cement as hydraulic cement produced by pulverizing clinkers containing hydraulic calcium silicates, normally involving one or more of the forms of calcium sulphate as an interground addition. Portland cement ASTM Type I was used in this research.

Figure 3.1 YTL ORANG KUAT Ordinary Portland Cement

3.2.2 Coarse Aggregate

Coarse aggregates are particles with size greater than 4.75mm and generally range between 9.5 mm to 37.5 mm. The coarse aggregate used in this experiment is crushed granite aggregates with the maximum size of 20 mm.

3.2.3 Fine Aggregate

The fine aggregates used in this research is river sand and is comply with ASTM C33-03. Sand of size passing 2.36 mm (No. 8) was used and shall be free from any impurities.

3.2.4 Water

Water is needed to mix the material and during the hydration process of the cement in concrete. Hydration process need sufficient water to produce calcium silicate hydrate gel that is responsible for most of the engineering properties of cement paste. It will forms a continuous layer that binds together the original cement particles into a cohesive whole. The water added to the concrete mixing must be free from impurities as these impurities will decrease the strength of the concrete produced. Potable tap water from municipal water supply is used in this investigation complying ASTM C1602.

3.2.5 Spent Mushroom Compost Ash

The spent mushroom composts used in this research are supplied by The Grow Enterprise in Maran, Pahang. The composts were oven-dried for 24 hours at 105 ˚C before being burnt by microwave using medium energy output. Before application in concrete, the spent mushroom compost ash (SMCA) was ground and sieved through 300 µm.

Figure 3.2 Spent Mushroom Compost Ash (SMCA)

3.3 Concrete Mixing

Analysis was done to choose the optimum cement replacement percentage with sawdust prior to mixing. Cement replacement studies were done referring to sawdust as the composts in Malaysia was initially produced from raw materials consists of rubber sawdust, rice bran and hydrated lime in ratio of 100 kg: 10 kg: 1 kg respectively (Abd Rasib, 2015). Moreover, the compost used in this research is also mixed sawdust, wheat bran and dolomite together at ratio 100 kg: 10 kg: 1 kg (The Grow Enterprise, 2016). Ten percent of cement replacement was chosen based on the several studies (Chugh and Bansal, 2016; Elinwa et al., 2007; Kumar and Krishna, 2015; Malik et al., 2015; and Marthong, 2012). All of those studies had proven 10 % of replacement can be considered optimum as the concrete compressive strength is still above 25 N/mm^2 with the replacement. The design strength of the concrete in this research is 30 MPa. The materials were weighed according to the ratio 1: 1.32: 1.98 (binder, sand and granite) and mixed in the mixer machine for 10 to 15 minutes to obtain homogeneous mix.

3.4 Concrete Casting

The procedure in which the concrete is cast comply with BS 1881: Part 108:1983 and EN 196-1. The mould used in this research is square cube with dimension of 100 mm x 100 mm x 100 mm. These concrete cubes will be used for compressive strength test, water absorption test, water permeability test, acid resistance, sulphate resistance and chloride resistance. First, the mould is checked to ensure it is free from any impurities before applying grease to the inner surface of the mould. This is to have a swifter demoulding process. The mould is placed on a rigid horizontal surface and the process of filling the mould is done carefully to eliminate entrapped air in the mix. The mould will be filled with 3 different layers. One-third of the cube is filled with concrete and then vibrated by using vibrator. This process is repeated when filling the cube with the second and third layer. The top compacted layer will be smoothened out by using shovel. The specimen will be left for 24 hours before curing process begins.

3.5 Curing Process

The curing process that will undergo but the concrete specimen in this research is water curing. All the concrete specimens were kept and fully immersed in potable water for 28 days. The purpose of curing is to reduce the initial temperature of the concrete and in the same time to provide an adequate amount of moisture for continued hydration and development of strength.

3.6 Slump Test

Slump test is conducted on the fresh concrete to determine its workability with standard test procedure in accordance to BS EN 12350-2:2009. The equipment involve in this experiment is steel slump cone, steel tamping rod and base plate. First, the base plate is place at a stable location and then the steel slump cone is placed on top of it. The cone is filled up in three layers. Each layers will be tamped for 25 times by using tamping rod follow by the second and third layer. When the cone is fully filled, the excess concrete is struck off with saving and rolling motion of tamping rod. With the mould still held down, surface below any concrete which may have fallen onto it or leaked from the lower edge of the mould is cleaned. The slump cone is then removed vertically and slowly to impact minimum lateral or torsional movement to the concrete. Then, the slump cone is placed carefully beside the concrete. The difference in the height between the concrete slump and slump cone is recorded. The entire operation from the start of filling to the removal of the mould shall be carried out without interruption and shall be completed within 150 seconds. The required slump of the concrete is in the range of 60 mm - 180 mm.

3.7 Compression Test

The specimens are left for curing up to 28 days. Compression test of water-cured specimen is conducted immediately after the removal of specimens from curing tank. Three hardened concrete specimens each for the normal concrete and 10 % SMCA partial cement replacement with the size of 100 x 100 x 100 mm are used in the measurement of concrete strength. Compression testing machine is used in this experiment. The test procedure conducted complied to BS 1881: Part116:1983.

Figure 3.3 Compressive Strength Machine

First, dimension and weight of each specimen is measured. The concrete cube surface is ensured to be clean and free from impurities. Bearing faces of upper and lower bearing plate of the machine is wiped clean before placing the specimen at the centre of the bearing plate. The compression plate is adjusted to the level where it touches the top surface of the concrete. The load is increased continuously at a nominal rate within 0.2 N/(mm s) to 0.4 N/(mm s) until no greater load can be sustained. The test stop once the concrete cube fail. The maximum load carried by the specimen during the test, type of failure and the appearance of specimen is recorded. The test procedure is repeated for the second and third cubes.

The calculation of the maximum compressive strength test is expressed in Eq. (3.1).

$$f_c = \frac{P}{A} \tag{3.1}$$

Where:

f_c = compressive strength of concrete specimen (N/mm^2 or MPa)

P = maximum load carried by the specimen during test (N)

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

3.8 Water Absorption Test

For water absorption test, the 100 x 100 x 100 mm concrete specimen are use and the test is conducted by complying with BS1881-122. Before the test is conducted, the concrete specimens are cured in the water. The test is conducted after water cured for 28 days. Three specimens are oven dried for 72 ± 2h at 105 ± 5 ℃ to obtain the oven dry mass of the specimens. Upon removing the specimens from the oven, the specimens will be cool for 24 ± 0.5 h in airtight vessel. Then, the specimens are weighted before completely immersed them in a water tank up to a depth where the water must be at least 25 ± 5 mm above the specimen. After 30 minutes, the specimens are removed from the water and a piece of dry cloth is used to dry the surface of the concrete cube. Then the weight of the specimens is taken.

The calculations to determine the water absorption of the concrete specimens are done as below.

$$\frac{Final\ weight - initial\ weight}{Dry\ mass\ of\ the\ specimen}\ x\ 100\ \% \tag{3.2}$$

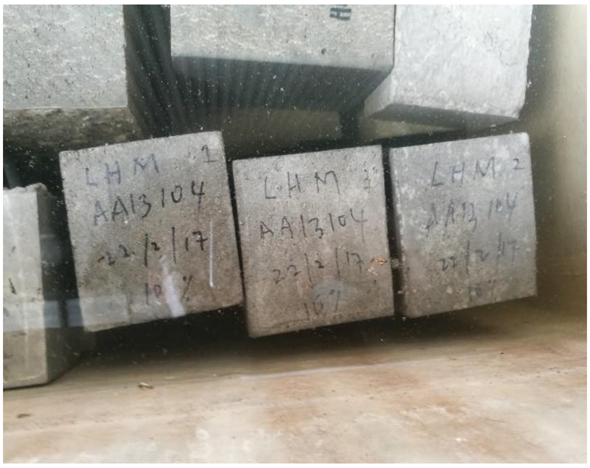


Figure 3.4 Water Absorption Test

3.9 Sorptivity

Three specimens of 100 mm cubes for sorptivity test were prepared for each normal concrete and SMCA partial cement replacement concrete. Measurements of capillary water absorption were carried out as Turk et al. (2012) to determine the sorptivity coefficient of concrete specimens, which were pre-conditioned in oven at 110 ± 5 ˚C until a constant weight and then cooled down in room temperature for 24 hours to achieve a constant moisture level. Then, four sides of the concrete specimens were sealed by epoxy resin to avoid evaporative effect as well as to maintain uniaxial water flow during the test and the opposite faces were left open. Before the specimens were located on water, their initial weights were measured to the nearest 0.01 g. One face of the specimen was placed in contact with water rested on glass or steel rods to allow the free access of water to the inflow surface. The water level in the tray was maintained at about 4-5 mm above the base of the specimens during the experiment. Immediately after the immersion of the cube surface into water, the water absorption was measured with scale of 0.1 g readability at intervals of 1, 2, 4, 8, 10, 20, 30, 60 and 90 minutes.

Figure 3.5 Epoxy Resin

Figure 3.6 Sorptivity Test

The sorptivity coefficient can be calculated by the following expression:

$$k = \frac{Q\ /A}{\sqrt{t}} \qquad (3.3)$$

Where:

k = the sorptivity coefficient of the specimen (mm/min$^{0.5}$)

$Q = \Delta W / d$

$\Delta W = W_2 - W_1$

W_1 = Oven dry weight of cube in grams

W_2 = Weight of cube after capillary suction of water in grams.

d = density of water (g/cm^3)

A = surface area of the specimen through which water penetrated (cm^2)

t = time (min)

3.10 Acid Resistance

The durability performance of both normal concrete and SMCA concrete are determined referring Shams (2015) by measuring the weight losses of the samples at 90 days of immersion in 5 % hydrochloric acid solution. Size of specimens are 100 x 100 x 100 mm with three cubes for each normal concrete and SMCA concrete. After removing the specimens from the solution, the surfaces are cleaned under the running tap water to remove weak products and loose material from the surface. Then the specimens are allowed to dry and measurements are taken. At the end of the day, compressive strength test was conducted to test the strength performance of OPC concretes versus SMC concretes immersed in acid solution.

3.11 Sulphate Resistance

Concrete cubes were cured for 28 days and were immersed in a sulphate solution that was prepared in accordance to PD CEN/TR 15697:2008 (BSI, 2008). The sulphate solution was prepared by mixing 5 % (by weight) sodium sulphate (Na_2SO_4) with 95 % (by weight) potable water. Three normal concrete specimens and three SMCA concrete specimens of 100 mm x 100 mm x 100 mm of sizes were immersed in sulphate solution immediately after the end of the curing. Sulphate attack was evaluated by measuring changes in weight, compressive strength and visual observation at approximately 90 days of continuous exposure to sulphate solution. The pH level was not monitored and sulphate solution was not changed throughout the course of the test.

3.12 Chloride Resistance

Three normal concrete **c**ubes and three SMCA concrete cubes of sizes 100 x 100 x 100 mm were cast and have water cured for 28 days. After 28 days of curing, cubes were taken out and initial weights were taken. A non-porous container is selected and chloride solution has been prepared by adding 5 % sodium chloride in water. This solution is stirred well so that all the sodium chloride salts get dissolved in the solution. Then the cubes are immersed in the chloride solution for 28 days. After 28 days, the changes of weight and compressive strength were determined and comparison is made between the normal concrete and SMCA concrete. The procedures are done as that has been done by Karthika (2016).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained from the experiments that were carried out according to the methods that were discussed in the methodology. The results are from the tests of compression test, water absorption, sorptivity, acid resistance, sulphate resistance and chloride resistance. In addition, the outcomes were discussed and compared with previous studies.

4.2 Compression Test

Compressive strength tests were conducted to control the quality of the concrete and to check specification compliance. At the ages of 28 days, three specimens from each of normal concrete and 10 % SMCA partial cement replacement concrete were tested to acquire the average results. The results for compressive strength of the concrete cubes are listed in Table 4.1.

Table 4.1 Compressive Strength of Normal Concrete and SMCA Concrete at 28 Days

Sample	Compressive Strength, MPa
Normal Concrete	51.18
SMCA Concrete	46.40

At 28 days, the average compressive strength of the normal concrete is 51.18 MPa while for SMCA concrete is 46.40 MPa which are both exceeding the designed strength of 30 MPa. This might be caused by the slower initial hydration process of pozzolan.

Study from Naik et al. (2003) concluded that control concrete mixture which wood waste ash content achieved a higher compressive strength than concrete mixtures containing wood waste ash at 28 days. However, at 365 days, concrete mixtures containing wood waste ash has higher compressive strength. It was stated that continuous strength was obtained from the wood fly ash concrete mixes upon prolonged curing durations. This implied a presence of pozzolanic reaction between wood waste ash and the cement hydration product as the strength gaining is slow but has a high ultimate strength. In addition, Udoeyo & Dashibil (2002) noticed that compressive strength for concrete mix with wood waste ash content ranging between 15 % and 25 % total binder weight gained faster at later curing ages of 56 and 90 days. Besides, test from Elinwa et al. (2008) observed that at 90 days, the best strength was achieved at 10 % cement replacement and this is roughly 30 % above the value of the normal concrete. This is because sawdust ash reacts with calcium hydroxide ($Ca(OH)_2$) that is produced during the cement hydration to form secondary C–S–H gel inside the cement paste through pozzolanic activity.

4.3 Water Absorption

Water absorption of the samples were obtained after 30 minutes of immersion in water by calculating the changes in weight. The average results were shown in Table 4.2 and Figure 4.1.

Table 4.2 Water Absorption of Normal Concrete and SMCA Concrete

Sample	Water Absorption, %
Normal Concrete	0.012
SMCA Concrete	0.003

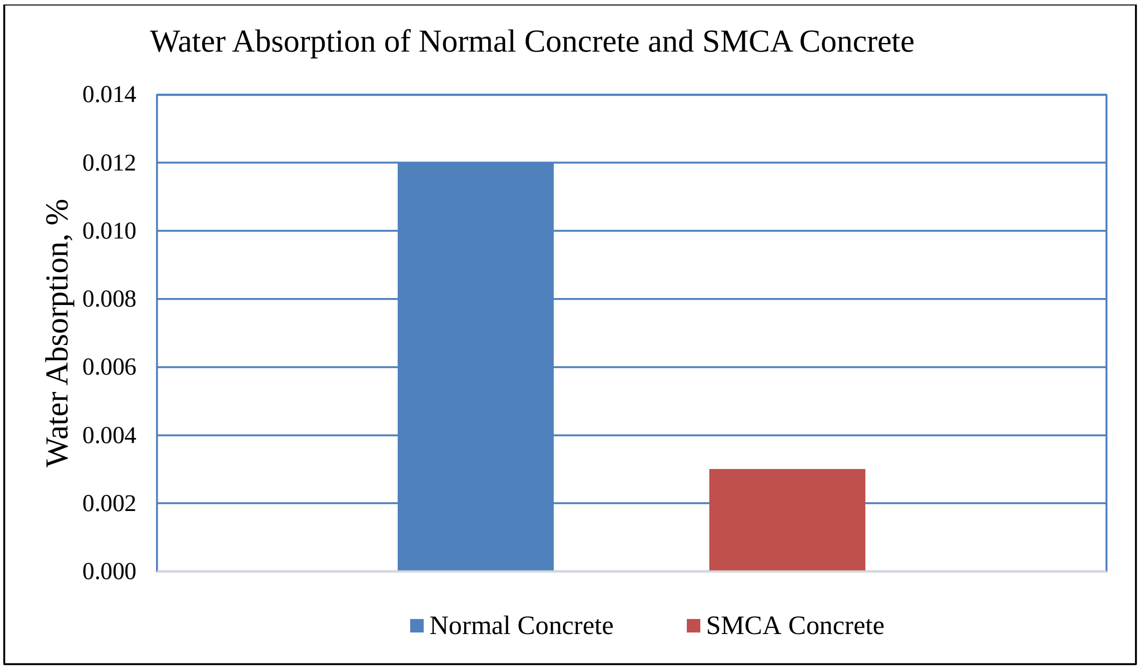


Figure 4.1 Water Absorption of Normal Concrete and SMCA Concrete

The results indicate that the water absorption of SMCA concrete is about four times less than the normal concrete. Elinwa et al. (2008) stated that the incorporation of 10 % of wood waste ash as substitution of ordinary Portland cement (OPC) in the formulation of concrete mix reduce the percentage of non-hydrated cement and portlandite amount while increasing the quantity of CSH gel present within the concrete mix produced after a given curing age.

4.4 Sorptivity

The lower the sorptivity value, the higher the resistance of concrete towards water absorption. The value of sorptivity illustrates the water mass uptake by concrete from the bottom surface, in unit of $mm^3/mm^2/min^{1/2}$. The results of the sorptivity test are shown in Figure 4.2 and Figure 4.3.

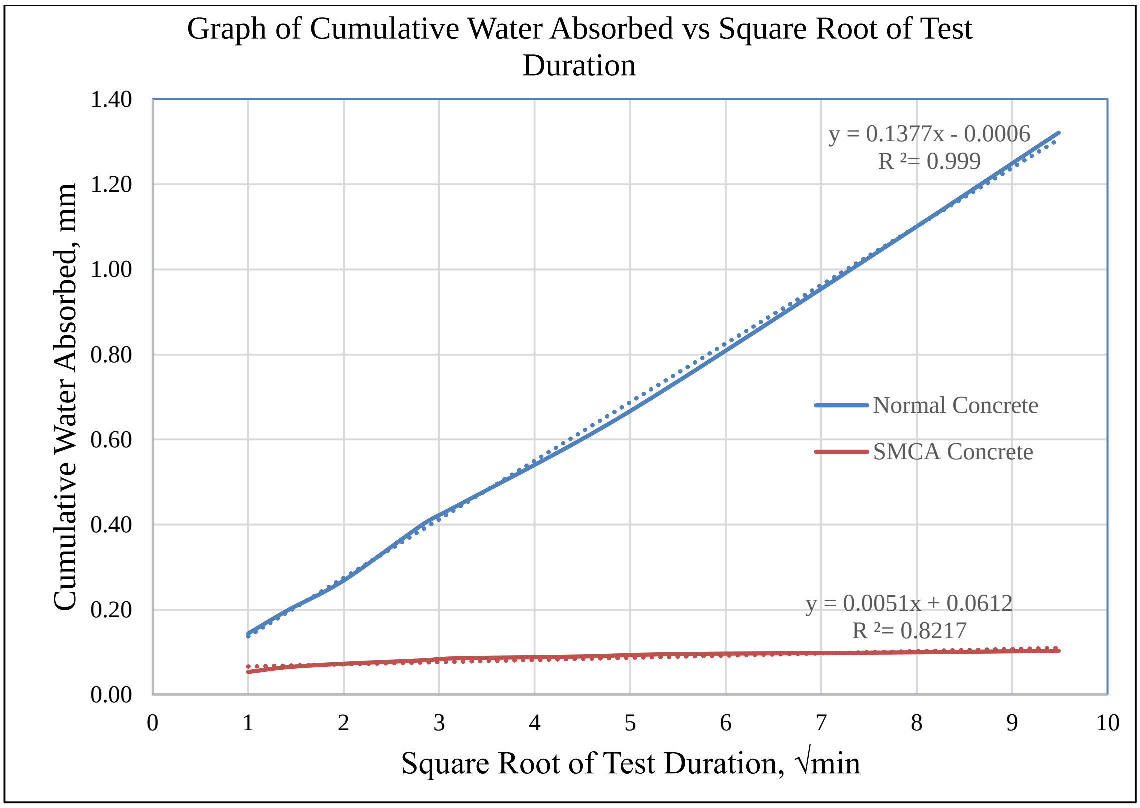


Figure 4.2 Absorption Plotted Against Square Root of Time for Normal Concrete and SMCA Concrete

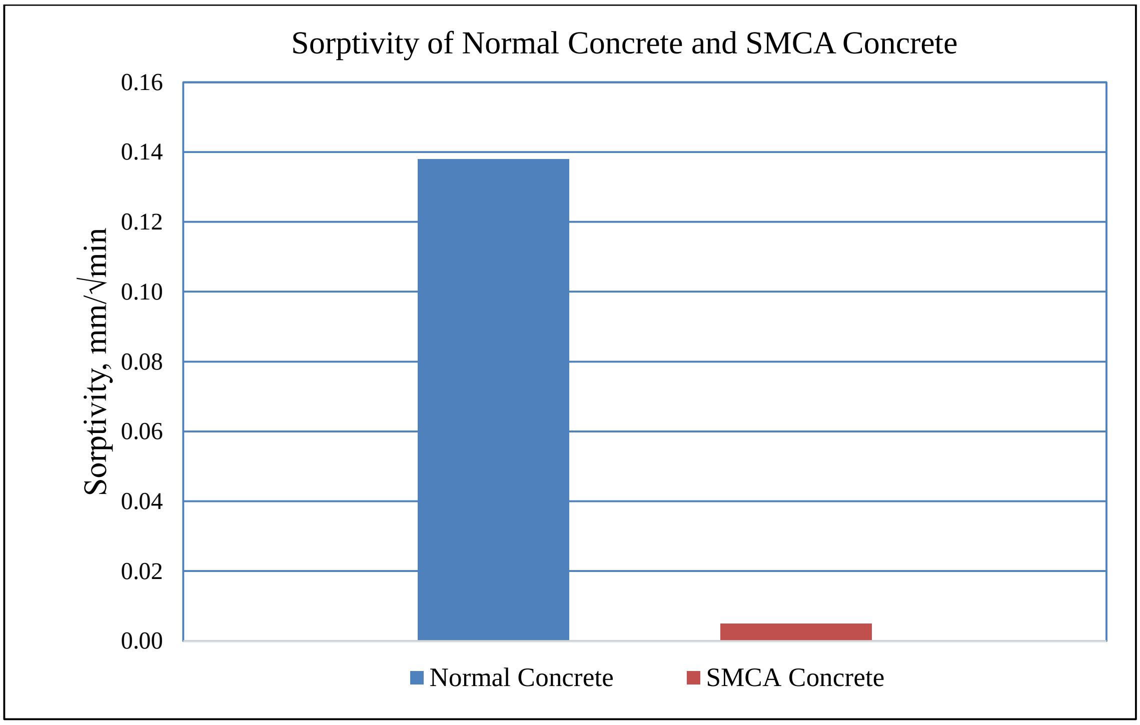


Figure 4.3 Sorptivity of Normal Concrete and SMCA Concrete.

Figure 4.2 illustrated the sorptivity as the slope of the line, which is drawn using least squares, linear regression analysis, to fit the curve of cumulative water absorbed plotted against square root of time. The plot shown that sorptivity for normal concrete is 0.138 mm/√min while SMCA concrete has sorptivity of 0.005 mm/√min. Meanwhile, the correlation coefficient, R of normal concrete and SMCA concrete plot is 0.999 and 0.910 respectively.

The SMCA concrete performed better than normal concrete can be due to finer pores and lesser interconnected network of capillary pores encountered by water, thus slowing the rate of sorption. Besides, even if the capillary pores form a strong integrated network through the interfacial zone around the aggregates with larger capillary pores, the ingress of water particles may still be slow as the air–water interface laid at a stable configuration in the pore space. Any additional water absorbed can only be transferred through gel pores that are much smaller than capillary pores (Razak et al., 2004).

4.5 Acid Resistance

The resistance of concrete to acid attack was found by visual inspection, the percentage loss of weight and compressive strength of concrete cubes on immersion in 5 % hydrochloric acid solution for 90 days. Visual inspection on specimens was conducted to determine any physical changes in the specimens after exposure to acid environment and the results are shown in Figure 4.4 and Figure 4.5. Meanwhile, Table 4.2 represents the average percentage loss in weight and average compressive strength of the normal concrete and SMCA concrete.

Figure 4.4 Physical Changes of Normal Concrete Before Immersion (left) and After Immersion in 5 % Hydrochloric Acid (right).

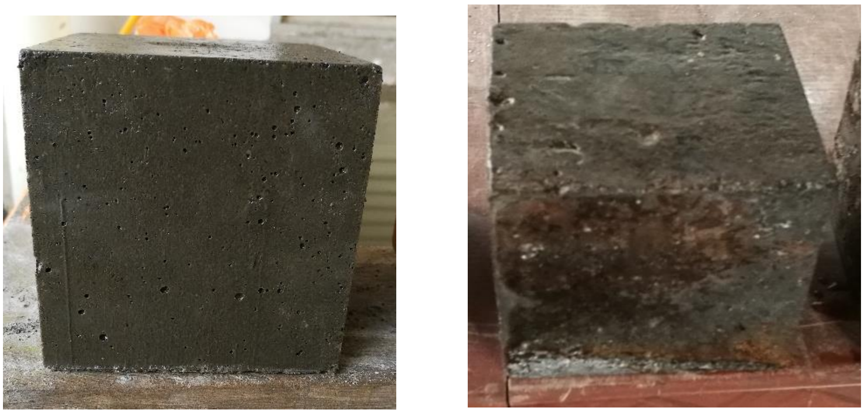


Figure 4.5 Physical Changes of SMCA Concrete Before Immersion (left) and After Immersion in 5 % Hydrochloric Acid (right).

Table 4.3 Percentage Loss in Weight and Compressive Strength of Normal Concrete and SMCA Concrete after 90 Days Acid Immersion.

Sample	**Percentage Loss in Weight, %**	**Compressive Strength, MPa**
Normal Concrete	0.13	45.06
SMCA Concrete	0.06	46.80

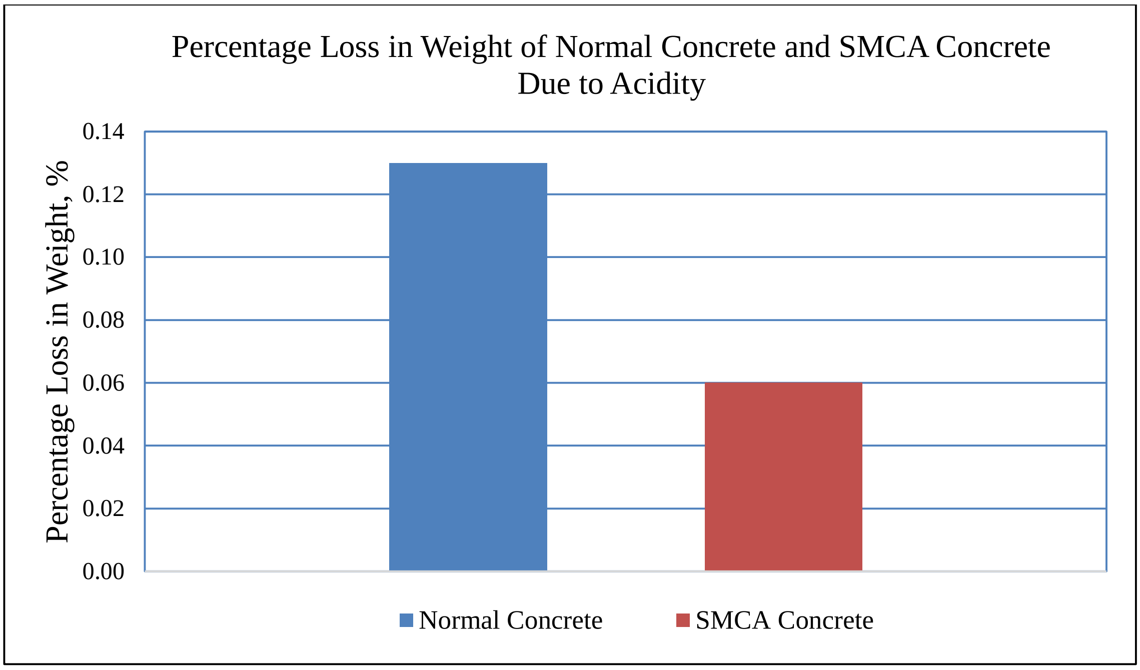


Figure 4.6 Percentage Loss in Weight Due to Acidity

From visual inspection, there is more colour changes in normal concrete than SMCA concrete. In addition, the losses at the corners and edges are more noticeable in the normal concrete compared to SMCA concrete. On the other hand, it can be observed that the percentage loss in weight of SMCA concrete after 90 days of 5 % hydrochloric acid immersion is lower than the normal concrete. SMCA concrete has 0.06 % loss in weight while normal concrete has 0.13 % loss in weight. Besides, the compressive strength of SMCA concrete at the end of the test is higher than the normal concrete. This may means that the SMCA concrete behaved better under acid attack when compared to normal concrete.

According to Ogork & Ayuba (2014), this improvement could be the result of the two factors. The pozzolan reacted with the lime in the paste matrix and therefore reducing the lime available in the state of free format. Lime is treated as harmful compound as it reacts with chemicals causing concrete deterioration. Second factor is due to better pore structure with lower permeability than the normal concrete. This will slow up the ingress of water and chemicals into the concrete.

4.6 Sulphate Resistance

The resistance of concrete to sulphate attacks was studied by determining the physical changes, loss of weight and the average compressive strength of concrete at 90 days of immersion in 5 % sodium sulphate solution. Table 4.4, Figure 4.7 and Figure 4.8 exhibited the test result obtained for the sulphate resistance test.

Figure 4.7 Physical Changes of Normal Concrete Before Immersion (left) and After Immersion in 5 % Sodium Sulphate (right).

Figure 4.8 Physical Changes of SMCA Concrete Before Immersion (left) and After Immersion in 5 % Sodium Sulphate (right).

Table 4.4 Percentage Gain in Weight and Compressive Strength of Normal Concrete and SMC Concrete after 90 Days Sulphate Immersion

Sample	**Percentage Gain in Weight, %**	**Compressive Strength, MPa**
Normal Concrete	0.19	52.21
SMCA Concrete	0.04	56.12

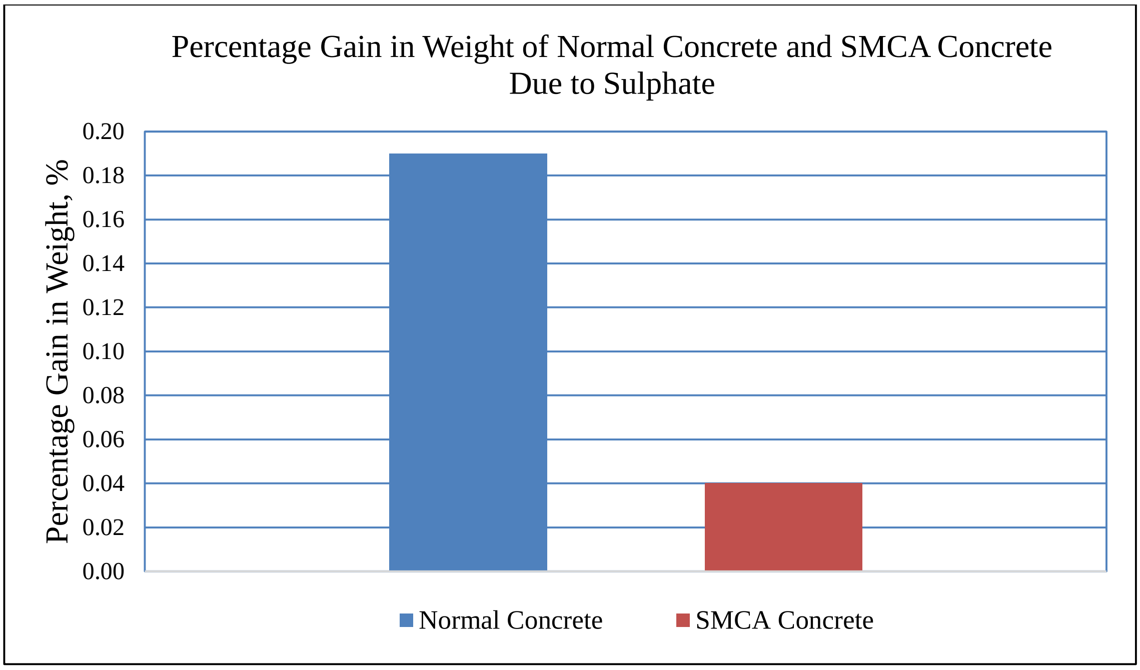


Figure 4.9 Percentage Gain in Weight Due to Sulphate.

Generally, there is not much changes in the physical appearances for both normal concrete and SMCA concrete. The percentage weight gain for normal concrete and SMCA concrete at the end of sulphate resistant test is 0.04 % and 0.19 % respectively. In the meantime, compressive strength for normal concrete at the end of test is 52.21 MPa while for SMCA concrete it is 56.12 MPa. It is observed that SMCA concrete have better resistance against sulphate attack than the normal concrete.

The weight gained in both normal and SMCA concrete is due to not only hydration (gaining water weight), but also because of the precipitating solids as the sulphates left solution to form gypsum and eventually ettringite (Bescher et al., 2017). The reaction of the hydration products with sulphate is expected to produce more gypsum ($CaSO_4$) and more ettringite ($C_3A \cdot 3CaSO_4 \cdot 32H_2O$). The volume of the ettringite is higher than the reactant components and therefore take up more space which bound to expansion and weight gained of concrete (Hamood, 2014). Meanwhile, SMCA concrete is less susceptible to sulphate attack may be due to finely dispersed hydration products that improve impermeable pore structure, decreasing the penetration of sulphate ions (Kropp & Hilsdorf, 2005).

4.7 Chloride Resistance

Chloride resistance test results were obtained after 28 days of immersion in 5 % sodium chloride solution. The results were presented in Table 4.5, Figure 4.10 and Figure 4.11.

Figure 4.10 Physical Changes of Normal Concrete Before Immersion (left) and After Immersion in 5 % Sodium Chloride (right).

Figure 4.11 Physical Changes of SMCA Concrete Before Immersion (left) and After Immersion in 5 % Sodium Chloride (right).

Table 4.5 Percentage Gain in Weight and Average Compressive Strength after 28 Days Chloride Immersion

Sample	Percentage Gain in Weight, %	Compressive Strength, MPa
Normal Concrete	0.067	52.42
SMCA Concrete	0.072	49.94

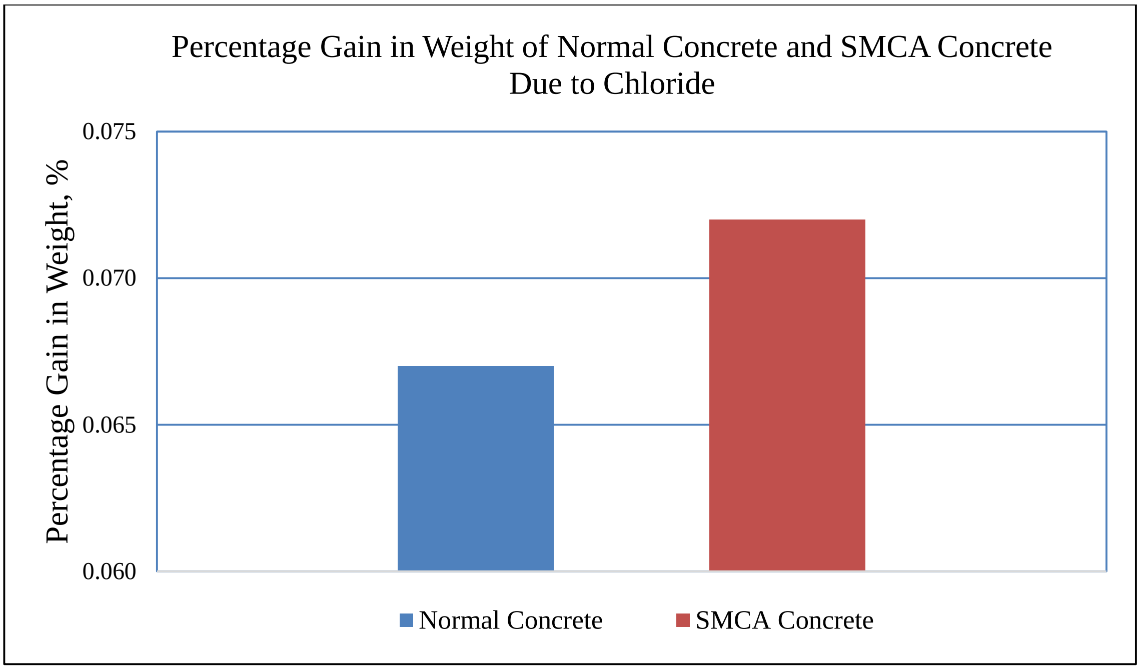


Figure 4.12 Percentage Gain in Weight Due to Chloride

Physical changes in SMCA concrete is more obvious than that of normal concrete. There are more whitish crystalline salts precipitated on the surface of SMCA concrete. Meanwhile, the percentage gain in weight for normal concrete and SMCA concrete show no large difference which is 0.067 % and 0.072% respectively. At the end of the test, the normal concrete has compressive strength of 52.42 MPa versus 49.94 MPa for the SMCA concrete. It is noticed that normal concrete fare better than SMCA concrete when exposed to chloride attack.

The weight gained in both normal concrete and SMCA concrete might be caused by the penetration and deposition of chloride ions inside the concrete pores (Akshatha et al., 2015). Moreover, Al-Attar & Abdul-Kareem (2011) expressed that tricalcium aluminate (C_3A) in the cement has a weighty effect on the reaction with chloride ions and forming the insoluble Friedel's salt ($3CaO \cdot Al_2O_3\ CaCl_2 \cdot 10H_2O$).

Normal concrete performed better towards 28 days of chloride attack might be due to the slower strength gaining in SMCA concrete. This is similar to the 5 % sodium chloride immersion test from Liu et al. (2014) that used fly ash as partial cement replacement in concrete. It has a slow early stage of hydration process when the reaction between calcium hydroxide and activated pozzolanic reaction of fly ash is very low. As the soaking time increases, surface chloride ion content in concrete without fly ash increases faster than the fly ash concrete. This is caused by the ongoing pozzolanic effect of fly ash, optimizing pore structure of concrete to reduce the porosity and amount of intercommunicating pore which improved chloride resistance. In addition, study from Elinwa & Mahmood (2002) also shown that the marginal difference of compressive strength between wood waste ash concrete and neat OPC control concrete mix inclined to decrease with extended curing durations, particularly beyond 28 days.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusion of this research based on the objectives that have been set. This research has investigated the durability performance of SMCA as partial cement replacement. Investigated mixes were tested for their durability properties such as water absorption, sorptivity, acid resistance, sulphate resistance and chloride resistance.

5.2 Conclusion

Based on the research conducted, conclusions can be drawn as below:

i. Water absorption is lower with partial cement replacement of SMCA in concrete at 0.003 % compared to 0.012 % for normal concrete.
ii. Concrete performs better in sorptivity with partial cement replacement of SMCA in concrete. Sorptivity for normal concrete is $2x10^{-4}$ mm/√min while SMCA concrete has sorptivity of $4x10^{-6}$ mm/√min.
iii. Acid resistance of concrete increases with partial cement replacement of SMCA in concrete. The average percentage weight loss due to acid attack at 90 days for SMCA concrete is 0.06 % compared to 0.13 % for normal concrete. Average compressive strength of SMCA concrete is also higher than normal concrete at the end of test.
iv. SMCA concrete is more resistant to sulphate attack compared to normal concrete. The average percentage weight loss due to sulphate attack at 90 days for SMCA concrete is 0.04 % while for normal concrete it is 0.19 %. SMCA concrete also has higher average compressive strength than normal concrete at the end of test.

v. At 28 days immersed in 5 % sodium chloride solution, normal concrete is less susceptible to chloride attack as its average percentage weight loss is 0.067 % compared to 0.072 % for SMCA concrete. At the end of chloride resistance test, normal concrete has higher average compressive strength than SMCA concrete.

5.3 Recommendation for Future Research

Based on the result of this study, the following recommendations would be useful:

i. Use smaller sizes of particles or finer SMCA as partial cement replacement in concrete.
ii. Study on other treatment methods of the SMC for better concrete mixes.
iii. Study on the effect of different curing method and duration of the SMCA concrete to its strength performance.
iv. Extent the duration of chemical resistant test to determine the durability performance of SMCA concrete in longer period.
v. Carry out the acid resistant test with different acid types to observe SMCA concrete performance in different acid environment.
vi. Investigate on different chloride resistant tests by using different methods and different types of chloride.

REFERENCES

Abalaka, A.E. and Okoli, O.G. (2013). Strength development and durability properties of concrete containing pre-soaked rice husk ash. *Construction Science*, *14*, 4–12.

Abd Rasib, N.A., Zakaria, Z., Tompang, M.H., Abdul Rahman, R. and Othman, H. (2015). Characterization of biochemical composition for different types of spent mushroom substrate in Malaysia. *Malaysian Journal of Analytical Sciences* 19(1), 41–45.

Ahlawat O.P. and Sagar M.P. 2007. *Management of spent mushroom substrate*. India: National Research Centre for Mushroom

Ahmad, S. (2003). Reinforcement corrosion in concrete structures, its monitoring and service life prediction - A review. *Cement and Concrete Composites*, *25*(4–5 SPEC), 459–471.

Akshatha, G.M., Kumar, B.G.J. and Pushpa, H. (2015). Effect of corrosion inhibitors in reinforced concrete. *International Journal of Innovative Research in Science, Engineering and Technology*. 6794–6801.

Al-Attar, T.S. and Abdul-Kareem, M.S. (2011). Effect of chloride ions source on corrosion of reinforced normal and high performance concrete. *Buletinul AGIR*.107–112.

Al Ansari, M.S. (2012). Improving solid waste management in Gulf Co-operation Council States: Developing integrated plans to achieve reduction in greenhouse gases. *Modern Applied Science*, *6*(2), 60–68.

Alexander, M.G., Bertron, A. and De Belie, N. 2013. *Performance of cement-based materials in aggressive aqueous environments*. Netherlands: Springer

Badgie, D., Abu Samah, M.A., Abd Manaf, L. and Muda, A. (2012). Assesment of municipal solid waste composition in Malaysia : Management, practice and challenges. *Pollution Journal Environment Studies*, *21*(3), 593–547.

Bahoria, B.V, Parbat, D.K., Naganaik, P.B., Waghe, U.P. and Email, W.S. (2013). Comprehensive literature review on use of waste product in concrete. *Internationalof Journal of Application or Innovation in Engineering and Management*. *2*(4), 387–394.

Baruya, P. (2015). *World forest and agricultural crop residue resources for cofiring*. United Kingdom: IEA Clean Coal Centre

Bescher, E., Rice, E.K., Ramseyer, C., Roswurm, S., Bescher, E., Rice, E. K. and Roswurm, S. (2017). Sulfate resistance of calcium sulphoaluminate cement. *Journal of Structural Integrity and Maintenance*, *5314*(April), 1–9.

BRE Construction Division. (2005). Concrete in aggressive ground (online). Retrieved from http://projects.bre.co.uk/sd1/pdf/PartBv6.pdf (13 November 2016)

Economic planning (2016) National Agrofood Policy, 2011-2020 and National Commodity Policy, 2011-2020 (online) http://www.epu.gov.my/en/content/q1-what-are-main-objectives-national-agrofood-policy-2011-2020-and-national-commodity-policy

Elinwa, A.U., Ejeh, S.P. and Mamuda, A.M. (2008). Assessing of the fresh concrete properties of self-compacting concrete containing sawdust ash. *Construction and Building Materials 22*, 1178–1182.

Elinwa, A.U. and Mahmood, Y.A. (2002). Ash from timber waste as cement replacement material. *Cement and Concrete Composites 24*, 219–222.

Gay, H., Meynet, T. and Colombani, J. (2016). Local study of the corrosion kinetics of hardened Portland cement under acid attack. *Cement and Concrete Research*, *90*, 36–42.

Guo, M. and Chorover, J. (2006). Leachate migration from spent mushroom substrate through intact and repacked subsurface soil columns. *Waste Management*, *26*(2), 133–140.

Hamood, A.A. (2014). *Sustainable utilisation of raw sewage sludge (rss) as a water replacement in cement-based materials containing unprocessed fly ash*. Ph.D. Thesis. University of Wolverhampton, England.

Jamaludin, A.A., Mahmood, N. Z. and Abdullah, N. (2012). Waste recycling: Feasibility of saw dust based spent mushroom substrate and goat manure in vermicomposting. *Sains Malaysiana*, *41*(11), 1445–1450.

Johari, A., Alkali, H., Hashim, H., Ahmed, S. I. and Mat, R. (2014). Municipal solid waste management and potential revenue from recycling in Malaysia. *Modern Applied Science*, *8*(4), 37–49.

John, J. (2012). Mathematical modeling for durability characteristics of fly ash concrete. *International Journal of Engineering Science and Technology 4*(1), 353–361.

Karthika, P. (2016). An experimental investigation on concrete with nano silica and partial replacement of cement with flyash. *International Journal of Scientific & Engineering Research 4*(7), 2013–2015.

Kosmatka, S.H. and Wilson, M.L. 2016. Design and control of concrete mixtures (online). http://www.ce.memphis.edu/1101/notes/concrete/PCA_manual/Chap05.pdf (24 November 2016)

Kropp, J. and Hilsdorf, H.K. (2005). *Performance criteria for concrete durability*. London: E & FN Spon

Liu, J., Wang, X., Xing, F. and Han, N. (2014). Influence of fly ash on surface chloride concentration under shallow immersion condition. *International Conference on the Durability of Concrete Structures*, pp. 282-286.

Manaf, L.A., Samah, M.A.A. and Zukki, N.I.M. (2009). Municipal solid waste management in Malaysia: Practices and challenges. *Waste Management*, *29*(11), 2902–2906.

Mason, S. (2015). UCLA scientists confirm: New technique could make cement manufacturing carbon-neutral UCLA. *UCLA Newsroom*, 1–5.

Mehta, P.K. and Monteiro, P.J.M. (2001). *Concrete microstructure, properties and materials.* Berkeley: University of California.

Meyer, C. (2009). The greening of the concrete industry. *Cement and Concrete Composites*, *31*(8), 601–605.

Ministry of Agriculture Malaysia. (2011). National Agro-Food Policy (online) http: www/moa.gov.my.

Naik, B.T.R., Kraus, R.N. and Siddique, R. (2003). Demonstration of manufacturing technology for concrete and CLSM utilizing wood ash from Wisconsin. *USA: University of Wisconsin*.

Ogork, E.N. and Ayuba, S. (2014). Influence of sawdust ash (SDA) as admixture in cement paste and concrete. *International Journal of Innovative Science, Engineering & Technology*. 1(10), 736–743.

Pang, X. (2007). *Beneficial use of spent mushroom substrate in the construction industry*. Degree of Master of Science Thesis. Villanova University, USA.

Phan, C.W. and Sabaratnam, V. (2012). Potential uses of spent mushroom substrate and its associated lignocellulosic enzymes. *Applied Microbiology and Biotechnology*, *96*(4), 863–873.

Pitroda, J. and Umrigar, F.S. (2008). Evaluation of sorptivity and water absorption of concrete with partial replacement of cement by thermal industry waste (Fly Ash). *ISO Certified International Journal of Engineering and Innovative Technology*, *2*(7), 245–249.

Razak, H.A., Chai, H.K. and Wong, H.S. (2004). Near surface characteristics of concrete containing supplementary cementing materials. *Cement & Concrete Composites 26*, 883–889.

Reddy, M.V.S., Ramana Reddy, K Madan Mohan Reddy and C M Ravi Kumar. (2013). Durability aspects of standard concrete. *International Journal and Civil Engineering Research. 2*(1), 40–46.

Russell, M., Basheer, P.A.M. and Rao, J.R. (2005). Potential use of spent mushroom compost ash as an activator for pulverised fuel ash. *Construction and Building Materials*, *19*(9), 698–702.

Sashidhar, C. and Rao, H.S. (2010). Durability studies on concrete with wood ash additive durability studies on concrete with wood ash additive. *Conference On Our World In Concrete & Structures*. J.N.T.A. University

The Business Year. 2016. It’s all grow (online). https://www.thebusinessyear.com/malaysia-2016/its-all-grow/review (24 October 2016)

The Sun Daily. (2016, February 4)

Udoeyo, F.F. and Dashibil, P.U. (2002). Sawdust ash as concrete material. *Journal of Materials in Civil Engineering*, *14*(2), 173–176.

Udoeyo, F.F., Inyang, H., Young, D.T. and Oparadu, E.E. (2006). Potential of wood waste ash as an additive in concrete. *Journal of Materials in Civil Engineering*, *18*(August), 605–611.

Young, D. and Ellsmore, D. (2008). *Salt attack and rising damp : a guide to salt damp in historic and older buildings*. Australia: Adelaide City Council

Zaffrie, M., Amin, M. and Harun, A. (2014). *Competitiveness of the mushroom industry in Malaysia*, *2009*, 1–5. Selangor: MARDI-UPM.

Zivica, V., Palou, M.T., Krizma, M. and Bagel, L. (2012). Acidic attack of cement based materials under the common action of high, ambient temperature and pressure. *Construction and Building Materials*, *36*, 623–629.

APPENDIX A
COMPRESSIVE STRENGTH RESULT

Normal Concrete

Specimen	Weight, g	Compressive Strength, MPa	Average, MPa
1	2330	51.19	
2	2349	50.94	51.18
3	2339	51.42	

SMCA Concrete

Specimen	Weight, g	Compressive Strength, MPa	Average, MPa
4	2343	45.70	
5	2314	47.11	46.40
6	2234	42.41	

APPENDIX B
WATER ABSORPTION RESULT

Normal Concrete

Specimen	Initial Weight, g	Final Weight, g	Water Absorption, %	Average, %
1	2085.24	2115.45	1.45	
2	2178.19	2202.38	1.11	1.15
3	2192.46	2212.18	0.90	

SMCA Concrete

Specimen	Initial Weight, g	Final Weight, g	Water Absorption, %	Average, %
4	2113.87	2121.59	0.37	
5	2247.40	2254.21	0.30	0.33
6	2221.98	2229.36	0.33	

APPENDIX C1
SORPTIVITY RESULT

Normal Concrete

Sample 1

Oven-dried weight = 2255.94 g

***t*, mins**	***W_2*, g**	**Δ*W*, g**	***Q*, g/g/cm^3**	***A*, cm^2**	***Q/A*, mm**	**√*t*, √min**
1	2257.86	1.92	1.92	100	0.192	1.000
2	2258.31	2.37	2.37	100	0.237	1.414
4	2259.07	3.13	3.13	100	0.313	2.000
8	2261.24	5.30	5.30	100	0.530	2.828
10	2261.63	5.69	5.69	100	0.569	3.162
20	2263.32	7.38	7.38	100	0.738	4.472
30	2264.77	8.83	8.83	100	0.883	5.477
60	2268.16	12.22	12.22	100	1.222	7.746
90	2270.92	14.98	14.98	100	1.498	9.487

Sample 2

Oven-dried weight = 2203.34 g

***t*, mins**	***W_2*, g**	**Δ*W*, g**	***Q*, g/g/cm^3**	***A*, cm^2**	***Q/A*, mm**	**√*t*, √min**
1	2204.32	0.98	0.98	100	0.098	1.000
2	2204.80	1.46	1.46	100	0.146	1.414
4	2205.27	1.93	1.93	100	0.193	2.000
8	2205.91	2.57	2.57	100	0.257	2.828
10	2206.19	2.85	2.85	100	0.285	3.162
20	2207.37	4.03	4.03	100	0.403	4.472
30	2208.46	5.12	5.12	100	0.512	5.477
60	2211.21	7.87	7.87	100	0.787	7.746
90	2213.17	9.83	9.83	100	0.983	9.487

APPENDIX C2
SORPTIVITY RESULT continued

Sample 3

Oven-dried weight = 2239.88 g

***t*, mins**	***W*₂, g**	**Δ*W*, g**	***Q*, g/g/cm³**	***A*, cm²**	***Q/A*, mm**	**√*t*, √min**
1	2241.30	1.42	1.42	100	0.142	1.000
2	2242.01	2.13	2.13	100	0.213	1.414
4	2242.88	3.00	3.00	100	0.300	2.000
8	2244.03	4.15	4.15	100	0.415	2.828
10	2244.58	4.70	4.70	100	0.470	3.162
20	2246.41	6.53	6.53	100	0.653	4.472
30	2247.94	8.06	8.06	100	0.806	5.477
60	2251.69	11.81	11.81	100	1.181	7.746
90	2254.71	14.83	14.83	100	1.483	9.487

SMCA Concrete

Sample 4

Oven-dried weight = 2219.80 g

***t*, mins**	***W*₂, g**	**Δ*W*, g**	***Q*, g/g/cm³**	***A*, cm²**	***Q/A*, mm**	**√*t*, √min**
1	2220.31	0.51	0.51	100	0.051	1.000
2	2220.41	0.61	0.61	100	0.061	1.414
4	2220.57	0.77	0.77	100	0.077	2.000
8	2220.66	0.86	0.86	100	0.086	2.828
10	2220.72	0.92	0.92	100	0.092	3.162
20	2220.77	0.97	0.97	100	0.097	4.472
30	2220.83	1.03	1.03	100	0.103	5.477
60	2220.86	1.06	1.06	100	0.106	7.746
90	2220.89	1.09	1.09	100	0.109	9.487

APPENDIX C3
SORPTIVITY RESULT continued

Sample 5

Oven-dried weight = 2189.53 g

***t*, mins**	**W_2, g**	**Δ*W*, g**	***Q*, g/g/cm^3**	***A*, cm^2**	***Q/A*, mm**	**√*t*, √min**
1	2189.91	0.38	0.38	100	0.038	1.000
2	2190.11	0.58	0.58	100	0.058	1.414
4	2190.16	0.63	0.63	100	0.063	2.000
8	2190.26	0.73	0.73	100	0.073	2.828
10	2190.28	0.75	0.75	100	0.075	3.162
20	2190.32	0.79	0.79	100	0.079	4.472
30	2190.37	0.84	0.84	100	0.084	5.477
60	2190.40	0.87	0.87	100	0.087	7.746
90	2190.45	0.92	0.92	100	0.092	9.487

Sample 6

Oven-dried weight = 2219.50 g

***t*, mins**	**W_2, g**	**Δ*W*, g**	***Q*, g/g/cm^3**	***A*, cm^2**	***Q/A*, mm**	**√*t*, √min**
1	2220.21	0.71	0.71	100	0.071	1.000
2	2220.25	0.75	0.75	100	0.075	1.414
4	2220.28	0.78	0.78	100	0.078	2.000
8	2220.33	0.83	0.83	100	0.083	2.828
10	2220.39	0.89	0.89	100	0.089	3.162
20	2220.43	0.93	0.93	100	0.093	4.472
30	2220.49	0.99	0.99	100	0.099	5.477
60	2220.54	1.04	1.04	100	0.104	7.746
90	2220.58	1.08	1.08	100	0.108	9.487

APPENDIX D
ACID RESISTANCE RESULT

Normal Concrete

Specimen	Initial Weight, g	Final Weight, g	Percentage Weight Lost, %	Compressive Strength, MPa
1	2333.60	2331.43	0.09	43.705
2	2336.99	2334.09	0.12	46.466
3	2396.84	2392.39	0.19	45.018
		Average	**0.13**	**45.063**

SMCA Concrete

Specimen	Initial Weight, g	Final Weight, g	Percentage Weight Lost, %	Compressive Strength, MPa
4	2276.83	2275.91	0.04	47.190
5	2254.52	2252.59	0.09	46.419
6	2330.56	2329.39	0.05	35.664
		Average	**0.06**	**46.805**

APPENDIX E
SULPHATE RESISTANCE RESULT

Normal Concrete

Specimen	Initial Weight, g	Final Weight, g	Percentage Weight Gain, %	Compressive Strength, MPa
1	2332.42	2337.23	0.21	53.086
2	2427.91	2432.25	0.18	47.489
3	2325.40	2329.59	0.18	51.340
		Average	**0.19**	**52.213**

SMCA Concrete

Specimen	Initial Weight, g	Final Weight, g	Percentage Weight Lost, %	Compressive Strength, MPa
4	2382.79	2383.10	0.01	44.349
5	2323.47	2324.50	0.04	55.580
6	2296.28	2297.38	0.05	56.655
		Average	**0.04**	**52.190**

APPENDIX F
CHLORIDE RESISTANCE RESULT

Normal Concrete

Specimen	Initial Weight, g	Final Weight, g	Percentage Weight Gain, %	Compressive Strength, MPa
1	2338.47	2340.33	0.080	48.937
2	2312.75	2314.42	0.072	55.898
3	2312.47	2313.58	0.048	48.559
		Average	**0.067**	**52.418**

SMCA Concrete

Specimen	Initial Weight, g	Final Weight, g	Percentage Weight Lost, %	Compressive Strength, MPa
4	2290.73	2292.49	0.077	49.638
5	2318.06	2319.88	0.079	50.250
6	2309.44	2310.83	0.060	33.023
		Average	**0.072**	**49.944**

APPENDIX G1
PHOTOS OF LABORATORY WORKS

APPENDIX G1
PHOTOS OF LABORATORY WORKS continued