ELUCIDATION OF BLENDED CEMENT USING INDUSTRIAL WASTE

RDU1703119

UNIVERSITI MALAYSIA PAHANG

48T

ABSTRACT

Urban population of Malaysia is stated as 72.8% of its total population, and growing every year. Due to this growing number of population, the sewage sludge waste produce every year has also gradually increased. Malaysia itself produces 3.2 million m^3 of sewage sludge annually. Normally all of this waste is disposed by landfill. This was a serious threat to the environment due to the toxic content of sewage sludge if it is dump away without proper measures. The increasing rate of production of sewage sludge waste has called for an alternatives way to develop good quality of construction material from waste resources. Furthermore, usual production of cement and sewage sludge ash consumes a lot of energy by using incineration process with a very high temperature. Thus microwave heating method was an alternatives use in this research to reduce the consumption of energy and time used to heat the sewage sludge ash. This research was conducted to investigate the optimum performances of different percentage (0%, 5%, 10%, 15% and 20%) by weight of cement of the Microwaved Sewage Sludge Ash (MSSA) concrete with different curing regime, which was air and water curing, its mechanical properties and also durability properties. The characteristic of MSSA was tested by X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). The mechanical properties of MSSA concrete was examined by Compressive Strength test, Flexural Strength test and Modulus of Elasticity test after 180 days of curing. While, the Durability properties of the MSSA concrete were identified by using Acid attack test, Sulphate resistance and water absorption test. Based on the results, water curing with 5% of MSSA had the best in results compared to other specimens. The mechanical properties of 5% MSSA content in concrete shows the most optimum samples due to the densification of pozzolanic reaction and filler effect of MSSA. The lowest mechanical performance was 20% MSSA. The curing effect with better result was water curing, as it got highest value of strength in compressive test, flexural test and modulus of elasticity test. Water curing with 5% MSSA also shows best in durability resistance towards sulphate and acid attack. As for water absorption test, all of the specimen shows better result as it is below than 10% rate of absorption. As conclusion, based on the results, it is shown the positive impact on using the MSSA as additional material to the cement mixture to improve the quality of the concrete. Thus, this will reduce the disposal of sewage sludge ash waste on dumping site and improves the quality performances of the concrete.

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

Malaysia is one of the developing countries that have rapidly growing number of population through the urbanization phenomenon. In 2011, urban population of Malaysia is stated as 72.8 % of its total population and growing from 2010 to 2015 with annual rate of change of 2.49% (Central Intelligence Agency, 2014). With this growing number of population, the waste generated every year has also gradually increased and concern to pose challenges on the environmental sustainability (Roslan, Ghazali, & Muhamed Asli, 2013). One of the major concern is on the effective management of the solid waste includes excessive sewage sludge from municipal wastewater treatment plant. Each person produces about 1 kg of solid waste per day and the waste production rate is increasing at 15% per year due to urbanization and population growth (Chin, Kusbiantoro, Wong, & Ahmad, 2016). High moisture, complex constituents and characteristic are the difficulties faced in handling and managing the wastewater sewage sludge (Bonfiglioli, Bianchini, Pellegrini, & Saccani, 2014). If the issues on unmanageable excessive sewage sludge continuously happen without any measures, it can cause serious impacts on health and problems to the surrounding environment.

Concerns towards the excessive and unused waste issues in Malaysia, various types of disposal method are used to help government in reducing it such as, land filling, open burning, incineration and also recycling. Nevertheless, the solid waste in Malaysia is managed or disposed through landfill and partly to recycle. Although there are methods to consolidate, dewater and stabilize the sludge, but most of the sludge is end up to be disposed by landfill. However, landfill is only a temporary solution for the disposal of sewage sludge because of the limitation space of the landfill area. Sewage sludge landfills area has also increasing the environmental concern on groundwater pollution, odour emission and also soil contamination that gives threat to pollution problems (Chin et al., 2016). There are 154 landfill areas operating and 35568 tons of waste is produced per day in Malaysia with the growth rate of 3.59 % per year (JPSPN, 2017).

The use of sewage sludge ash as the additional material in producing concrete may minimize the effect on environmental pollution. The major components of sewage sludge make it functioned as pozzolanic material because when finely ground, it is found to be cementitious (Yusuf, Abba, & Noor, 2016). The construction industries nowadays are looking for the alternative products that can reduce the construction cost. The sewage sludge is potentially reused to produce mortar, concrete, brick and pavement (Naamane, Rais, Taleb, Mtarfi, & Sfaira, 2016). With the current rate of urbanization, it is expected that the demand of concrete in construction industries will increase further. Thus further research should be conducted to investigate on the usage of sewage sludge ash as additional material in concrete for structural use.

1.2 Problem Statement

The presence of heavy metal in the sewage sludge composition is one of the major concerns that may lead to the environmental issues. The disposal process for the sewage sludge was very particular and must be treated before it can dispose. It is necessary to burn the sludge to remove the heavy metals form the materials. The conventional method in burning the sludge is by using the incineration process and produced the Sewage Sludge Ash. This method required high energy consumption and also need longer time to burn the sludge. Although the temperature of burning influences the properties of Sewage Sludge Ash, this method is not economical where it use high amount of electricity. The temperature of incineration applied by Zeedan, 2010 to produce SSA is at 650°C and 850°C for 4 hours. Meanwhile, Lin et al. 2008 prepared the SSA sample by oven dried the sewage sludge at 105°C for 24 hours and incinerate it at temperature between 600°C and 1000°C. Whereas, Chen et al. 2006 incinerated the sewage sludge samples from 25°C to 900°C at a rate of 10°C per min. Therefore, the idea of using microwave burning method in burning the sludge has a huge potential to be used to replace the conventional method.

The excessive amount of wastage gives challenge in dumping the waste without effecting the environment and polluted to nature. Nowadays, the large amount of waste produced by water treatment plant has overloaded the landfill, not to mention other waste from different sources. (Chin et al., 2016) stated that Malaysia has limited landfill site. Based on the constituents removed by effluent treatment, sludge is by far the largest in volume. Therefore the handling methods and disposal techniques are matter of great concern. Meanwhile, the research on sewage sludge waste in Malaysia is not as much as foreign country. There are abundances of research conducted in foreign country on application of sewage sludge as construction materials gives positive results.

As the highly demand of concrete production for construction project, the usage of the non-renewable resources consumed in concrete production in producing good quality must be concerned also. This research that use Microwaved Sewage Sludge Ash as additive in the concrete production will not only reducing the dependence on non-renewable resources but also reducing the wastage exceeded every year produce by sewage treatment plant. Utilization of sludge as an addition to construction and building material is a win–win strategy because it not only converts the wastes into useful additive material in construction industry but it also alleviates the disposal problems (Yusuf et al., 2016).

1.3 Objectives

The main objective of this research is to investigate the mechanical properties and durability of the concrete that contains Microwaved Sewage Sludge Ash (MSSA) as additional component to concrete mixture. In order to achieve the required outcome, the research objectives are summarized:

i. To identify the optimum performance of concrete containing Microwaved Sewage Sludge Ash (MSSA) in concrete.
ii. To investigate the mechanical properties of concrete contains Microwaved Sewage Sludge Ash (MSSA) in terms of compressive strength, flexural strength and modulus of elasticity under various curing regimes.

iii. To determine the durability properties of the Microwaved Sewage Sludge Ash (MSSA) concrete in terms of water absorption, acid attack and sulphate resistance.

1.4 Scope of Research

The scope of work for the research is important to satisfy the objectives introduced. This study will focused on the usage of sewage sludge ash as addition to the concrete mixture. A preliminary analysis will be test on the characterization properties of Raw Sewage Sludge Ash and Microwaved Sewage Sludge Ash (MSSA).A number of trial mix will also be done to determine the optimum temperature for microwave heating and optimum water cement ratio to be used in this research

The raw sewage sludge taken from Indah Water Consortium Kuantan Branch, were undergo 24hours of normal oven dried process at 105ºC to make sure it is completely dry before it then incinerated using microwaved burning method with three different temperature which are medium, medium high and high temperature. The optimum temperature of the MSSA will be decided based on the chemical composition analysis using X-Ray Fluorescent test, test on the weight loss of the MSSA after the burning process and also testing on the morphology analysis of the MSSA sample using Field Emission Scanning Electronic Microscope (FESEM).

In order to determine the most optimum percentage of MSSA as additive in the concrete, batches of concrete mix with various percentage of MSSA (5%, 10%, 15% and 20%) with targeted 30MPa compressive strength were casted. The best performance of MSSA concrete was selected based on their compressive strength by compared with control mix concrete result. The effect of curing regimes namely water curing and air curing on the mechanical properties of the concrete specimen were investigated at 3, 7, 28, 60, 90 and 180 days.

Slump test will be performed to determine the workability of the concrete which comply the BS 1881: Part 102. The analysis of the concrete specimens was divided into two groups which is durability test and mechanical test. The mechanical properties test involves compressive strength, flexural strength and modulus of elasticity while durability properties compromise acid attack, sulphate resistance and water absorption.

1.5 Research Significance

The usage of waste materials in construction industry will preserve non-renewable natural resources and reducing amount of waste to be dump into landfill. Through this research, the properties and characterization of MSSA will clearly determine. The optimal percentage of MSSA addition in concrete will be reveal based on the result from the mechanical and durability performance of the concrete subjected to different curing regime. The mechanical strength achieved in this research is able to shows the capability of additional MSSA in concrete to sustain load while the durability test will evaluate the resistance of this concrete toward water and other soluble chemical.

In a nutshell, this research can be a mile stone for future researcher to investigate further into the application of Microwaved Sewage Sludge Ash in concrete production. This research is also the alternative method for the problems of sewage sludge disposal method where it can resolve the space limitation in landfill. Furthermore, this research is also the pioneer of introducing the microwave heating method on sewage sludge drying method which is more efficient compare to conventional heating method in term of time and energy consumption.

1.6 Thesis Outline

There are total 7 chapters in the proposal which are consists of Introduction, Literature Review, Methodology, basic properties of MSSA concrete, mechanical properties analysis, durability analysis, and also conclusions & recommendations . The first chapter will focus on the introduction part which explaining about the purpose of the research, the problem statement of the research, scope of the research, significance of the research and also the lay out of the proposal.

Next, follows by Chapter two which highlight on literature review part of the Microwaved Sewage Sludge Ash as the material addition in concrete, its production, as well as its properties. Furthermore, the mechanical and durability properties of the concrete which is compressive strength, flexural strength, the modulus of elasticity, acid attack, sulphate resistance and water absorption also will be discussed further in this chapter. Chapter two will conclude with the summary of research gap.

Chapter three will explains the methodology of this research project. This chapter will describe how was the research will be carried out in term of material preparations, method and testing standards used and also how was the experimental work was conducted. Furthermore, the method for characterization test for the Microwaved Sewage Sludge Ash will also be discussed in this chapter includes the X-Ray Diffraction Test, X-Ray Fluorescent test, and also Scanning Electronic Microscopy test. The mixture design method used to obtained trial mix that used in the test for the concrete specimen will also discuss in this chapter.

Next chapter will focus on the basic properties of MSSA concrete where the preliminary analysis of the Microwaved Sewage Sludge Ash (MSSA) will be conducted. This chapter is very important where the properties of MSSA studies will really effects the mechanical and durability properties of the research. The optimum trial mix slump test result of the trial mix also will be shown in this chapter.

Chapter five will discuss the results of the analysis of mechanical properties of the MSSA concrete, including the properties of fresh concrete. Compressive strength, flexural strength, modulus of elasticity analysis of the results will be shown in this chapter. In this chapter also will be discussed on the relationship between compressive strength and flexural strength and also the relationship between compressive strength and modulus of elasticity analysis.

As same as chapter five objectives, this chapter will also discuss on the results but in the durability aspect of the concrete. This chapter will show the results of water absorption test, acid attack and sulphate resistance test. The acid attack will discuss the effect in term of strength, mass loss and visual observation after sinking the concrete in acid solution. The sulphate resistance will also test the concrete effect after sinking the concrete cube in sulphate solution.

Last chapter will conclude all the results that have been done in this research. The conclusion will be made clearly in details based on the results. Several recommendations will be made for further research purposes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review is the past relevant studies on the proposed materials which concern to the topic and objectives of this research. The information and data from the past literature were summarized in this chapter where the scope of study in this research can be set. In this chapter, component of concrete, additional waste material used in concrete mixed, mechanical and durability properties of concrete are present. At the end, the summary of research gap and how the current research will fill in the gap.

2.2 Concrete

Concrete is a composite of cement, aggregate and water in a suitable mix proportion. Its raw material has high availability and the characteristic of durability and able to form in many dimension gives it advantage as the primary material in construction (Poon, 2014). The development of country is the main factor of increasing of concrete usage especially in infrastructure systems (Henry & Kato, 2012). In addition, concrete is employed as construction material to resist high compressive stresses in a structure as it exhibits higher performance in compressive strength (Abd Elaty, 2014).

The global environmental issue is also highlighted in concrete industry and new technology is invented to reduce environmental impact. In Nordic countries, a centre of green concrete is established in Denmark to face the challenges of environmental impact. Meanwhile, Norway supported this action by creating the online database and documentaries for green concrete (Henry & Kato, 2012). The green technology in production of concrete and construction is very popular and encouraged in construction sector. Besides, construction industry is affected by its sustainability issue. There are few methods to reduce environment impact which are to increase the performance and lifetime of concrete (Müller, Haist, & Vogel, 2014). Concrete also has its sustainable advantages such as resource efficient, long span life and carbon absorption (Hooton & Bickley, 2014).

2.2.1 Ordinary Portland Cement

Cement is defined as materials that have adhesive and cohesive properties which enable it to bond material fragments into compact whole. In construction, the term of cement will defined as the material that enables the binding of materials that creates concrete mixture which consists of coarse and fine aggregates, water and also cement itself (Naidu & Pandey, 2014). Cement also function in fill voids in between sand and coarse aggregate particles to form a compact mass of concrete.

There are various types of cement with different mixed composition in production in industry. Ordinary Portland Cement (OPC) is one of the most common types of cement that have general usage in construction field. OPC is hydraulic binder that obtained from limestone and clay and traditionally used for building in construction. Portland cement is also known as hydraulic cement which the cement not only hardens by reacting with water but also forms a water-resistant product that produced by pulverizing clinkers consisting essentially of hydraulic calcium silicate. The hydration process of the Portland cement results in hardening and increment strength gain when mixed with water.

The ASTM has designated five types of Portland cement, designated Types I-V. Physically and chemically, these cement types differ primarily in their content of C_3A and in their fineness. In terms of performance, they differ primarily in the rate of early hydration and in their ability to resist sulphate attack. The general characteristics of these types are listed in Table 2.1.

Table 2.1 General features of the main types of Portland Cements

	Classification	Characteristic	Application
Type I	General purpose	Fairly high C_3A content for good early strength	General construction (most buildings, bridges,

		development	pavements, precast units, etc.)
Type II	Moderate Sulphate resistance	Low C_3A content (< 8%)	Structures exposed to soil or water containing sulphate ions
Type III	High Early Strength	Ground more finely, may have slightly more C_3S	Rapid construction, cold weather concreting
Type IV	Low heat of hydration (slow reacting)	Low content of C_3S (<50%) and C_3A	Massive structure
Type V	High Sulphate Resistance	Very low C_3A content (<5%)	Structures exposed to high levels of sulphate ions
White	White Colour	No C_4AF, low MgO	Decorative (otherwise has properties similar to Type I)

Source: (The Science of Concrete 2015)

2.2.2 Fine aggregates

Durability of concrete is also one of the concerns in construction industry. In concrete mixing, aggregate is the contributor of durability of concrete which has chemical resistance and high density (Poon, 2014). Fine aggregate has also the role of filling the voids between coarse aggregate to act as workability agent. The voids determine the density and strength of concrete (Zhang & Shahsavari, 2016).

Natural sand is the common fine aggregate that used in concrete production resulting from natural disintegration of rocks, while crushed stone is the fine aggregates that produced by crushing the hard rocks or natural gravel. Fine aggregate is the material that passes through a 4.75mm BS 410 Test Sieve. Sand is the material that generally considered have lower size limit of about 0.07mm. Material sized between 0.06mm and 0.002mm is already classified as silt and smaller particles are classified as clay. Sand may described as two types which is natural sand and crushed stone. The purposes of the fine aggregate are basically to fill the voids in the coarse aggregate and to act as a workability agent in concrete mixture. If the fine aggregate is round shaped, the workability will be increased as reflected by use of less cement. Table 2.2 shows the grading of fine aggregate by Public Work department (JKR).

Table 2.2 Grading of fine aggregate

Sieve Size	Percent Passing by Weight (%)
3/8 in. (9.5 mm)	100
No. 4 (4.75 mm)	95 to 100

No. 8 (2.36 mm)	80 to 100
No. 16 (1.18 mm)	50 to 85
No. 30 (600 μm)	25 to 60
No. 50 (300 μm)	10 to 30
No. 100 (150 μm)	2 to 10

Source: Jabatan Kerja Raya (2005)

2.2.3 Coarse aggregate

Coarse aggregate is important to make sure the concrete mixture reach the desired strength. Coarse aggregate is the major determinant in the contribution of concrete durability (Zhao, Sun, Wu, & Gao, 2012). The form must be nearly rounded and the surface must be rough to produce a strongest concrete. To avoid such kind of spaces, aggregates shape is a main factor and if aggregates voids are minimized, the amount of cement paste required to fill those voids also minimized maintaining workability and strength. Furthermore, (Wu, Chen, Yao, & Zhang, 2001) states that the mechanical behaviour of concrete can be affected by the type of coarse aggregate used due to their natural properties such as strength, brittleness, proper texture and mineralogical characteristics

There is relationship between the voids of aggregates and shape, texture and grading of aggregates. In rounded, cubical and well graded particles exhibits lower void content than flaky, elongated and angular aggregates. Roundness and angularity are the important characteristics of aggregates. Roundness is the outline of the particle and it may be measured in terms of convexity where angularity indicates the sharpness of the edges and corners. Nonetheless, flaky and elongated particles can produce harsh mixtures and seriously effect in workability. An excess of poorly shaped particles could decrease the strength of concrete through the increase of water demand. Additionally, flat particles can be oriented in such a way that they could impair the strength and the durability of concrete. So from that it is clear that crushing type of aggregates definitely has effects on properties of concrete because crushing type of aggregate can change and control the shape factor directly (Muhit, Haque, & Rabiul Alam, 2013).

Coarse aggregate are any particles larger than 4.75 mm or retained on sieve no. 4, but generally range from 9.5 mm to 37.5 mm in diameter. Types of coarse aggregate widely used by construction industry in Malaysia are granite, limestone, sandstone and basalt. Granite is the most common igneous rock where it comes from hardened magma on the ground surface. Limestone is the result of crushing of sedimentary rock which consists mainly of calcium carbonate ($CaCO_3$). Sandstone is another type of sedimentary rock which contains cementing material to bind the sand grains together.

2.2.4 Water

Water may be one of the most essential components in the concrete preparation. Since water may be required to those hydration method to the cement to produce concrete. There should be sufficient amount of water to complete the hydration process. Thus, the water-cement proportion will be extremely critical factor throughout the concrete mix design in produce appropriate concrete.

However, too less amount of water in the concrete mix will provide no sufficient quantity of water to complete the hydration process, yet some of the cement might be harden and bond with dry cement furthermore transform the concrete become fragile and brittle. Excessively amount water included of the concrete blend might make the condition of the concrete turned into slurry and makes the bond between cement and aggregated infected. Therefore, excessively water on the concrete blend will diminish the quality of the concrete. Likewise those result, the hydration procedure might finished, however it will give little strength of the last stage concrete (Arel, 2016)

The determination of water to be used in the concrete production should consider the source of the water. Since the quality of the water is directly have an effect on the hydration system as well as the ultimate stage of the harden concrete. Basically, the water that used in the concrete manufacturing not often incorporate more than 2000ppm dissolved solid. Thus, the type of water that used in the concrete mixing process in the testing program was normal tap water.

2.3 Sewage Sludge

Sewage sludge is the by-product from municipal waste such as human excreta, commercial waste, industry waste, agriculture waste, rainwater runoff and biological waste material (Roslan et al., 2013). The municipal waste is carried to the sewage treatment plant through sewer to be treated. After treated, the sewage sludge will be dried at the sludge bed. The dried sewage sludge becomes a waste and either disposes to the landfill or being burned in incinerators (Roslan et al., 2013). (Usman, Khan, Ghulam, Khan, & Khan, 2012) defined sewage sludge as a rich source of organic nutrients, which is high concentrate of organic matter, macro and micro nutrient. Sewage sludge is a good source of micro/macronutrients for plants besides its richness in organic matter. Table 2.3 shows the different types of sewage sludge and the method of handling.

Table 2.3 Type of sewage sludge and its characterization

Sewage Sludge	Method and Characterization
Liquid sludge	Containing 2% to 7% of dry solid and 75% of the solid is organic matter
Untreated sewage cake	Dewatered of liquid sludge, consistency similar to soil
Conventionally treated sludge	Subjected to digestion, where 99% of microbiological content are removed
Enchanted treated sludge	Pathogen is eliminated, sludge is in form of granules where 98% if dry solid

Source: (Usman et al., 2012)

2.3.1 Disposal of Sewage Sludge

After treatment, and dependent upon the quality of sludge produced (for example with regards to heavy metal content), sewage sludge is most commonly either disposed of in landfills or applied to land. Bio-solids are the term widely used to denote the by-product of domestic and commercial sewage and wastewater treatment. National regulations that dictate the practice of land application of treated sewage sludge differ widely and e.g. in the US there are widespread disputes about this practice. Depending on their level of treatment and resultant pollutant content, bio-solids can be used in regulated applications for non-food agriculture, food agriculture, or distribution for unlimited use. Treated bio-solids can be produced in cake, granular, pellet or liquid form and are spread over land before being incorporated into the soil or injected directly into the soil by specialist contractors. It used to be common practice to dump sewage sludge into the oceans. However, this practice has stopped in many nations due to environmental concerns as well to domestic and international laws and treaties.

(Khuder et al., 2007) in his research shows the results of the health survey of residents living near sludge disposal land has revealed that some reported health-related symptoms were statistically significantly elevated among the exposed residents, including excessive secretion of tears, abdominal bloating, jaundice, skin ulcer, dehydration, weight loss, and general weakness. The frequency of reported occurrence of bronchitis and upper respiratory infection were also statistically significantly elevated. The fin dings suggest an increased risk for certain respiratory, gastrointestinal, and other diseases among residents living near farm fields on which the use of bio-solids was permitted. Although correlation does not imply causation, such extensive correlations may lead reasonable people to conclude that precaution is necessary in dealing with sludge and sludge farmlands.

2.3.2 Properties of Raw Sewage Sludge

Sewage sludge tends to accumulate heavy metals existing in the wastewater. The compositions of sewage sludge and its content of heavy metals vary widely depending on the sludge origins and treatment options. The preliminary findings found that Malaysia domestic wastewater sewage sludge contains subsequent properties (Rosenani, Kala, & Fauziah, 2008). This is found through the various experiments which were through some analysis as shown in Table 2.4.

Table 2.4 Properties of Malaysian Domestic Wastewater Sewage Sludge

Analysis	Properties (%)
Proximate analysis	Moisture Content : 12% Volatile Matter : 48.86% Fixed Carbon : 19.32% Ash Content : 31.86%
Ultimate analysis	Carbon : 33.01% Hydrogen : 4.97% Nitrogen : 5.52% Sulphur : 1.18%

Sources: (Abbas, Ibrahim, Nor, & Aris, 2011)

(Rosenani et al., 2008) also recorded that the sewage sludge from Malaysia is acidic and contains high amount of heavy metal. The acidic properties of sewage sludge have an average low pH level which is about 4.9, 3.6 and 4.0 at different area in her research which is Bungor, Serdang and Jawa. Furthermore, according to the working document of sewage sludge, two main types of pollution by sewage sludge were identified; heavy metals and certain groups of organic compound (Rizzardini & Goi, 2014). The presence of heavy metals such as Zn, Cu, Ni, Cd, Pb, Hg and Cr is restricting the use of sludge for agricultural purposes. In general, Cd, Pb and Zn represent the biggest concentrations of heavy metals in sewage sludge from domestic wastewaters which can be a source of pollution for soils (Chin et al., 2016).

The X-ray Diffraction Test (XRD) that has been done by (Kang, 2015) shows that mainly components of sewage sludge are quartz (silicon dioxide, SiO_2), phosphorus pentoxide (P_2O_5) and iron oxide (Fe_2O_3). The peak of XRD patterns is at 27° with intensity of 92 cps, which is silicon dioxide, followed by silicon dioxide and phosphorus pentoxide at 21° with 33.21 cps. Raw sewage sludge sample in this research consist of high amount of quartz as shown in Figure 2.1. (Tantawy, Abdalla, & Abdelzaher, 2012) and (Jamshidi, Jamshidi, Mehrdadi, Shasavandi, & Pacheco-Torgal, 2013)both indicated that the main phase of sewage sludge is quartz.

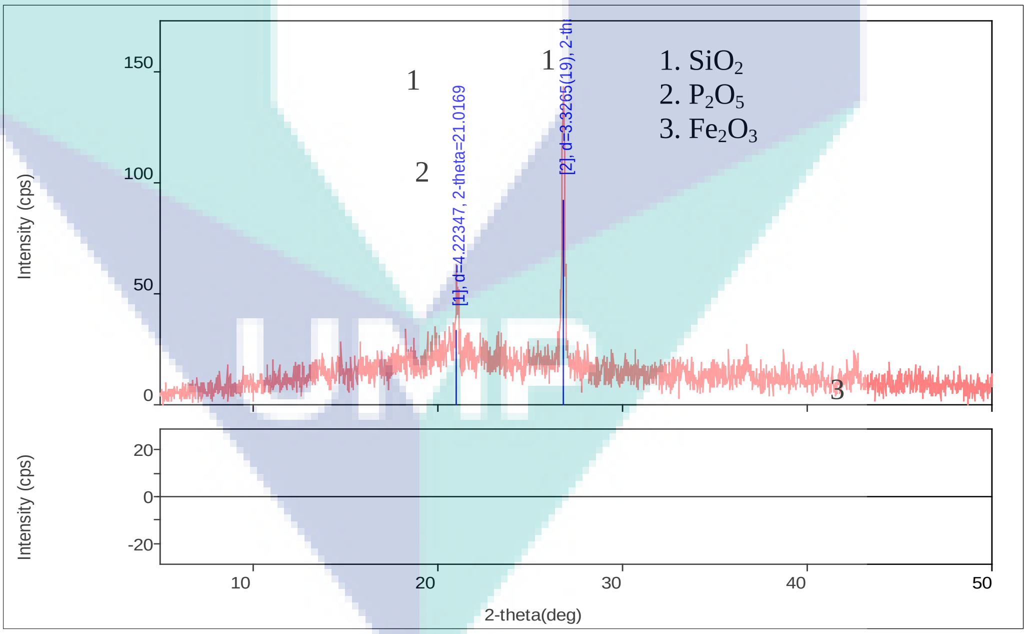

Figure 2.1 XRD pattern of Raw Sewage Sludge

Sources: (Kang, 2015)

Next, the X-Ray Fluorescent (XRF) test summary in the Table 2.5 shows the content of elements in raw sewage sludge. Sewage sludge contains primarily the elements Silicon (Si), Iron (Fe), Aluminium (Al), Phosphorus (P), followed by heavy metals such as Sulphur(S), Titanium(Ti), Zinc(Zn), Barium(Ba), Copper(Cu) and Manganese (Mn). With the small content of Silicon, the process of burning in the high temperature like incineration and microwave heating method may produce more silicon which is the main component that is responsible for pozzolanic activity in cementitious material.

Table 2.5 XRF Test for element content in Raw Sewage Sludge

Element	Percentage (%)
Silicon (Si)	4.82
Iron (Fe)	12.07
Aluminium (Al)	1.59
Phosphorus(P)	4.85
Calcium (Ca)	2.76
Sulphur (S)	1.35
Potassium (K)	0.49
Titanium (Ti)	0.36
Magnesium (Mg)	0.17
Zinc(Zn)	0.40
Barium (Ba)	0.12
Copper (Cu)	0.05
Manganese (Mn)	0.05
Chlorine (Cl)	0.14
Lead (Pb)	0.04
Bromine (Br)	0.04
Chromium (Cr)	0.03
Nickel (Ni)	0.01
Rubidium (Rb)	0.01
Zirconium (Zr)	0.03
Strontium (Sr)	0.03

Sources : (Chin et al., 2016)

2.3.3 Properties of Incinerated Sewage Sludge ash

Incineration is the process of high temperature burning on the municipal solid waste to produce ashes, which reduce the volume and organic content of the waste. Sewage sludge ash (SSA) is the residue of sewage sludge through incineration process. Sewage sludge reacts with oxygen under high temperature and forms oxide elements. According to (M. Chen, Blanc, Gautier, Mehu, & Gourdon, 2013) high porosity of SSA altered the mechanical properties of cementitious material. Superplasticizer is recommended to use to compensate this negative characteristic

Another main property of sewage sludge ash is the content of heavy metal which can cause deterioration to the cement based material and heath issue. Incinerated Sewage Sludge Ash (ISSA) may comprises high content of sulphur and presences of toxic metal such as Cr, As, Hg, Ni, Pb and Zn. Barbosa & Filho (2004) determined the presence of heavy metal in SSA as shows in Table 2.6.

Table 2.6 Content of heavy metal

Species	ISSA (mg/l)	Species	ISSA (mg/l)
Ba	< 0.01	Chloride	60.2
Pb	< 0.015	Na	7.71
Ag	< 0.03	Sulphur	2442
Se	< 0.01	Cu	< 0.002
Fluoride	< 0.1	Zn	<0.002
Cr	0.02	Mn	0.698
Fe	< 0.02	Al	<0.05
Hardness	2500	Cd	NA
Nitrate	0.4	Hg	NA

Source: (Barbosa & Filho, 2004)

Meanwhile, (Kae Long Lin, Chiang, & Lin, 2006) identified the present of quartz (SiO_2), P_2O_5 and (hematite) Fe_2O_3 in the SSA. The pattern of XRD analysis also shows the present of $AlPO_4$ and Al $(OH)_3$ in SSA. (Kae Long Lin et al., 2006) shows the main crystalline component in SSA is Al_2O_3, SiO_2, and Fe_2O_3. Furthermore, (Kae Long Lin et al., 2006) also indicated that the cement paste with sewage sludge ash replacement has the similar main component as Ordinary Portland Cement which is C_3S, C_2S, C_3A, and C_4AF. This shows that ISSA might have binder properties as cement. In addition, heavy metals such as Cr, Zn, Ni and Cu can be found in the formation phase when the replacement of sewage sludge ash into the cement paste is more than 5%.The XRD pattern acquired by (Kae Long Lin et al., 2006) is shown in Figure 2.2.

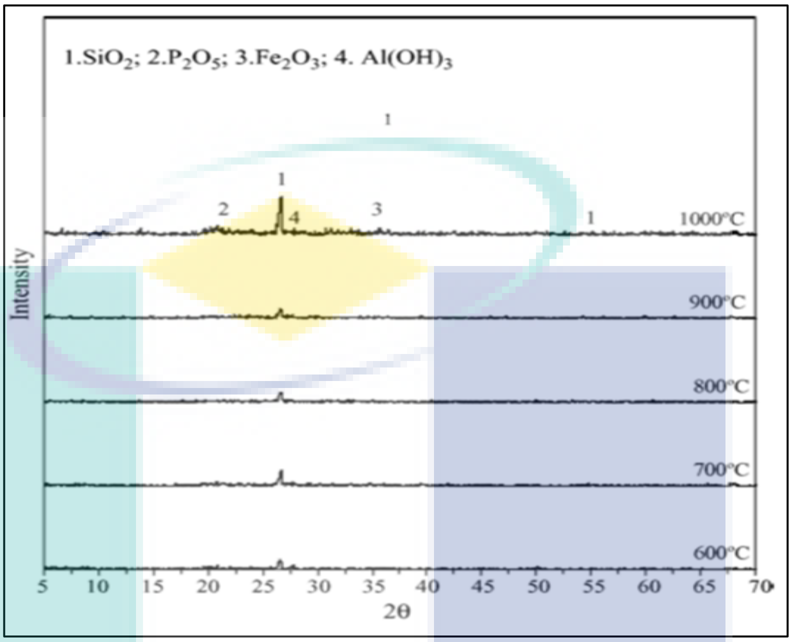

Figure 2.2 XRD Pattern of sewage sludge ash at different sintered temperature
Sources: (Kae Long Lin et al., 2006)

X-ray Fluorescence or XRF analysis is carried out to identify the chemical composition of an object. The chemical composition such as oxide and element can determine the characterization of the ISSA. Table 2.3 shows the summary of the ISSA chemical composition determined by different researchers. The temperatures of burning of ISSA in the following journal are ranging from 550°C to 900°C. From Table 2.7, it was found that the most abundant component presences in SSA are SiO_2, CaO, Al_2O_3, Fe_2O_3, P_2O_5 and SO_3. The incineration process of sewage sludge at high temperature triggers the formation of the oxide in SSA. After the burning process of sewage sludge, the main oxide of SSA will be formed. The main chemical compositions in SSA are similar with the major content of cement, SiO_2, Al_2O_3 and CaO. This can be evident that the partial replacement of SSA to cement is possible.

Table 2.8: Result of XRF Analysis

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	P_2O_5
Author					
(Cyr, Coutand, & Clastres, 2007)	34.2	12.6	4.7	20.6	14.8
(Pan, Tseng, Lee, & Lee, 2003)	50.6	12.8	7.21	1.93	1.67
(Monzó et al., 2003)	20.8	14.9	7.4	31.3	NA
(Baeza et al., 2014)	19.2	8.9	10	30.6	12.3
(Barbosa and Filho, 2004)	39.02	19.09	12.48	10.12	4.94
(Monzó, Payá, Borrachero, & Peris-Mora, 1999)	20.8	14.9	7.4	31.3	6.7
(Kosior kazberuk, 2011)	34.68	6.32	10.32	15.42	18.17
(Baeza Brotons et al., 2014)	17.27	9.64	8.52	30.24	14.25
Mean	29.57	12.39	8.50	21.44	10.40
Max	50.6	19.09	12.48	31.3	18.17
Min	17.27	6.32	4.7	1.93	1.67

Table 2.8: Continued

Oxide	SO_3	Na_2O	K_2O	TiO_2	MgO	MnO
Author						
(Cyr et al., 2007)	2.8	1	1.7	0.9	1.9	0.06
(Pan et al., 2003)	2.38	0.32	1.7		1.48	NA
(Monzó et al., 2003)	10.7	NA	NA	NA	2.2	NA
(Baeza et al., 2014)	11.1	0.8	1.4	1	NA	NA
(Barbosa and Filho, 2004)	6.38	1.26	1.76	NA	1.89	NA
(Monzó et al., 1999)	12.4	NA	NA	NA	2.6	NA
(Kosior kazberuk, 2011)	0.6	0.7	1.3	0.41	2.65	NA
(Baeza Brotons et al., 2014)	8.95	0.94	1.28	0.92	3.22	0.07
Mean	6.91	0.84	1.52	0.81	2.28	0.07
Max	12.4	1.26	1.76	1	3.22	0.07
Min	0.6	0.32	1.28	0.41	1.48	0.06

Sources: (Baeza-Brotons et al., 2014; Baeza et al., 2014; Barbosa & Filho, 2004; Cyr et al., 2007; Kosior-kazberuk, 2011; Monzó et al., 1999, 2003; Pan et al., 2003)

2.3.4 Pozzolanic Activity in Sewage Sludge Ash

Pozzolan is siliceous or siliceous and aluminous material that can react with calcium hydroxide in the present of water to form compound with cementitious properties. The X-ray Diffraction (XRD) pattern from (Zeedan, 2010) shows that sewage sludge ash is an amorphous that consist of pozzolan component such as SiO_2 and Al_2O_3. While (Cyr et al., 2007) concluded that SiO_2 and Al_2O_3 are responsible for the pozzolanic activity in the cement based materials. However, the pozzolanic activity of SSA is relatively low as compared to other common pozzolans for example fly ash. (Pan et al., 2003) found that strength activation index (SAI) of SSA when added to Portland cement is between 56.7% to 67.2% at the same time SAI of F-class fly ash is between 96% to 134%. Sewage sludge ash has average strength activation index which enable them to be applied into normal cement based material.

(Tantawy, El-Roudi, Abdalla, & Abdelzaher, 2013) determined the chemical composition of the sewage sludge ash and compared it with the Ordinary Portland Cement (OPC). From the result obtained by (Tantawy et al., 2013), it can be concluded that sewage sludge ash consist of high amount of silicon dioxide (SiO_2) which is function as pozzolan after the early hydration process. However, the result suggested that sewage sludge ash may consist of respectively low calcium oxide (CaO) content which is the main oxide for early strength development in OPC.

Table 2.8: Chemical composition of OPC and sewage sludge ash

Material	Silicon Dioxide (SiO_2)	Aluminium Oxide (Al_2O_3)	Iron Oxide (Fe_2O_3)	Calcium Oxide (CaO)
OPC	20.88	6.08	3.18	63.00
Sewage sludge Ash	53.90	9.13	8.05	6.80

Source: Tantawy et al. (2013)

The hydration of calcium oxide (CaO) makes cement provide structural strength to the concrete. Calcium oxide (CaO) or limestone takes part in hydration reaction of the cement paste and develop strength in cement at the early stage. Besides, a reaction between $CaCO_3$ of limestone and aluminate phase of cement (C_3A) takes place. Due to the insufficiency of the limestone in SSA, makes the replacement of SSA as cement only can be done partially. The partial replacement of SSA into mortar may cause the loss of compressive strength at the early stage because the pozzolanic activity only occurs after the hydration of cement with water. The early strength of the mortar with SSA replacement needed to be studied because it is important during the removal of mould. Insufficient early strength may cause the structure to collapse. (Luo, Chang, & Lin, 2009) recorded that when the replacement of sewage sludge ash more than 20%, half of the compressive strength will be reduced. The pozzolanic activity fails to occur when too much SSA is replaced into the cementitious material.

2.3.5 Sewage Sludge Ash in Concrete Production

Sewage sludge nowadays has been claimed as useful building construction materials by many researchers. Components of sewage sludge ash such as SiO_2, CaO, Al_2O_3, and Fe_2O_3 are the oxides which play an important role in carry out pozzolanic reactions. The fineness effect also effect on the pozzolanic activity of sewage sludge. Milled Sewage Sludge Ash has improved pozzolanic activity when the Strength Activity Index (SAI) and Frattini Test were Applied (Donatello, Cheeseman, Tyrer, & Biggs, 2006). When Sewage Sludge Ash (SSA) fineness was $500m^2/kg$, the initial and final setting time of SSA-cement paste was about 3 and 4 h respectively. However, the typical initial and final setting of Ordinary Portland Cement (OPC) paste occurs in 2-4 and 5-8 h respectively (Yusuf et al., 2016).

Another researcher (Garcés et al., 2008) conducted the experiment with 10%, 20% and 30% cement replacement with SSA by weight in term of workability, mechanical strength, porosity and shrinkage. He has concluded that the 10% replacement of SSA produced the highest compressive strength compare to other percentage of replacement but similar or slightly lower than the control mortar. However, the result with 10% SSA replacement satisfied the mechanical requirement in accordance to European standard in terms of early compressive strength and nominal compressive strength. Research by (Ing, Chin, Guan, & Suil, 2016) and (Naamane et al., 2016) in their research on incinerated SSA also has shown the similarity finding where 5% up to 10% replacement of SSA in cement shown the best percentage. Table 2.9 shows typical range of compressive strength of incinerated sewage sludge ash concrete.

Table 2.9 Comparison of compressive strength results on 28 days

Sample	Compressive strength (MPa)	
	Doh et al. (2016) (at 600°C)	Nasmane et al. (2016) (at 700°C)
0%	30	33
5%	33	35
10%	25	34
15%	23	31
20%	16	30

Source:(Ing et al., 2016) and (Naamane et al., 2016)

Likewise, (Jamshidi et al., 2013) in his research on application of SSA in concrete stated that mechanical performance of concrete mixtures with 5% and 10% SSA replacement only show minor reduction when compare to the control sample. Further increment of SSA replacement shows a reduction in compressive strength and flexural strength as 20% SSA contents result about 20% reduction in his research. It is evident that by increasing sludge content, compressive strength decreases.

In a study of waste management, (Cusidó & Cremades, 2012) it was found that the sewage sludge can be reused to produce building block or brick. Waste sewage sludge ranging from 5% to 25% of the brick weight can be incorporated into brick. More than 25% of replacement will cause deterioration to the mechanical properties of the clay brick. The clay brick is produced by mixing of clays, sludge and saw dust. The concentration of heavy metal inside the clay brick is not significant hence there is no health risk for using sewage sludge brick. The brick has become lighter and more thermal and acoustical insulate than conventional clay brick.

Meanwhile in India, (Dhinesh, Karthikeyan, Dinesh, & S, 2014) carried out a study on the reuse of sewage sludge in manufacturing of solid block. An attempt has been made to replace base material of block by 15% waste sludge. From the experimental works, this research has determined that waste sewage sludge can be replaced up to 15% in the manufacture of block as it recorded compressive strength of 8.33 N/mm2. This project also stated that the sewage sludge in India has more amounts of calcium oxide or lime that can further improves the mechanical performance of the sludge block. Other than that, the water absorption of the block with the replacement of sewage sludge is evaluated in the research. The block manufactured with sewage sludge has lower water absorption as compared to the conventional brick. Lower water absorption makes the sludge brick more resistance to the surrounding environment. The sludge brick is less permeable to water and other soluble chemical. Lower water absorption can prevent the sludge brick from chemical attack, sulphur attack and chloride penetration.

2.3.6 Microwaved Sewage Sludge Ash

One of the major problems that causes to environmental issue is the present of heavy metals in sewage sludge. Therefore, it is necessary to burn sludge in high temperature to remove heavy metals from the materials. In conventional heating process, energy is delivered to the sewage sludge through the process of convection, conduction and heat radiation on the material's surface area. Whereas, microwave energy is transferred directly to the sewage sludge using electromagnetic field to interact with sewage sludge particles.

According to (Appleton, Colder, Kingman, Lowndes, & Read, 2005) microwave heating is a potential heating technique since it supplies a volumetric heating process compared to conventional heating methods. Uniform heating on the materials can be achieved since the heat is generated volumetrically throughout the whole material. (Jamali et al., 2009) stated that the use of microwave heating techniques for drying sewage sludge is fast compared to conventional heating methods. This means that lesser consumption of time in microwave heating to acquire same drying product in conventional heating methods and thus require less energy consumption (Menendez et al., 2010). A significant characteristic of sewage sludge drying using microwave heating is the reduction in volume which contributes a solution for landfill problems.

(Zhenyu Chen, Afzal, Salema, & Preparation, 2014) investigated the effect of microwave power level on the characteristic of sewage sludge. The researcher used 480W, 840W and 1080W microwave power to dry 120g sewage sludge. The drying period of the sludge is decrease by 60% when the power increased by 125%. According to (Menendez et al., 2010) the carbonaceous solid residue of sewage sludge as a result from pyrolysis can be reuse as microwave receptor to increase the heating efficiency.

Microwave heating has more benefits compared to conventional heating technique, where it gives higher heating rates, less energy consumption and greater control of heating process (Jones, Lelyveld, Mavrofidis, Kingman, & Miles, 2002). Besides, it contributes an alternative method to waste disposal which is more environmental controversial by reducing the waste volume instead of incineration or landfilling. However, there are no studies conducted on the use of Microwave Sewage Sludge Ash (MSSA) as additional material to concrete production.

2.4 Waste Product as Additional Material in Concrete

Research by (Corinaldesi & Moriconi, 2011) is comparing on additional of recycled concrete with limestone powder in several self-compacting concrete by using three different types of fibres made of steel. By using water-cement ratio constant at 0.40, the fresh concrete behaviour was evaluated by means of slump flow, V-funnel and L-Box tests while hardened concrete behaviour was evaluated by means flexure and compressions test as well as free drying and restrained plastic shrinkage tests. Excellent performances were generally obtained when addition of powder from recycled concrete to the concrete mixture instead of using limestone powder. The use of recycled-concrete powder instead of limestone powder for producing the concrete seems to be promising in terms of fresh concrete flow-ability.

Next, research project by (Gyurkó, Szijártó, & Nemes, 2017) was investigate the effect of different construction waste materials on the strength and durability of normal concrete. 10% by mass of the cement of the cellular concrete powder and powdered clay brick were used in the mixes and compared the performance with control mix and mixture that contained air-entraining agent. Based on the result, the cellular concrete powder is able to increase the compressive strength significantly 37% and it has a positive effect on the durability performance of the concrete.

Study by (Baeza-Brotons et al., 2014) analyses the ability of using Sewage Sludge Ash as a raw material in the composition of concrete with a similar dosage to when it used to manufacture blocks. A scale with the percentages of addition of ash in relation to cement (5, 10, 15 and 20%) was designed and the replacement of sand by this material, as well as the addition of an inert material such as marble dust. For a better understanding about how these mixtures behave in other cementitious systems, thermogravimetric analysis were performed on pastes with curing ages of 7, 28 and 90 d, and physical and mechanical tests on mortars cured for 28 and 90 d. It was proved that the addition of SSA in concrete used for manufacturing blocks cured for 28 days provided densities and resistances similar to the control sample and significantly reduces the water absorption.

2.5 Mechanical Properties of Concrete

Performance of concrete always evaluated from mechanical properties by researchers to study the potential of waste products as additional materials to concrete mixture. Moreover, performance of concrete with different material admixture can be compared and studied through mechanical behaviour of concrete.

2.5.1 Mechanical Characteristic

Concrete is known to have high compressive strength. Execution of the hardened concrete is assessed from mechanical properties which incorporate compressive strength, flexural strength and modulus of elasticity. In addition, compressive strength of the concrete is the most crucial properties and it is generally assumed that change of the compressive strength will enhance its mechanical performance. However, certain concrete in which the cement is partially or completely replaced by mineral admixture, all the mechanical properties are not specifically connected with compressive strength and the impact on the mechanical properties of hardened concrete likewise will be distinctive (Ayub, Khan, & Memon, 2014)

Mechanical properties of the concrete are closely related to its porosity and pore dispersion (Narayanan & Ramamurthy, 2000). Additional of mineral admixture considerably refines the pore configuration by reducing the pore sizes and porosity. During the hydration process of the cement, hydrated lime is form. If moisture is available, mineral admixture react with the lime to form tri-calcium silicate which refines the pore configuration of the cement matrix. It is essential to mention the rate and speed of the reaction since it much dependent on the pozzolanic nature of the mineral admixture.

2.5.2 Compressive Strength of Concrete

Compressive strength of the concrete is the most essential properties and it is generally assumed that improvement of the compressive strength will improve its mechanical performance. Compressive strength of concrete is an indexing property as the purpose of concrete casting is to withstand compressive loadings (Ayub et al., 2014). It is the foremost priority mechanical property of concrete to be determined by researchers for examining the strength exhibit by pozzolanic materials in the concrete. Compressive strength test is conducted immediately after the curing period of concrete reached for the designed age. Concrete size of 100 mm x 100 mm x 100 mm or 150 mm x 150mm x 150 mm is used for the test.

There are several factors that need to be considered before mixing the concrete to ensure the ideal end result and strength of concrete which are the quality of raw materials used, water-cement ratio, coarse and fine aggregate ratio, coarse aggregate-cement ratio, ages of concrete, temperature and also curing. Water to cement (w/c) ratio is one of the influence parameter on the compressive strength (Albano, Camacho, Hernández, Matheus, & Gutiérrez, 2009). Water used to produce concrete mix that is both plastic and easy to work with. The smaller water cement ratio gives the better compressive strength. But then, if the water used is too low, it is difficult to be mixed and concrete hydration process is not perfectly done. If water used is more than had supposed, strength and density of concrete will decrease. Meanwhile, (Koenders, Pepe, & Martinelli, 2014) confirmed that the initial moisture content of aggregate influence the development of compressive strength.

For coarse and fine aggregate ratio, when the proportion of fines and coarse aggregate is increased, the overall aggregate surface area will also increase, thus the water demand also increasing. Assume that the water demand is increased, the water-cement ratio will increase thus the compressive strength of it will decreasing. Fine and coarse aggregates shall consist of various sizes to produce a minimum void. The use of cement should be sufficient to fill the void in the sand and cement sand sufficient to cover the void in the coarse aggregate. However, it would produce a rough concrete. Therefore, more cement and sand is required to produce a mixture which has high workability.

Next, the compressive strength of concrete is also dependent on the temperature. This is due to the rate of hydration reaction that temperature dependent. If the temperature increases the reaction conjointly will increase. This implies that the concrete kept at higher temperature can gain strength more quickly than the same concrete kept at a lower temperature. However, the ultimate strength of the concrete kept at the higher temperature is going to be lower. This can be as a result of the physical type of the hardened cement paste is less well-structured and more porous when hydration proceeds at quicker rate. This is a very important purpose to remember because temperature contains a similar but more pronounced damaging result on permeability of the concrete.

The age of the cured concrete is also important. Concrete gradually builds strength after mixing due to the chemical interaction between the cement and the water. It is normally tested for its 28 day strength, but the strength of the concrete may continue to increase for a year after mixing. Curing of concrete can be classified into sprayed curing, air curing, natural weather and also water curing. Curing concrete with water prevents excessive loss of moisture and allows controlling the evaporation of moisture from the concrete surface. The continuous presence of water allows better hydration process and pozzolanic reaction to occur which eventually increase concrete strength. Therefore, sufficient moisture is essential to allow cement hydration and concrete microstructure development (Wang, Schaefer, Kevern, & Suleiman, 2006).

2.5.3 Flexural strength

Flexural strength can be defined as the ability of a beam or slab to resist failure in bending. The flexural strength is also known as Modulus of Rupture in psi. For flexural strength behaviour, the flexural strength test is the important parameter that must be examined. Plain concrete beam size of 100 mm x 100 mm x 500 mm or 150 mm x 150 mm x 750 mm is used for the flexural strength test. The beam samples will be subjected to loading at specific rate until failure is reached. Flexural strength is expressed as Modulus of Rupture where the relation of stress and strain is assumed to be linear. Two types loading for flexural strength test are the three-point loading and centre-point loading.

The three-point bending flexural test provides values for the modulus of elastic in bending, flexural stress, flexural strain and flexural stress-strain response of the materials. The main advantage of the three-point flexural test is the ease of the specimen preparation. However, this method is sensitive to specimen and loading geometry and strain rate. The scatter of the crack pattern of the beam is relatively small since the span of the beam is shorter which result a higher bending moment in the middle span length of the beam (F. A. N. Silva & Horowitz, 2008). The location of the first crack is the point where the tensions exceed the tensile strength which is usually happened at the mid-span of the beam.

Centre-point flexural strength test is conducted by (Owaid, Majeed, Jawad, & Hamid, 2016) on the unreinforced concrete beam with 100 mm x 100 mm x 500 mm size. Flexural strength test of the samples were carried out at 28 days of curing for alum sludge replacement of 6%, 9%, 12% and 15%. Another researcher (Jamshidi et al., 2013) investigated the flexural strength of concrete beam by third-point loading test. 150 mm x 150 mm x 750 mm SSA concrete beam with 5%, 10% and 20% were prepared and tested at the age of 28 days.

Size and shape of aggregate are usually known as the factors that affecting the value of flexural strength of a concrete. Angular aggregate with higher surface area than rounded aggregates exhibits better interlocking effect in concrete that contributes to the strength of concrete. Smaller size aggregate still produces higher compressive strengths in concrete compared to concretes containing larger aggregate due to higher packing density. Similarly to ordinary concrete, the flexural strength of LWAC also depends directly on the compressive strength of concrete (Yap, Alengaram, & Jumaat, 2013).

2.5.4 Modulus of Elasticity

Modulus of elasticity is an important test to estimate the elasticity deformation of a concrete structure. This property can be determined by static as well as dynamic compression test (Ayub et al., 2014). Modulus of elasticity also described as a stress to strain ratio value for hardened concrete. According to ASTM C469:2010, this test is applicable to the customary working stress ranging from 0 to 40% of the ultimate concrete strength. Nevertheless, the stress and strain behaviours of concrete significantly depend on the compatibility of both mortar and coarse aggregate in term of their modulus of elasticity, E_a and E_m respectively.

2.6 Durability Properties of Concrete

Durability of the concrete can be defined as the ability of the concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.

2.6.1 Durability Characteristic

Durability is the ability to last a long time without huge disintegration. A durable material helps the nature by monitoring resources and diminishing wastes and the ecological effects of repair and replacement. The creation of new building materials exhausted natural resources and can deliver air and waste contamination. As the outcomes, most of the design service life for the most of the building up to 30 years. However, most of the concrete and masonry structures are demolished because of out of date quality instead of decay. Concrete can withstand nature's ordinary deteriorating mechanism and as well as natural disasters.

Different concrete requires different degree of durability, it mostly depend on the exposure environment and properties desired. Even concrete exposed to outside weather conditions like exposed columns and beams will have different requirements than interior beams and columns. Thus, concrete ingredients, proportion of mixing ingredients, placement, compaction, curing and external environment determine the durability of the concrete.

2.6.2 Water Absorption

The pore structure of concrete is known to be of high importance for the durability of the material. A characterization of this pore structure by means of a simple test is often investigated, in order to find a very simple compliance criterion with respect to concrete durability. Within some daily-used Belgian technical guidelines, the water absorption by immersion is considered to be a relevant parameter in this respect.

The durability of concrete subjected to aggressive environments depends largely on transport properties, which is influenced by the pore system. One of the principal mechanisms that govern transport in cementitious systems is absorption.

Absorption can be described as the volume of pore space in concrete, as distinct from the ease in which fluid can penetrate it. Most good concretes have absorption below 10 percent by mass. This mechanism is heavily influenced by the volume of pores as well as the connectivity of the pore network. According to (Castro, Bentz, & Weiss, 2011) there are few factors that influence the rate of absorption in concrete, which is the volume of paste in the samples, water to binder ratio and also the curing condition. Besides that, temperature and types of binder used also influences the rate of water absorption (Mendes, Sanjayan, Gates, & Collins, 2012).

(Schutterr & Audenaert, 2004) have investigated some technological parameters, related with the volume to surface ratio of the specimens used for the water absorption test. It is concluded that the influence of the volume-to-surface ratio of the specimens is not significant when considering the natural scatter on the test results. Furthermore, the water absorption by immersion is not a reliable parameter for the estimation of the concrete durability. The water absorption by immersion gives an estimation of the total (reachable) pore volume of the concrete, but gives no indication on the concrete permeability, which is more important with regard to durability.

High water absorption decreases resistance of concrete towards aggressive environments such as acid attack, sulphate attack as well as the carbonation attack. When excess water in concrete evaporates, it leaves voids inside the concrete element creating capillaries that are directly related to the concrete porosity and permeability. Through proper selection of ingredients, mix proportioning and following sound construction practices, almost impervious concrete can be obtained. The flow of water through concrete is similar to flow through any porous body. The pores in cement paste consist of gel pores and capillary pores. The pores in concrete as a result of incomplete compaction are voids of larger size that give a honeycomb structure leading to concrete of low strength (Gambhir, 2013).

2.6.3 Acid Attack

Portland cement concrete usually does not have good resistance to acids. Some weak acids, however, can be tolerated, particularly if the exposure is occasional. America's Cement Manufacturers (2016) has essentially stated three ways to improve concrete's resistance to acids, firstly choosing the right concrete composition to make it as impermeable as possible, Next, isolating it from the environment by using a suitable coating and lastly, modifying the environment to make it less aggressive to the concrete.

Acids attack concrete by dissolving both hydrated and non-hydrated cement compounds as well as calcareous aggregate. In most cases, the chemical reaction forms water-soluble calcium compounds, which are then leached away. Siliceous aggregates are resistant to most acids and other chemicals and are sometimes specified to improve the chemical resistance of concrete. Concrete deterioration increases as the pH of the acid decreases from 6.5. In fact, no hydraulic cement concrete, regardless of its composition, will hold up for long if exposed to a solution with a pH of 3 or lower. To protect concrete from such severely acidic environments, surface treatments are often used.

Acid attack will induce surface deterioration of the concrete as the components of the cement paste break down during contact with acids. Acid cause leaching of all compounds of the hydrated cement paste and, in particular, those containing calcium. Leaching occurs due to the formation of soluble salts as shown in Equation 2.1 resulting in the concrete disintegration. The damage caused by acid attack often initiated at the edges and corners that follows with the cracking and spalling of the concrete. Acid attack will also result in strength and mass loss of the concrete.

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O \qquad \text{Equation 2.1}$$

The decomposition of concrete depends on the porosity of the concrete, concentration of acid and the fluid transport through the concrete. According to (Turkel, Felekoglu, & Dulluc, 2007) blended Portland cements with pozzolans are considered to be more resistant to the acidic attack than ordinary Portland cements. Addition of pozzolanic in concrete will lead to the pozzolonic reaction with production of extra C-S-H gel that decrease the volume of pores in concrete. The improvement of concrete microstructure will inhibit the acid attack penetration into the concrete. Hence, additional material such as pozzolonic material that is rich in silica needs to be added to enhance the concrete properties. Protective coatings were also used in an attempt to improve the acid resistant of the concrete.

2.6.4 Sulphate resistance

A properly designed concrete for use in aggressive environments needs to have an appropriate cementitious content, a low water-cement ratio, and be well compacted and cured. It is recommended that specialist advice be obtained during the project design stage to ensure that the concrete is adequate for the expected service. A concrete designed to provide improved sulphate resistance should have greatly reduced permeability which should also provide increased resistance to the penetration of chloride ions, reducing the risk of corrosion in reinforcing steel (Cement Australia, 2011).

Sulphate attack is a series of reaction that attack concrete by reacting with hydrated compound in hardened concrete with the presence of sulphate ions. The formation of sulphate phases takes place through dissolution of the cement paste as the sulphate ions consume calcium ions from calcium hydroxide. These new crystals occupy a greater volume than the host reactants by inducing sufficient pressure and thus cause an internal expansion of the cement paste in the hardened concrete. According to (Neville, 2004) concrete attacked by sulphates has a characteristic whitish appearance, followed by cracking, spalling and mass loss of concrete that resulted in the loss of cohesion and strength. This is fundamentally, due to decalcification of C-S-H, which is responsible for the binding capacity of the cement paste.

Degradation of cementitious systems exposed to sulphate salts is the result of sulphate transport through the pore system, chemical reaction with the hydration product phases present, generation of stresses due to the creation of the expansive reaction products, and the mechanical response (typically spalling and cracking) of the bulk material due to these stresses. Each component of this process plays a unique role in the ultimate response of the concrete; change the material properties relevant to any one component and the concrete performance can change dramatically. Therefore, laboratory tests of sulphate attack that is based primarily on submerging the specimens in sulphate solution and then measuring some physical property, such as expansion, are effectively lumping all of these mechanisms into a single test. The result is a test that characterizes how a particular concrete performs under specific conditions. If the field conditions are different, the performance of the concrete can also be different (Portland Cement Association, 2006).

Sulphate attack is a complex process that is mainly affected by the concrete and environmental condition. Different types of sulphate salt namely sodium sulphate and magnesium sulphate will result in various rate of concrete deterioration. Magnesium sulphate has a greater effect on the reduction of concrete compressive strength (Park, Suh, Lee, & Shin, 1999). The mechanism of sulphate attack is also affected by sulphate concentration. According to (Khan, 2009) the rate of deterioration increases with the increase of sulphate concentrations in all cements. (Ramezanianpour & Atarodi, 2009) suggests that the chemical reactions occur depends on the type of cement used. Sulphate attack that occurred in the concrete when ingression sulphate reacts with calcium hydroxide will produced gypsum that later turn into ettringite after further reactions. Ettringite is viewed as the cause of concrete deterioration on sulphate attack concrete as it causes internal expansion that eventually leads to cracking.

2.7 Summary of Research Gap

The waste water treatment plant industry in Malaysia produces a massive amount of wastes annually which is sewage sludge that usually discarded without used. Previous studies had shown that the use of Incinerated Sewage Sludge Ash (ISSA) is a major success where it comply the standard for pozzolanic materials that designated followed ASTM C168-05. The new method introduced, burning the Sewage sludge by using Microwaved heating process was looking forward to have the same result.

In order to reduce the amount of sewage sludge produced by the waste water treatment plant, the usage of ISSA in the concrete production had shown a positive impact. However, the high usage of energy in term of electricity has shown negative impact to the previous research as the energy used to burn the sewage sludge by using incineration method is really high. Furthermore, incineration method of burning may use longer time with only small amount of sludge may be produced after burning the sludge in very high temperature of incineration. The new method of burning the sludge by using the microwave method can be the new exploration that may help the researcher produces more quality sludge ash with the least usage of energy and time. There is no publication either on the mechanical and durability performances of concrete that contains Microwave Sewage Sludge Ash (MSSA) as additive to concrete production.

Therefore, in this research, the performance of MSSA in concrete will be investigates towards mechanical and durability properties. The mechanical testing was involves compressive strength, flexural strength and modulus of elasticity. While the durability parts will be tested on the performance of the concrete towards acid attack, sulphate resistance and the water absorptions.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter gives the information of the properties of the materials and methods of the test work to investigate the concrete specimens. The experimental procedures for determine the mechanical properties and durability of the concrete. The standard that utilized as a part of this investigation is British and American Standard to decide the properties of the solid. The selection and way of handle the materials including sewage sludge ash, sand, coarse aggregate and cement is also reviewed.

3.2 Research Methodology Flowchart

Figure 3.1 shows the Research Methodology Flow Chart of the research from the process of preparing the materials until getting the results for the test required. The results obtained then will compare with the objectives of the research to make sure the goals of the research will be achieved.

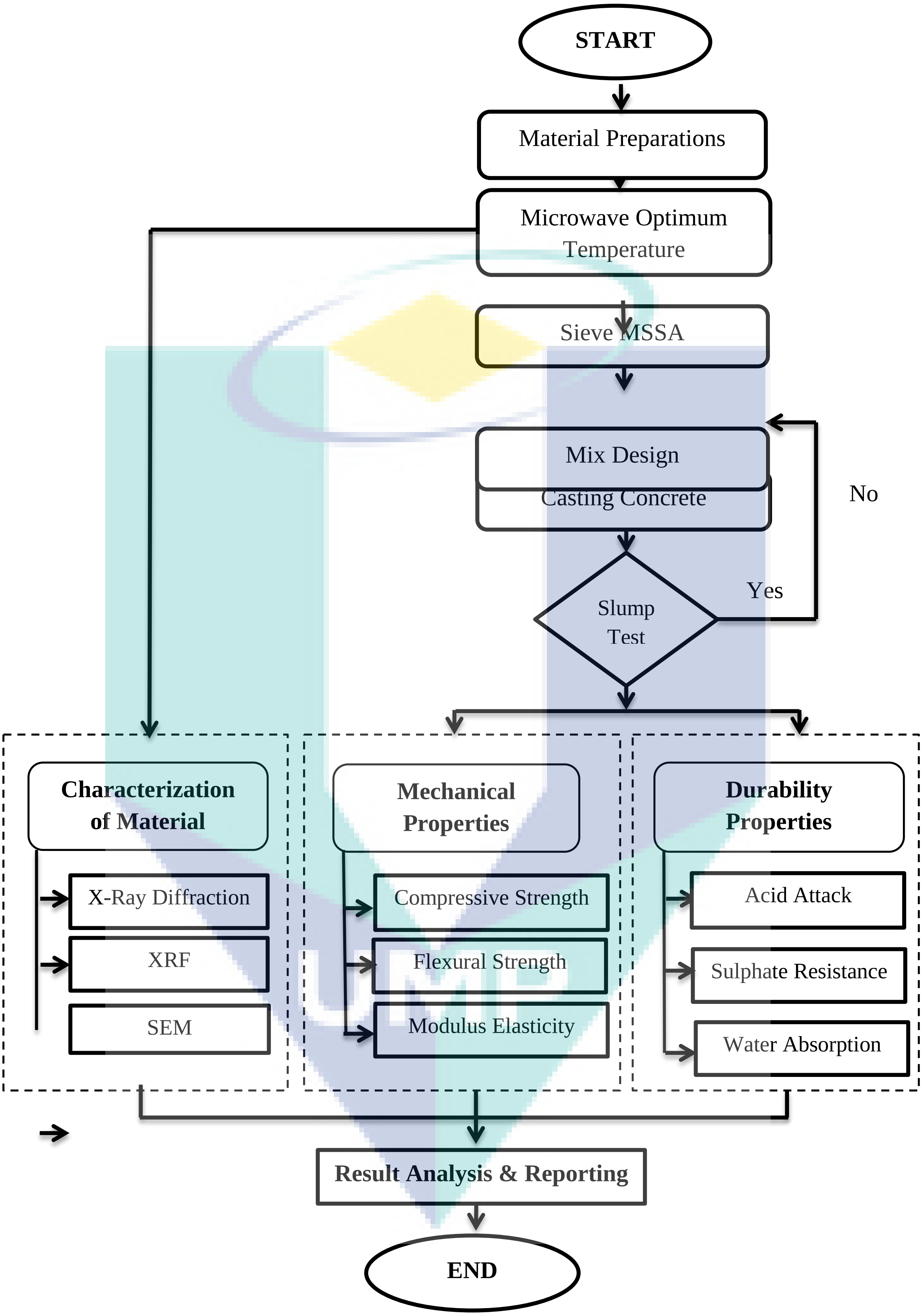
START
Material Preparations
Microwave Optimum Temperature
Sieve MSSA
Mix Design
Casting Concrete
No
Slump Test
Yes
Characterization of Material
X-Ray Diffraction
XRF
SEM
Mechanical Properties
Compressive Strength
Flexural Strength
Modulus Elasticity
Durability Properties
Acid Attack
Sulphate Resistance
Water Absorption
Result Analysis & Reporting
END

Figure 3.1 Research methodology flowchart

3.3 Materials

The raw material that utilized as a part of this research were locally accessible which included Ordinary Portland Cement (OPC), river sand as fine aggregates, crushed granite as coarse aggregates, tap water, and also sewage sludge from Indah Water Consortium as additive. All materials for concrete mixing are needed to prepare carefully and store in the right place before used to ensure the quality of the concrete specimens. Definite descriptions of every material are given in the following sections.

3.3.1 Cement

Ordinary Portland Cement (OPC) are opted in the concrete mixing for this research due to the zero additive in the constituent of the cement, which provides an ideal study on MSSA concrete. YTL ORANG KUAT Ordinary Portland Cement is selected and it is certified to MS 522-1: 2007 (EN 197-1:2000), CEM I 42.5N/ 52.5N and MS 522: Part 1: 2003. This cement is commonly used and easily available in Malaysia. The ordered cement was stored at dry place in the laboratory to protect it from dampness, which can cause hydration process of the cement. The chemical compositions of OPC are listed in Table 3.1.

Table 3.1 The Chemical Composition of Ordinary Portland Cement.

Constituent	**Percentage (%)**
Silicon Dioxide (SiO_2)	16.05
Aluminium Oxide (Al_2O_3)	3.41
Iron (III) Oxide (Fe_2O_3)	3.41
Calcium Oxide (CaO)	62.28
Magnesium Oxide (MgO)	0.56
Sodium Oxide (Na_2O)	0.06
Potassium Oxide (K_2O)	0.82
Sulphur trioxide (SO_3)	4.10
Loss of Ignition (LOI)	1.20
BET Surface Area (m^2g)	1.29

3.3.2 Fine aggregate

Generally, mining sand and river sand is used as fine aggregates in the concrete production. In this investigation, river sand was used as fine aggregates. Fine aggregate that available in the laboratory are already stored in the air dry condition. This is to prevent excess water content and impurities (dirt, dust, etc.) before mixing process. According to BS410:1986 specifications for sieve test, aggregate that passes through sieve 4.75 mm is considered as fine aggregate. Hence, the fine aggregate was prepared by passing through 4.75 mm sieve.

3.3.3 Coarse aggregate

Crushed granite aggregates available from local sources are used for this research. To obtain a reasonably good grading, the coarse aggregate are test on the sieve analysis to consider the size of distribution of the particle following BS812: Part 103. The aggregate that is used is in the range between minimum of 5 mm and not exceeded maximum size of 10 mm. Thus, the conditions of the coarse aggregates need to be dust clean before used in the concrete mixing.

3.3.4 Water

Water is one of the crucial materials in concrete design. The function of water is to grant cement to carry out hydration process and reacts as binder. The volume of water required is calculated in concrete mix design. The water to cement ratio (W/C) in this research is 0.51. The quality of water shall be controlled to assure the concrete quality. In this research, supplied tap water is clean and free from impurities for mixing and curing purposes.

3.3.5 Microwaved sewage sludge ash (MSSA)

The sewage sludge was gotten from the sewage treatment plant owned by Indah Water Konsortium (IWK), Kuantan branch. The treatment plant was encompassed by private and business region and categorized as domestic sludge. At the sewage treatment plant, the sewage sludge was sun dried at the sludge bed. As shown in Figure 3.2, just the top part of the sludge bed were gathered by using scoop as underneath the sewage sludge is fine sand which is function to filter the sewage sludge. The sewage sludge was gathered into plastic packs and stored in a dry store room. Figure 3.3 shows the raw sewage sludge collected from sewage treatment plant. The sewage sludge was sun dried at the treatment plant yet at the same time has high moisture content. To further remove the moisture content, the raw sewage sludge was oven dried at the laboratory for 24 hour at 105ºC (Zhenyu Chen et al., 2014). Next, the oven dried sewage sludge was then burned by using microwave different temperature which is medium, medium high and high temperature for 30 minutes to find the optimum temperature. The model of the microwave oven is ELBA EMO-A2072 (SV) with the operation frequency of 2450 MHz and rated power outlet of 700W. The wavelength of microwave is 12.2 cm. The dried sewage sludge is placed on the clay pot and put into the microwave oven.

Figure 3.2 Collecting sewage sludge at sewage treatment plant

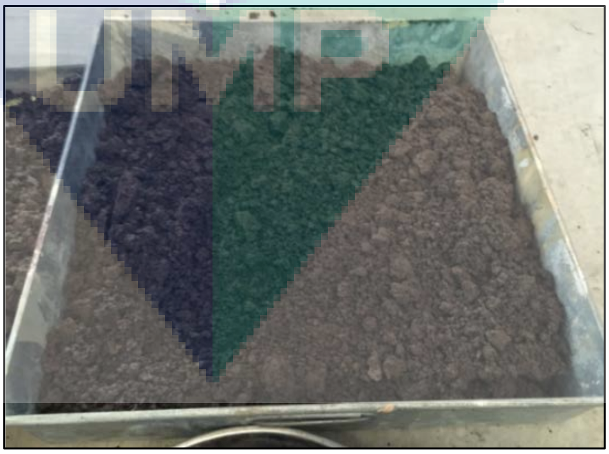

Figure 3.3 Raw sewage sludge

The product from the burning is called Microwaved Sewage Sludge Ash (MSSA). After the burning procedure, MSSA (Figure 3.4) was stuffed and labelled for the next procedure. For the next procedure, the ash was grind into powder form and the size of MSSA sieved passed through 150µm was used (Chin et al., 2016). Figure 3.5 presents the strainer shaker. Figure 3.6 summarize the flow chart for the Microwaved Sewage Sludge Ash production.

Figure 3.4 Microwave Sewage Sludge Ash MSSA)

Figure 3.5 Sieve shakers

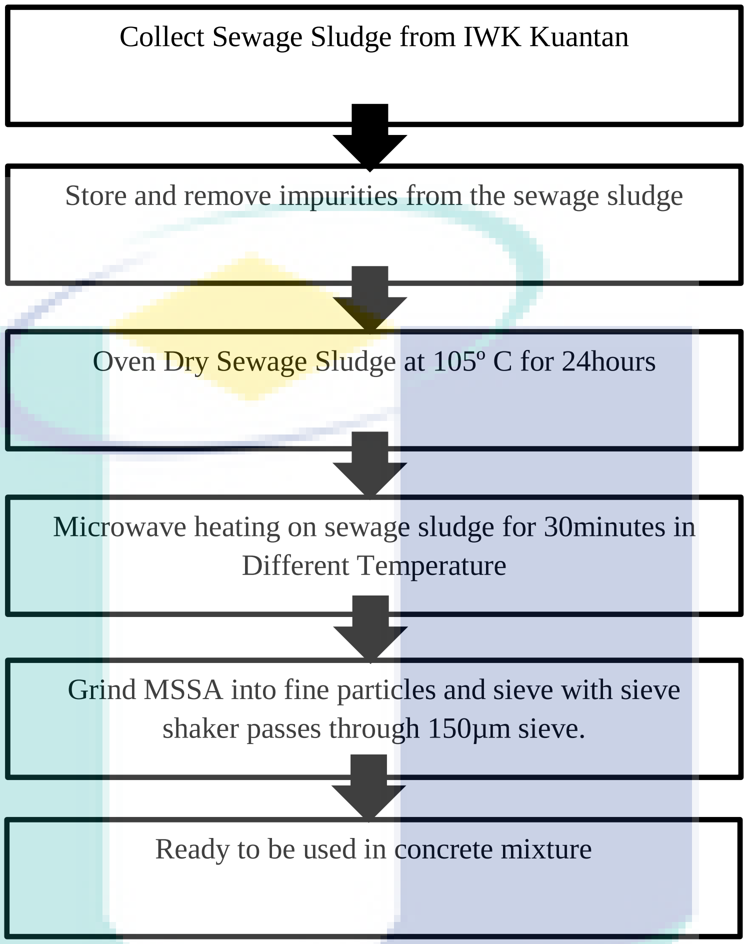

Figure 3.6 Flow chart for the MSSA preparation

3.4 Trial Mix Design

The purpose of trial mix design is to identify the suitable mixture proportion for the research with desired strength and workability. Through this process, the suitable water-cement ratio also can be identified. Table 3.2 shows the summary of the trial mix design for the trial mixture.

Table 3.2 Trial Mix Design

Materials (kg/m³)	Mix A	Mix B	Mix C
Coarse Aggregates	1120	1120	1120
Fine Aggregates	690	690	690
Cement	390	390	390
Water/Cement Ratio	0.45	0.50	0.55

3.5 Specimen Preparations

Blending of concrete was carried out complying with BS1881: Part 25. For creating the samples which required expansive volume of concrete, blending was done using rotating mixer with 56kg capacity. All the materials were weighted according to concrete mix design form before mixing by using weighing balance. Concrete mix design is used to control the uniformity of concrete.

In this study, the optimum percentages of Microwaved Sewage Sludge Ash (MSSA) addition in concrete mixture were tested to find the suitable MSSA content in the concrete to act as additive to concrete. The MSSA were tested varied from 5% to 20% percentage replacement (5%, 10%, 15%, and 20%). The best percentage of MSSA concrete was tested based on compressive strength test for 7, 28, 56, 90 and 180 days of water curing and air curing compared with control specimens. Table 3.4 shows naming of the concrete specimens with different curing method.

Table 3.2 Naming of concrete specimens with different curing method

Water Curing	Air Curing
W0	A0
W5	A5
W10	A10
W15	A15
W20	A20

To obtain a uniform concrete mix, the coarse aggregates was first fed into the mixer followed by fine aggregates, cement and microwaved sewage sludge ash. Then, the fresh concrete was poured into moulds. The specimens were also compacted by following the standard BS 1881: Part 108. The specimens were left in laboratory for 24 hours. After removed the specimens from the moulds, the specimens were cured.

Curing is the key in controlling moisture content and temperature. The properties of hardening are very dependent on this process. In this study, the specimens were cured in the water curing tank for water curing method (Figure 3.8) and also air curing method. For water curing method, all of the specimens were kept and totally immersed in the potable water until the testing day at the temperature of water is 24±3°C. The period of curing is 3, 7 and 28, 56 and 90 and 180 days. Thus the air curing method, all the concrete specimens is in the open space area covered with shade under the room temperature 24±3°C.

Figure 3.7 Curing tank

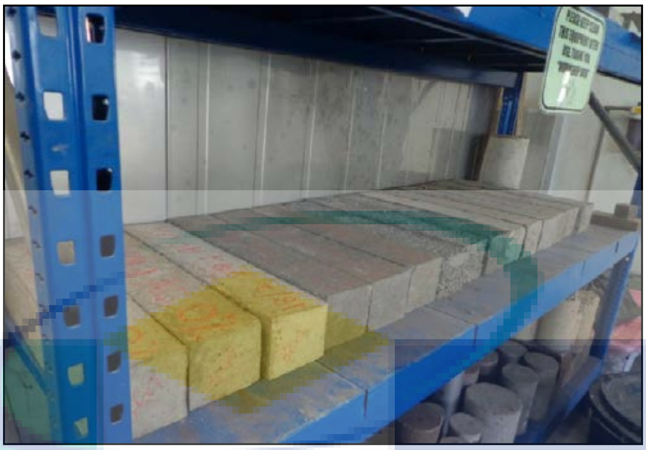

Figure 3.8 Air Curing

3.6 Properties of Fresh Concrete

Slump test is conducted on fresh concrete to determine its workability and consistency. The test is carried out according to BS EN 12350-2 (2000). Firstly, the apparatus of the slump test were cleaned and damped. The internal surface of the mould also must free from superfluous moisture. The mould is then placed on a smooth, horizontally levelled rigid and non-absorbent surface such as a rigid plate. Then, the fresh mixed concrete was filled into the slump cone until 1/3 of the cone height was achieved. During the filling process, the mould is hold firmly in place by standing on the two foot pieces provided in the slump cone. The fresh concrete layer was stroked for 25times using stamping rod with 16mm diameter and 600mm length. The procedures were repeated by filling the slump cone with second and third layer as well as the tamping process. After the top layer is rodded, the concrete is struck off the level with a sawing and rolling motion of the tamping rod. Next, the slump cone was lifted gently in vertical direction immediately in 5 s to 10 s. After the slumping of fresh concrete, the height between the slump cone and fresh concrete was measured in mm by using ruler. The slump result can be classified into true slump, shear slump and collapse slump.

3.7 Physiochemical of Concrete

The characterization analysis included X-Ray Diffraction test (XRD), X-Ray Fluorescence test (XRD), Scanning Electronic Microscopy & Energy Dispersive X-Ray Spectroscopy (SEM-EDX) & Thermogravimetric Analysis (TGA). Brief explanation of each test was discussed in the subtopic below.

3.7.1 X-Ray Diffraction (XRD)

The X-ray Diffraction (XRD) is performed to identify the phase chemistry of the specimens. XRD test can be used to analyse unknown crystalline such as mineral and inorganic compound in the specimens. Cathode ray tube in the XRD instrument emits monochromatic radiation on the specimen. The specimen and the detector are rotated and the reflection intensity of the radiation is detected and recorded. A pattern will be generated where the frequency of diffraction at different angle. Different angle of diffraction shows different type of element. The analysed material is finely ground, homogenized, and average bulk composition is determined. In this research, XRD was performed by using a XRD machine with the method of 2θ scanning ranging between 10° and 80°. The analysis scan was set to run at 0.02° steps, with 1 second counting time. The samples send for XRD test is in powder form as shown in Figure 3.10. Figure 3.11 illustrates the XRD equipment used in this research.

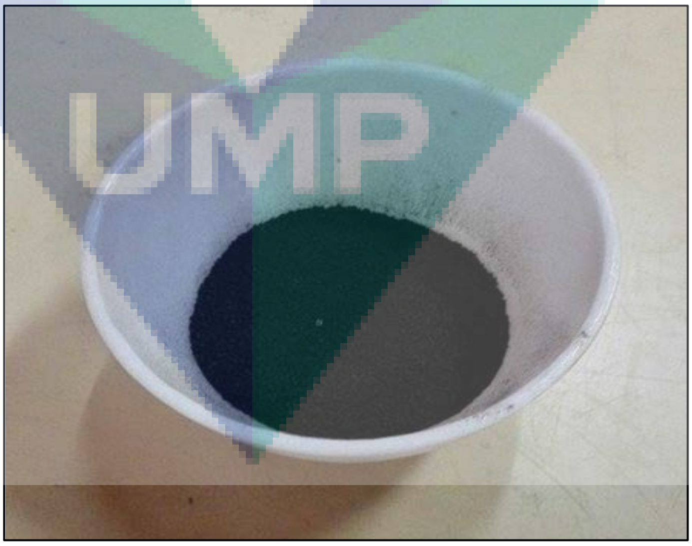

Figure 3.8 Ground MSSA

Figure 3.9 X-ray Diffraction Machine (XRD)

3.7.2 X-Ray Fluorescent (XRF)

The main function of XRF analysis is to determine the chemical composition of the specimens. The XRF used X-ray to detect the chemical composition in solid, liquid as well as powder form samples. This test was considered as non-destructive test that allowed to be used in wide range of the chemical elements from sodium till uranium which able to provide the concentration up to 100%. XRF works on the wavelength-dispersive spectroscopic principles. The specimen is exposed to short-wavelength X-ray which ionizing the component of the specimen. Energy in form of photon is released during the process. The number of photons that emitted from the specimen is counted and the element present in the sample can be identified. In this research the samples were studied in a powdery form which consisting of fine grains of single crystalline material. Raw sewage sludge and MSSA were sent for the XRF test. Figure 3.12 shows the Bruker S8 XRF spectrometer used in this research.

Figure 3.10 Bruker S8 Tiger XRF spectrometer

3.7.3 Scanning Electronic Microscopy & Energy Dispersive X-Ray Spectroscopy (SEM-EDX)

The Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-Ray (EDX) analytical system were undergo to determine the microstructural features of the field concrete and the compositions of the phase.

A JEOL JSM-840 microscope with Tracor Northern EDAX system was used for SEM-EDX analysis at the accelerating voltage of 15kV and a beam current in the range of 1 to 3nA and 60second time. A JEOL JSM-6300F field emission gun SEM (FEG SEM) was also used for image observation of the samples at the accelerating voltage of 5 kV. Samples for both JSM-840 and JSM-6300F analyses were placed on the sample holders supported by carbon paint filled by 1-min sputter coating of gold. The SEM analysis was performed under low vacuum mode with a low nitrogen pressure.

The samples of controlled, 10% and 20% of MSSA addition to the concrete with different curing regime were involved in this testing. The concrete samples were crushed and grind in order to obtain the powder form. The chemical composition of the Microwaved Sewage Sludge Ash (MSSA) concrete was studied through the EDX method in order to compare the chemical compositions of the MSSA concrete due to heat treatment.

3.7.4 Thermogravimetric Analysis (TGA)

The possible effects of the thermal treatment on the MSSA concrete were studied in detail by Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). The studied samples were exposed to linear heating up to 700°C under nitrogen compressed air atmosphere.

In TGA test, the powdered sample was prepared with the mass of 3- 10 mg in a container and placed in the specimen holder. An empty container was also prepared as a control for this test. The nitrogen gas flow rate was established at 40°C/min. The heating program was then initiated within the desired temperature of 700°C. The specimen mass change was recorded continuously over the temperature interval. As the results, the relationship between mass loss and temperature was obtained.

For this study also the TGA test was carried out to determine the total $Ca(OH)_2$ present in the Control specimen, and specimen contains 10% and 20% of Microwaved Sewage Sludge Ash (MSSA) at different curing ages and conditions. The crushed concrete samples were grounded in a grinding machine in order to obtain the powder form.

3.8 Mechanical Properties of Concrete

This test is to investigate the mechanical properties of the concrete by destructive test. The destructive test included compressive strength test, flexural test and modulus of elasticity. Further portrayal was described at each subtopic.

3.8.1 Compressive strength test

Compressive strength test is conducted to determine the strength of concrete under crushing loads. The test was carried out by following the standard of BS EN 12390-3 (2002). In this test, the weight of each specimen was measured before the sample was placed inside the compressive strength machine. The bearing surface of the compressive strength machine should have wiped clean and loose grit or any extraneous substance should be removed from the surfaces of the concrete cubes which were contact to the platens of the machine. This is to ensure the loading can steadily have applied to the whole surface are of the cubes. The size of the specimens is 100mm x 100mm x 100mm.

The specimen was placed in compression testing machine as shown in Figure 3.13. The specimen was place at the centre of the machine with the valve closed. The compression test was automatically terminated when the specimen reach it maximum strength. The maximum load was recorded. After the test was terminated, the valve was released and the cube was removed from the machine. The type of deformation of the concrete cube was observed and recorded.

Figure 3.11 Compressive testing machine

The compressive strength of the concrete cubes specimens that subjected to water curing was tested at age of 3, 7, 28, 60, 90 and 180 days of curing. Three specimens for each series of the concrete mixed design were tested to provide more accurate data.

3.8.2 Flexural strength test

Flexural strength test is used to measure the tensile strength of concrete beam, which is a measure on unreinforced concrete beam to resist failure in bending. The test is conducted according to BS EN 12390-5: 2009. Concrete beam with size 100 mm x 100 mm x 500 mm at 3, 7, 28, 60, 90 and 180 days of water and air curing will be used in this experiment. . This test was performed by using flexural testing machine with two points loading. The flexural machine consists of two supporting rollers and two load applying rollers that need to be wipe clean in order to remove grit. Three specimens for each different proportion of material in the specimens at respective curing date are prepared and undergo flexural strength test to obtain the average result in order to increase the result's accuracy. Figure 3.14 showed machine that involved in this test.

Figure 3.12 Flexural machine

3.8.3 Modulus of elasticity

The method for measuring the static modulus elasticity or also known as Young's Modulus in compression is complying standard BS 1881-121: 1983. This test was conducted to determine the ability of concrete to maintain its original form when it is stretched. The cylinder concrete example with diameter 100mm and tallness of 200mm were utilized as a part of this investigation. The specimens were cured by total submerging in water for 28 days. After the curing age, the rough surface of the concrete was smoothed using sandpaper. After that, the surface of the specimens was attached with two strain gauges at the centre of the specimen with the distance of not less than 1/4 of the length of specimen from the end. After the specimen was ready, it was placed axially at the centre of the machine. The static modulus elasticity in compression of the concrete sample was calculated using equation showed in Equation 3.2 following BS 1881-121 (1983). Figure 3.16 shows the compressive machine that will be used in this test.

$$\frac{\Delta\sigma}{\Delta\varepsilon} = \frac{\sigma a - \sigma b}{\varepsilon a - \varepsilon b} \qquad \text{Equation 3.1}$$

Where;

E = chord modulus of elasticity, psi

S_2 = stress corresponding to 40% of ultimate load

S_1 = stress corresponding to a longitudinal strain of 50millionths psi

ε = longitudinal strain produced by stress S_2

Figure 3.13 Modulus of Elasticity Testing

3.9 Durability Test

Concrete durability is defined as resistance of concrete towards weathering action, chemical attack, abrasion and other degradation processes (American Concrete Institute, 2011). The durability execution of the concrete in this research was resolved through a few tests which included water absorption, acid attack and sulphate resistance.

3.9.1 Water absorption

The water absorption test is conducted based on ASTM C 642 (2006). The rate of water absorption test was test on the concrete cubes of 100mm x 100mm x 100mm. Water absorption tests were done to measure the amount of water absorbed by the concrete sample. Furthermore, this test will evaluate the quality of concrete as it is highly related to concrete porosity and permeability. The test was carried out after the 3rd, 7th, 28th, 60th, 90th and 180th days of the specimens cured in two different conditions which are water curing and air curing. First, for the water cured condition, the hardened concrete was removed from the water curing tank while the air curing was directly used. The surface specimen that cured with water was wiped by a dry cloth to prevent free water on the surface. Both specimens was then dried in oven for 72h ± 2h at temperature of 60^{o} C. After that, the specimen was left to cool down for 24h ± 0.5h and weighted as the initial weight.

After recording the initial weight, the concrete cubes were then submerged in the water and also has to make sure the water absorption was done throughout all the surface of the specimens at a depth which there was 50mm of water above top of the specimens for 48h. Before recorded the mass of the concrete cubes, ensure the surface of the specimens were wiped off to remove the extra water content on the concrete cubes. The specimens were weighed and the mass was recorded. The water absorption by mass is calculated as equation 3.2.

$$\text{Absorption \%} = \frac{Ws - Wd}{Wd} \times 100\% \qquad \text{Equation 3.2}$$

Where;

Wd = dry weight of the specimen

Ws = saturated weight of the specimen after submersion in water

3.9.2 Acid attack

The acid attack test was conducted to determine the effect of concrete contains MSSA as additive towards acid resistance. The specimens of concrete cube size 100mm x 100mm 100 mm consents to ASTM C 267-97. Sulphuric acid of 3% concentration was taken as a medium for acid resistance test. All the concrete specimens were cured for 28days before immersing it in acid solution.

Weight measurement was done for every 100 hours until 1800 hours of immersion in sulphuric acid. Any changes in term of the specimens shape and deterioration was also observed until the period of 1800 hours. The variation of weight was compared with the initial weight before immersion in acid solution. The weight measurement is important to determine the mass loss of the specimen after immersed in the acid solution. The compressive strength test of acid attack specimens was also determined after 1800 days of immersion in acid solution. The cube specimen was placed on the compression testing machine in such a manner that the load was applied to the opposite site of cubes as cast (Sanjeev et al. 2015). Strength resulted was then compared with the compressive strength of normal concrete as done by Thomas et al. (2015).

3.9.3 Sulphate resistance

Concrete cube specimens were 50 weeks immerse in the sulphate solution for different percentage of MSSA concrete following (PN CEN/TR 15697). The sulphate solution was set by blending 5% of the sodium sulphate (Na_2SO_4) with 95% of water. This test was to quantify the weight changes of the concrete samples and its compressive strength when submerged in the sulphate solution. The mass loss was determined by using equation 3.3 (Murthy et al., 2007.)

$$\text{Mass loss} = \frac{m1-m2}{m1} \qquad \text{Equation 3.3}$$

Where;

m_1: mass of specimens before immersion

m_2: mass of specimens after immersion

Concrete cube specimens with size 100mm x 100mm x 100mm were also tested on compressive strength in order to determine the strength reduction when the specimens was immersed in sulphate solution. For the case of compressive strength, the concrete specimens were tested by the compressive strength test machine according to BS EN 12390-3 (2002).

CHAPTER 4

MSSA CONCRETE OPTIMUM DESIGN

4.1 Introduction

This chapter will discuss on the selecting suitable mix design of the concrete to achieve its required workability, durability and strength. This chapter consist of the analysis of the different water cement ratio and microwaved temperature used in the burning process of the sewage sludge and its effect to the properties of the sewage sludge. Normal slump test and compressive strength test was undergo to determined suitable water cement ratio. The Microwaved Sewage Sludge Ash (MSSA) as the product of the burning process will undergo X-Ray Diffraction test, X-Ray Fluorescent test and Scanning Electron Microscopy test to identify the optimum temperature of the microwaved.

4.1 Water Cement Ratio

In order to find suitable mixture for the concrete, trial mix design must be done in this experimental work. This is important to ensure the concrete mixture will achieve best mix proportion with desired density, strength and workability. The water cement ratio used to undergo the trial mix test was 0.45, 0.50 and 0.55. Table 4.1 below shows the specification requirement for the concrete.

Table 4.1 Specification Requirement

Property	Requirement
Desired strength (MPa)	30MPa
Slump (mm)	75mm to 100mm

The result of the slump for fresh concrete and its strength after 28days curing for each trial mix design was tabulated in Table 4.2 below. The result for Mixture with

0.45 and 0.55 Water Cement Ratio was not fall in the desired specification where the slump and its strength were 70mm with 26.66 MPa and 110mm and 24.73MPa respectively. Meanwhile, Water cement ratio for 0.50 result is within the acceptable range, with 95mm slump and 31.84MPa strength. Thus, 0.50 is the best mixture proportion for the concrete.

Table 4.2 Mixture Proportion Results

Water Cement Ratio	Slump Result (mm)	Strength (MPa)
0.45	70	26.66
0.50	95	31.84
0.55	110	24.73

4.2 Optimum Microwave Temperature for MSSA

Preliminary study to identify the suitable temperature to burning the sludge has been done in the early stage of this research by using microwaved method. This is important to ensure the significance temperature is used to produce the best quality of concrete by using optimum energy consumed by using same model of microwaved, ELBA EMO-A2072(SV). The most optimum temperature of the microwaved was tested and identified by using X-Ray Fluorescent test, Field Emission Scanning Microscope and also X-Ray Diffraction test of the Microwaved Sewage Sludge Ash (MSSA) after the burning process. Three different temperatures which are Medium, Medium High and High Temperature were used to heat the MSSA with duration of 30 minutes.

4.2.1 X-Ray Fluorescent Test (XRF)

The chemical composition of each different samples of MSSA that burned in three different temperatures was summarized in Table 4.3. The main oxide group found in the Microwaved Sewage Sludge Ash (MSSA) was Silicon Oxide (SiO_2), Sulphur Trioxide (SO_3) and Iron Oxide (Fe_2O_3). There was a high content of Silicon Oxide after the microwave burning process. High Temperature of MSSA shows the highest content of Silicon Oxide with 14.94% followed by Medium High temperature MSSA nearly to High Temperature MSSA with 14.79%. Medium temperature of

MSSA shows the least content of SiO_2 with just only 9.41%. This summarizes that the burning process occur may triggers the formation of Silicon in the MSSA as Silicon is the main component that responsible in the pozzolanic activity in the cementitious material.

Table 4.3 X-Ray Fluorescent Result for Different Temperature of MSSA

Oxide Group	Medium Temperature (%)	Medium High Temperature (%)	High Temperature (%)
SiO_2	9.41	14.79	14.94
Fe_2O_3	10.31	9.25	11.14
SO_3	7.34	6.05	6.86
CaO	5.14	5.66	5.36
Al_2O_3	2.31	2.00	2.57
MgO	0.27	0.30	0.34
TiO_2	0.73	0.62	0.76
ZnO	1.02	0.83	1.16
K_2O	0.75	0.84	0.84
P_2O_5	3.17	2.93	3.57

4.2.2 Field Emission Scanning Electron Microscope (FESEM)

Field Emission Scanning Electron Microscope (FESEM) of MSSA mortar was carried out to analyse the morphology of the samples with different temperature of burning MSSA which are Medium, Medium High and High temperature. Figure 4.1 shows the micrograph of Medium-MSSA. From the micrograph, it was obtained that the Medium-MSSA mortar has mostly angular shape particles. The bonding between the angular particles has spherical particle that possibly produced from the hydration of cement that resulting C-S-H formation bond. The C-S-H particles bond holds the particle together and provides strength to the mortar.

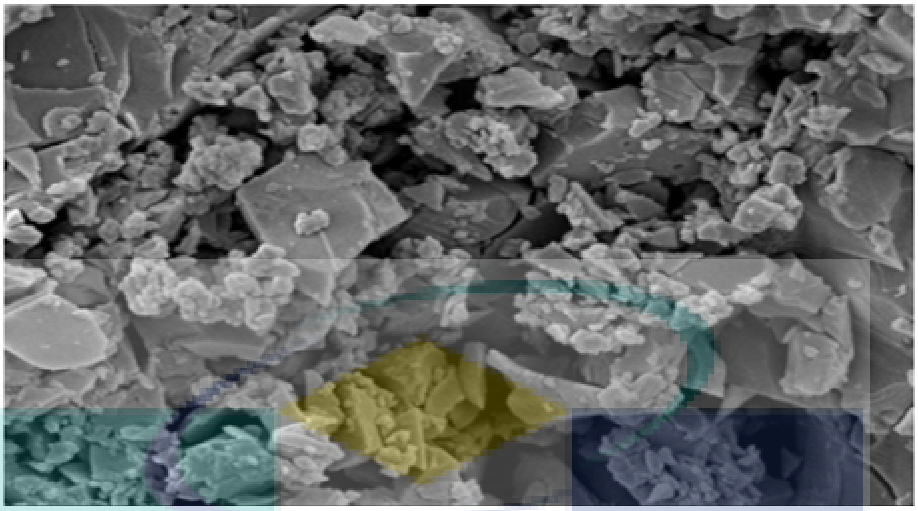

Figure 4.1 FESEM image of Medium heated MSSA

Figure 4.2 shows the micrograph of Medium High-MSSA mortar. From the figure, can be shown the formation of needle-shape particles in the mortar that contains Medium High heated MSSA. The pores also has been filled with small spherical and needle shaped particles that formed by the SSA components. The needle shaped particles formed are able to fill the pores in the mortar. The reduction of pores in the mortar can improve the strength of the mortar.

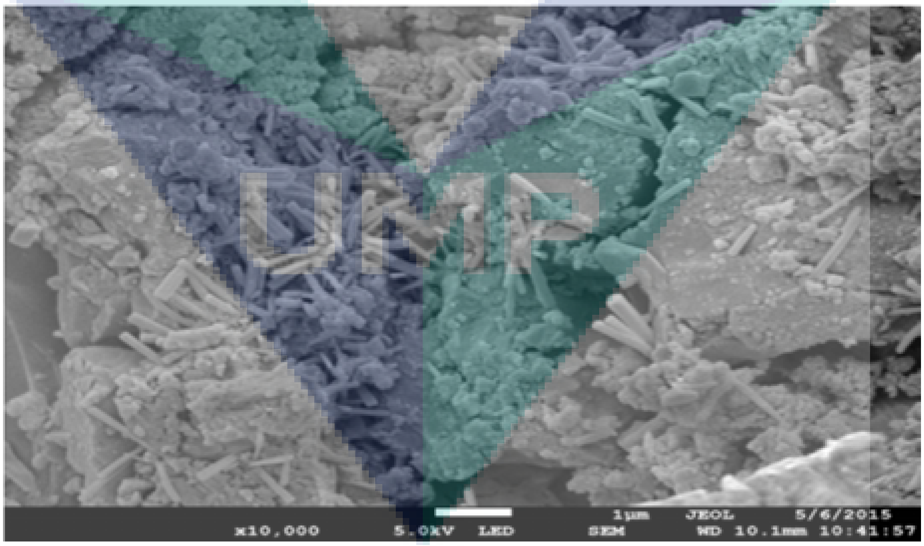

Figure 4.2 FESEM image of Medium-High heated MSSA

The formation of smooth surface structure can be observed from the Figure 4.3 of High Temperature heated of MSSA. This is due to the pozzolanic reaction material from MSSA with the $Ca(OH)_2$ in the mortar mixture. This smooth structure has also filled the void and pores in the mortar. This proven can increase the strength of the mortar.

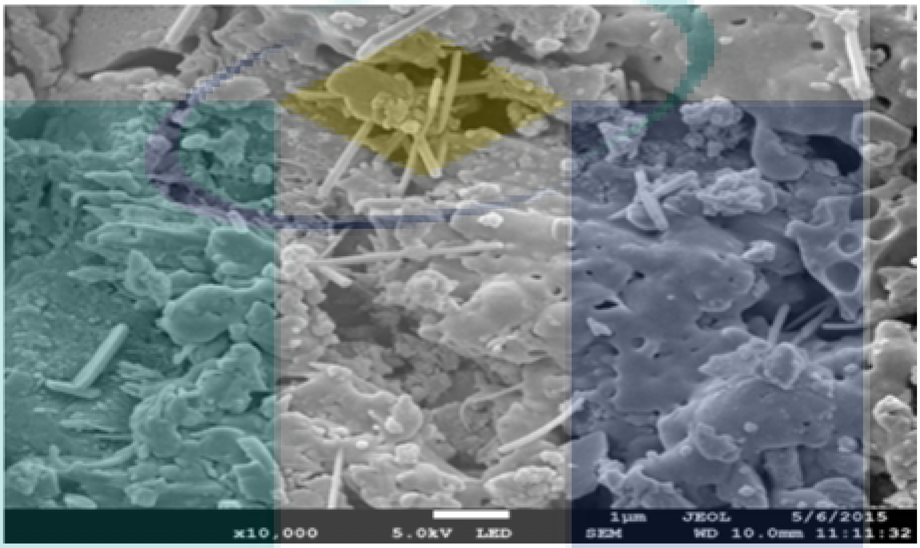

Figure 4.3 FESEM of High temperature heated MSSA

4.2.3 X-Ray Diffraction Test (XRD)

X-Ray Diffraction test used to identify the chemical composition of the different heated temperature of Microwaved Sewage Sludge Ash (MSSA). The chemical phase of the component will be identify through the pattern graph and indicates the amount of component present in the sample. The peak on the graph will show the intensity of the element in the samples.

Figure 4.4 presents the XRD result for Medium Temperature of MSSA. From the graph, it is indicated that the MSSA consist mainly Silicon Oxide. The peak is at 27^o with intensity of 163cps.

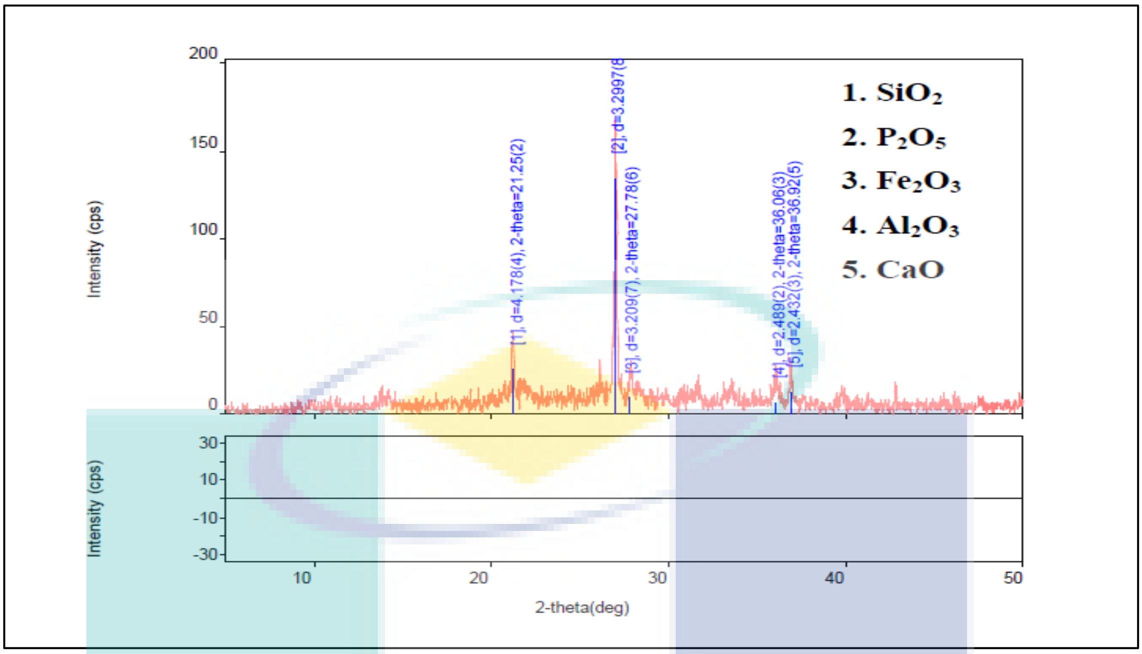

Figure 4.4 XRD of Medium Temperature MSSA

Figure 4.5 shows the X-Ray Diffraction of Medium High Temperature heated of MSSA. From the graph, MSSA heated with Medium High Temperature consist mainly of Silicon Oxide and Cesium Niobium Sulfide. The peaks of XRD patterns showed the intensity of the Silicon Dioxide (SiO_2) is 1334 cps at 27.16^o and 274cps at 21.32^o.

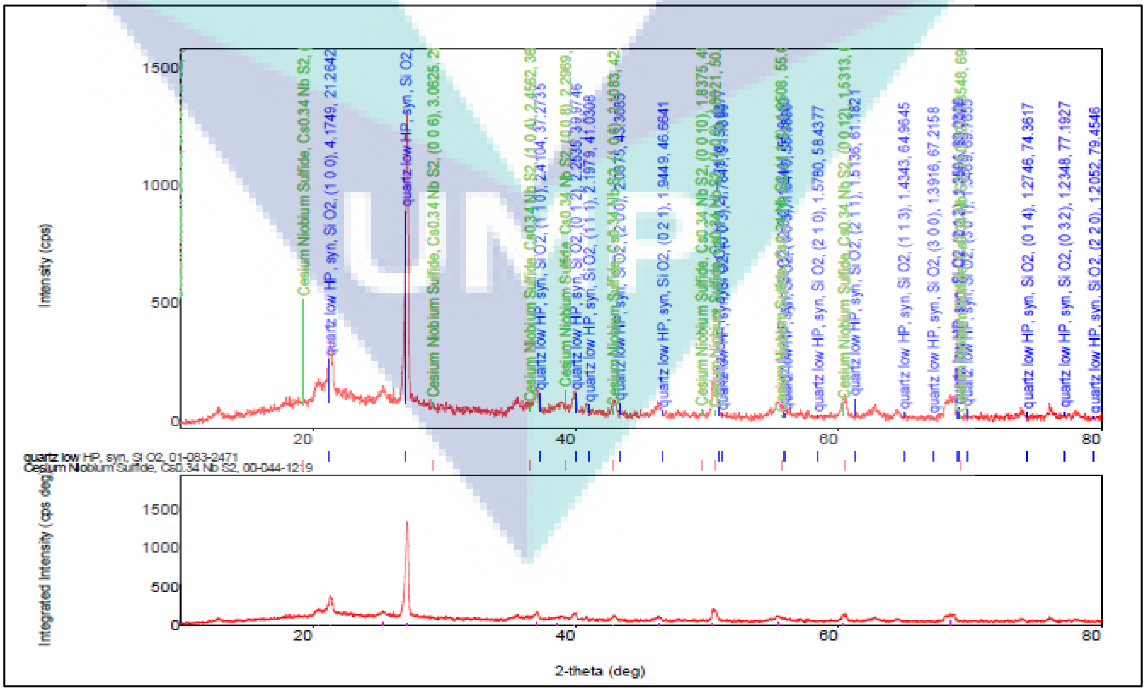

Figure 4.5 XRD graph for Medium High temperature of MSSA

Figure 4.6 indicates the XRD pattern of MSSA microwaved heated to High Temperature. Based on the pattern, only Silicon Dioxide (SiO_2) exists in the specimens. High Temperature MSSA consist high amount of Silicon Dioxide with intensity of 627cps at 31.42^o, 2452cps at 27^o and 1211cps at 68.64^o.

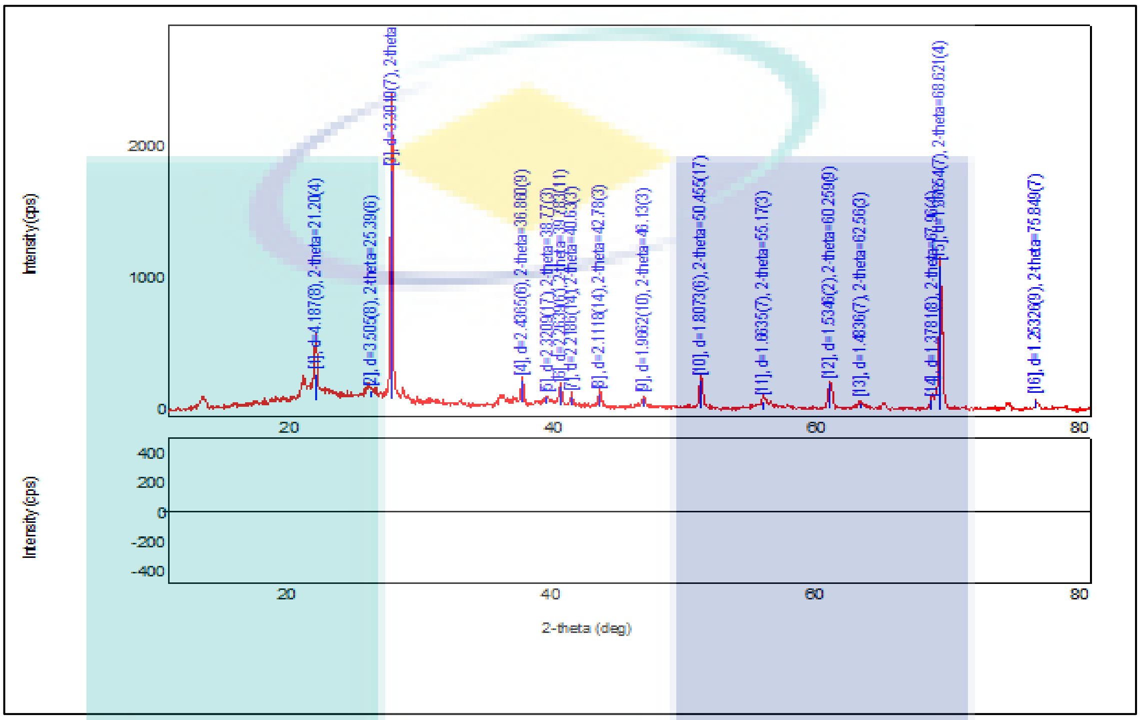

Figure 4.6 XRD result for High Temperature MSSA

4.3 Optimum Mixture Proportion

From the results of water cement ratio in Table 4.2, the most optimum ratio is 0.50 with the highest compressive strength, 31.84MPa with 95mm slump. This ratio is selected for the best ratio due to the good result of compressive strength according to the designated strength and slump loss.

The recommended temperature for the MSSA production for the concrete is High Temperature. This is due to the good result of MSSA for X-Ray Fluorescent test as its shows the highest in the content for pozzolanic element which are SiO_2 and Fe_2O_3. The mineralogical composition and the crystalline phase of the High temperature MSSA due to X-Ray Diffraction test also shows high content of SiO_2 as the major component as it is good for pozzolanic reaction in concrete. The smoother structure and ability to fill the void and pores in the mortar as shown in the result of FESEM test were also proves that High temperature of MSSA is better temperature.

CHAPTER 5

MSSA CONCRETE PROPERTIES ANALYSIS

5.1 Introduction

In general, this chapter will discuss on the properties of the Microwaved Sewage Sludge Ash (MSSA) concrete in term of its fresh concrete properties and mechanical properties. Properties of the fresh concrete were focused on the workability by using slump test. While the hardened concrete includes compressive strength test, flexural strength test and modulus of elasticity test. The details of all of the analysis were discussed in the following subtopics.

5.2 Properties of Fresh MSSA Concrete

The slump test was an important method to characterize the workability of the fresh concrete. Workability is defined as the easement of the freshly mixed concrete can be placed, compacted and finished. Figure 5.1 shows the result of the slump test for the concrete specimens based on different percentage content of Microwaved Sewage Sludge Ash (MSSA). The results show that all of the specimens with 0.50 Water –Cement ratio are classified as True Slump as all the slumps for each sample fell under the acceptable range of 75±25 mm. It means that the amount of MSSA used in this research and the other materials are well mixed and well distributed.

From the results, it is shows that the control sample achieved the highest slump with 75mm slump followed by 5% MSSA concrete with 70mm height of slump. The slump height result shows in decreasing as the amount of MSSA increasing. This can be observed from the result as the 10%, 15% and 20% of MSSA concrete slump is 65mm, 60mm and 60mm respectively. This is due to the ability of the sewage sludge to absorb the water than cement and caused by the rough texture of the ash particles which may lead to higher adsorption of water (Garcés et al., 2008). The shape of the sewage sludge ash particles that not spherical has also caused the negative influenced on workability of the concrete (Ing et al., 2016).

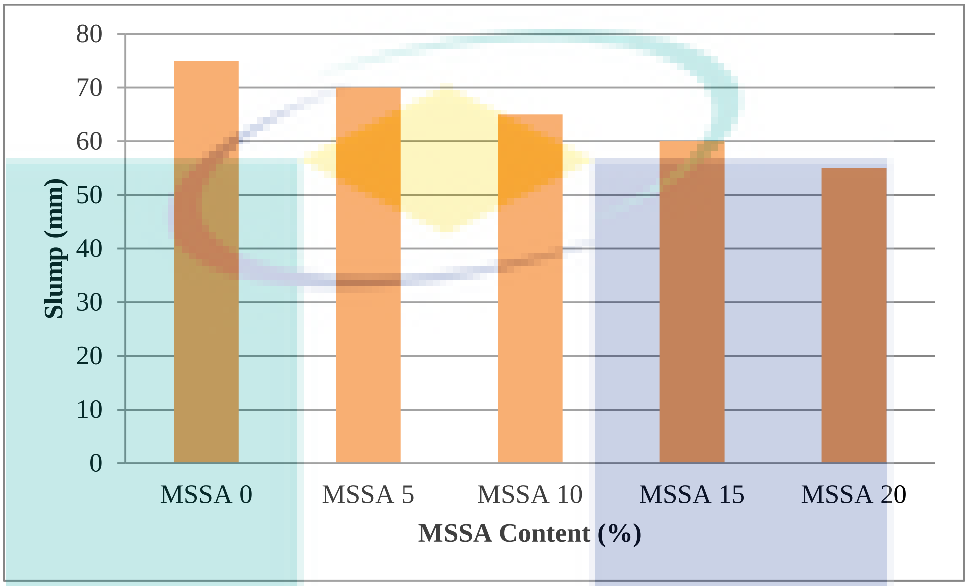

Figure 5.1 Slump result for different Microwaved Sewage Sludge Ash (MSSA) content

5.3 Mechanical Properties of MSSA Concrete

The hardened concrete mechanical properties of the MSSA concrete were determined by using compressive strength test, flexural strength test and modulus of elasticity test. All of the following test were discussed below.

5.3.1 Compressive Strength Test Results

Compression test is one of the most important aspects in analysing the strength of the concrete as it will determine the maximum amount of compressive load that the concrete can sustain before its fracture state. The results of the compressive strength of the specimens in this research are shown in Figure 5.2 and Figure 5.3. The microwave sewage sludge concrete samples undergo two different curing regimes, which are Water Curing (W) and Air Curing (A). Four different percentages amount of Microwave Sewage Sludge Ash (MSSA) (5%, 10%, 15% and 20%) are used to see the effect of the amount of MSSA added to the strength of the concrete.

From the graph, it is shows that the highest strength was achieved by W5 concrete with 55.85 MPa at the age of 180days, 9.94% higher than control strength, while the lowest was recorded by A20 sample with the strength of 30.36 MPa at the ages of 180days. It is also shown that the strength of all of the samples is increased along the curing period. There is significant relationship between the concrete age, curing method and strength of the specimens. Overall, the strength of the samples that undergo water curing method is higher than concrete sample that exposed to air curing method. This shows that the curing method will influences the strength development of the concrete. Proper curing method is important to ensure the concrete samples meet their expected strength performance and to control the early volume change. The exposure of the concrete sample to the favourable moist conditions will control the hydration process of the concrete (Ismail, Kwan, & Ramli, 2017). Based on the result also prove that the specimen that submerged under water for longer time will produce the higher in compressive strength.

The additional of the MSSA to the concrete mixture shows positive impact to the strength of the concrete as we can see from the graph the strength of the concrete is higher than the normal concrete by additional up to 5% amount of MSSA in both curing method. The presence of MSSA in the concrete mixture acts as pozzolanic material and react with calcium hydroxide ($Ca(OH)_2$) and Calcium Silicate Hydrate (C-S-H) that produce after the hydration reaction in the cement occurred. This reaction may increase the strength of the specimen. The presence of sufficient moisture due to the curing method through-out the hydration process was also helping in accelerating the formation of C-S-H gel.

The early strength of the MSSA concrete for both water and air curing samples at the ages of third day are recorded lower compared to controlled samples. Finding by (A Yagüe , S Valls , E Vàzquez, 2015) stated that this is due to delay of hydration of the cement at the early age of the concrete. The increasing amount of the sewage sludge slowing the evolution times of the crystalline phases of the concrete mixture. The greater the amount of the sludge in the mixture, the lower the hydration speed and the greater the time necessary to reach the end of setting, as is observed in the evolution of the anhydride and hydrated phases. This concludes that any accelerator may be needed to help the early hydration process when MSSA is added to the concrete mixture.

Air dry curing MSSA concrete shows 9.96% lower than water cured MSSA concrete in compressive strength result. The air dried MSSA concrete only depends on the concrete moisture itself for the hydration process. As the result, insufficient moisture content had slowed the formation of Calcium Silicate Hydrate gel during the hydration process. Furthermore, continuous curing of concrete with water will prevents excessive loss of moisture and controlled the evaporation of moisture from the concrete surface. The highest compressive strength result recorded by the air-dried MSSA concrete was 50.29MPa at 180days by A5, while the lowest was A20 by only 30.36MPa, 21.97 % lower than control specimen. This may due to the pozzolanic activities of the MSSA after the early hydration process of the cement mixture (Ing et al., 2016)

It is observed that the concrete specimen strength for 10%, 15% and 20% of MSSA addition to the mixture is lower than the control specimen for both curing method with values range of 52% below than control specimen strength. The compressive strength graph trend is decreases when the amount of MSSA increases. This means that the pozzolanic reaction in the concrete contains higher amount of MSSA may associated with higher absorption value and associated with higher porosity, lowering the strength (Baeza-Brotons, Garcés, Payá, & Saval, 2014). This also implies that the MSSA addition should be restricted to be not more than 5% as it best in improve the strength up to 5% addition.

In conclusion, 180days ages of MSSA concrete specimens that subjected to water curing condition produces higher in strength compared to air-cured MSSA concrete. This type of curing also provide better in strength when additional of 5% MSSA as it is functional as pozzolanic material. On the other hand, Air Curing specimen record the lowest in strength until the last day of testing due to the low humidity that interrupt the hydration process and pozzolanic reaction of the MSSA concrete.

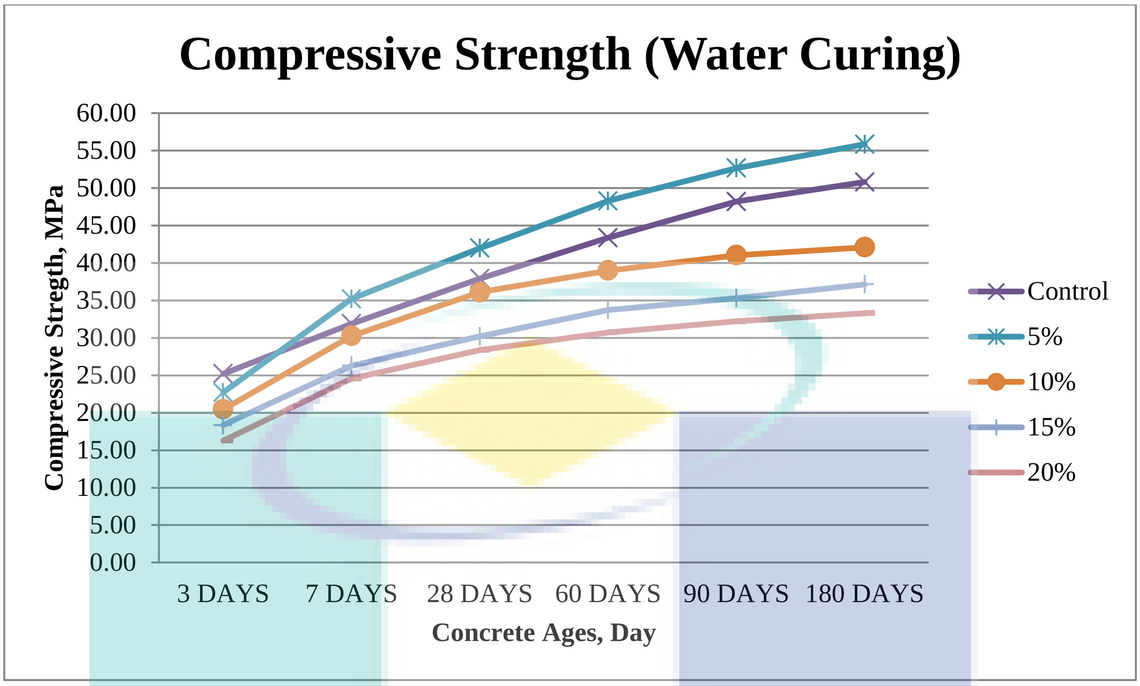

Figure 5.2 Compresive strength result for Water Cured MSSA Cocnrete

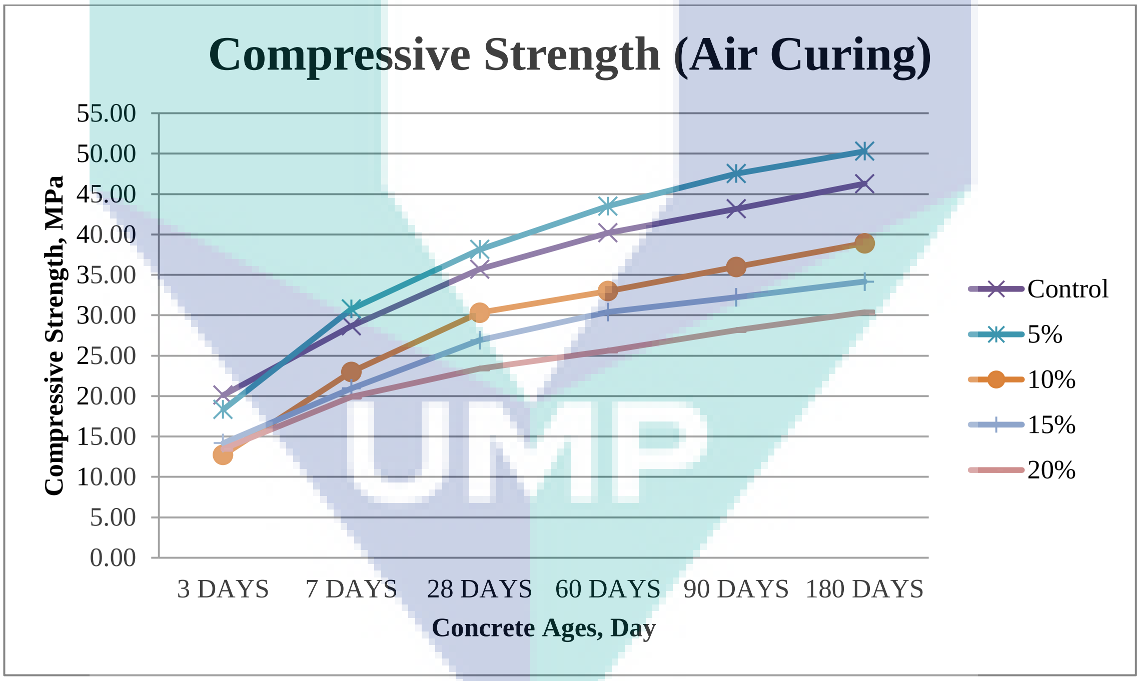

Figure 5.3 Compresive strength result for Air Cured MSSA Cocnrete

5.3.2 Flexural Strength Test Results

Flexural strength test is conducted to determine the tensile strength of the concrete beam to resist failure in bending. The results are summarized in Figure 5.4 for water cured concrete, and Figure 5.5 for air cured concrete. Based on the graph, the trends of the results for flexural strength of the Microwave Sewage Sludge Ash (MSSA) concrete is almost similar to the compressive strength result. Like compressive strength result, water cured MSSA concrete shown the best in result compared to air cured concrete. This proves that water curing regime is better than air curing. Continuous water curing is the ideal method of preventing loss of moisture from the concrete to provide better hydration process and pozzolanic reaction take place.

The highest flexural strength was recorded by W5 sample, with 9.88MPa at 180days while the lowest was 7.15MPa for A15 sample at 180days of air curing. Regarding to the flexural strength graph, all of the result is positively increased with the curing time, but only 5% amount of MSSA in the concrete were acceptable as it is higher than the controlled sample in both curing method. This show that the pozzolanic reactions in the concrete by MSSA may influence the increase of flexural strength although exceeded amount of MSSA may decreasing the flexural strength as higher porosity and higher water absorption of the concrete sample were take part (Baeza-Brotons et al., 2014).

During the early days of the research, the result for both water and air curing concrete controlled samples are higher than concrete that contained MSSA. This may be due to the initial absorption of water into MSSA pores particles reduces the effectives of the water/cement ratio that counterbalances the dilution effect (Zhen Chen & Poon, 2017). The flexural strength of the W5 and A5 MSSA concrete starting to shows best in result when the sample achieved 28days of curing with 7.97MPa and 7. 74MPa. Highest flexural strength of the MSSA concrete for W5 at 180days is recorded 10.02% higher than control sample. Water cured and air cured MSSA concrete graph both show reduction in the flexural strength with additional of 15% and 20% amount of MSSA. This implies that the Microwave Sewage Sludge Ash addition should be restricted to up to 5% as the optimum percentage to maximize the flexural strength of the concrete.

Moreover, the flexural strength for Air Dried Curing sample is still higher than controlled sample at the 5% addition (A5) at 180 days. The difference between maximum A5 and W5 MSSA concrete at 180 days was about 9% in flexural strength. This difference may due to dependency of pozzolanic reaction on the availability of moisture. In conclusion, water curing regime and 5% MSSA should be selected as it able to allow the MSSA concrete had the higher flexural strength.

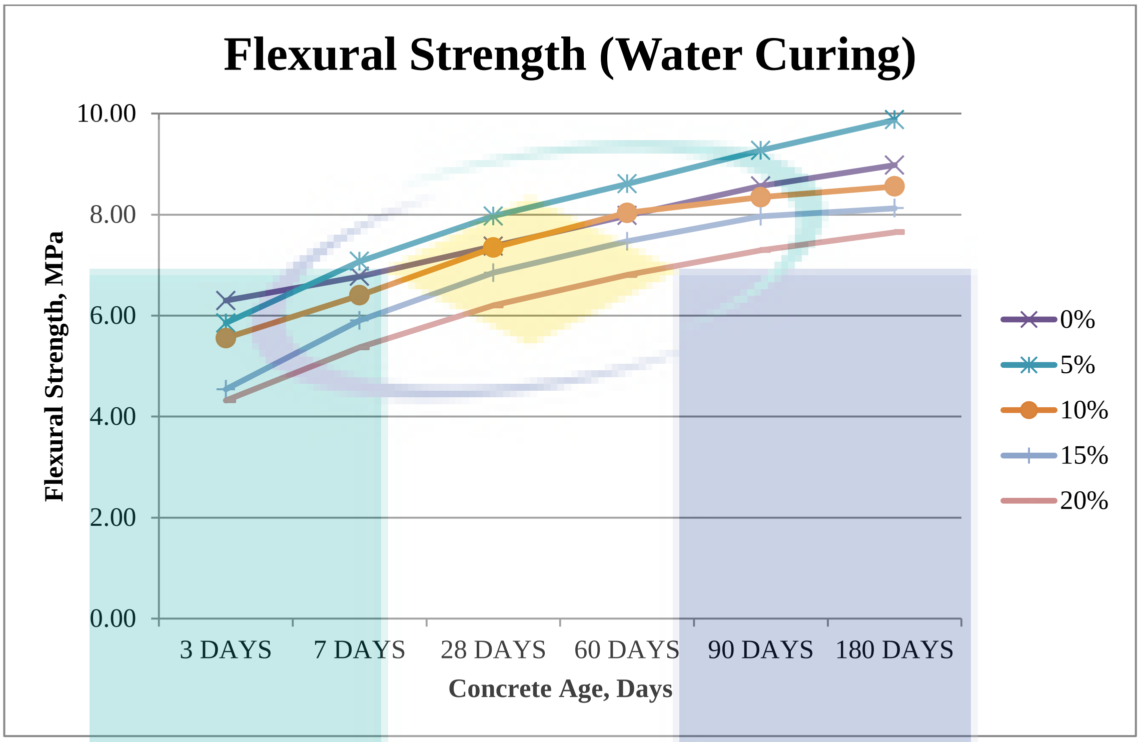

Figure 5.4 Flexural strength of water cured MSSA concrete.

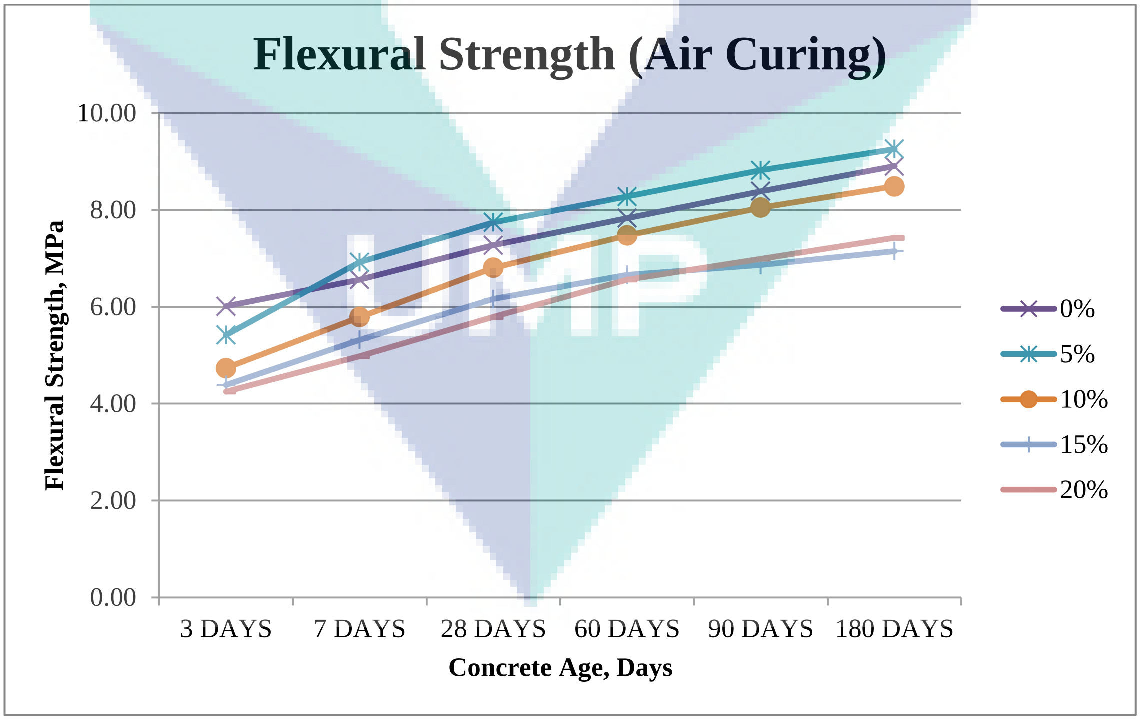

Figure 5.5 Flexural strength of air cured MSSA concrete.

5.3.3 Modulus of Elasticity Results

Analysis from the Modulus of Elasticity test is very important as it will represent the stiffness characteristic of the specimen material that behaves elastically. All of the specimens subjected to compression process with maximum load. The relationship between Microwaved Sewage Sludge Ash (MSSA) addition and Modulus of Elasticity of the specimen at the age of 28 days, involving different type of curing were shown in Figure 5.6 and Figure 5.7. The result shows reduction in Modulus of Elasticity value when the percentages of MSSA were increases for both curing method, air and water curing. The results indicate that the lesser percentages of the MSSA will increase the stiffness of the MSSA concrete. This trend were also showing in the report by Fontes, Toledo Filho, & Barbosa, (2016). The curing methods were also affecting the results of the Modulus of Elasticity. As shown in the graph, specimens with water cured curing were higher in result compared to air cured specimens. The modulus of elasticity of the concrete is influenced by the cement paste, aggregate's stiffness, and compactness of the concrete (R. V. Silva, De Brito, & Dhir, 2016). Based on this research, the value of Modulus of Elasticity were due to the lesser amount of CSH gel that may reduce the stiffness of the concrete due to the pozzolanic reaction.

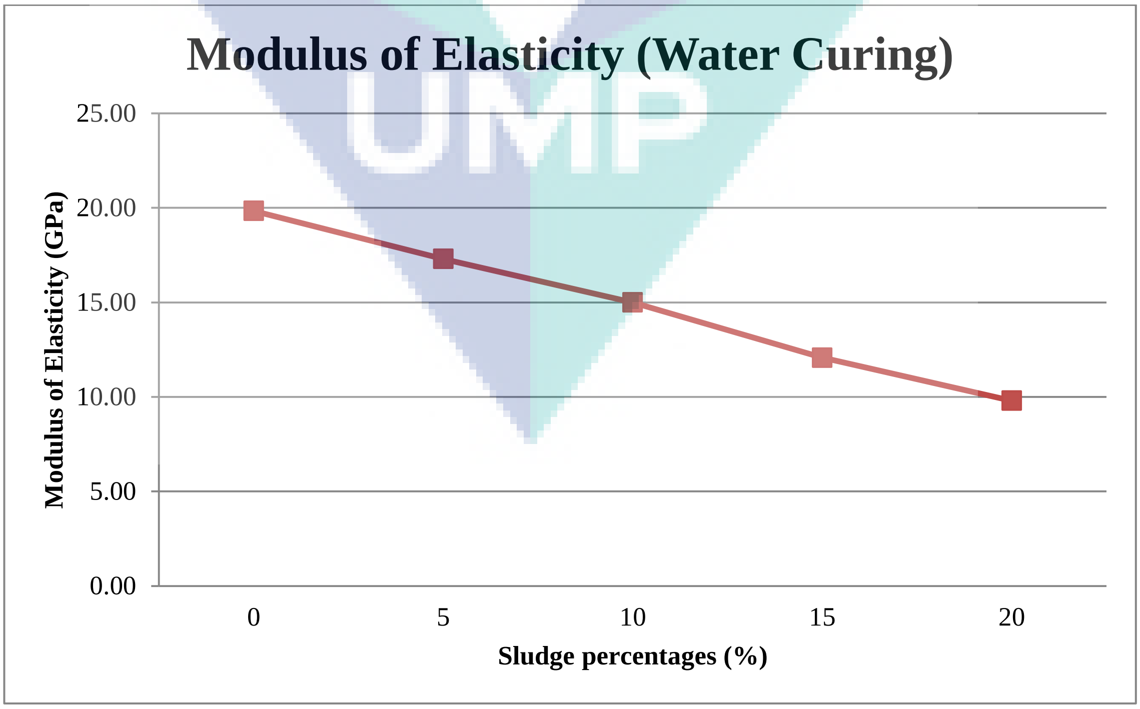

Figure 5.6 Modulus Elasticity of water cured MSSA concrete.

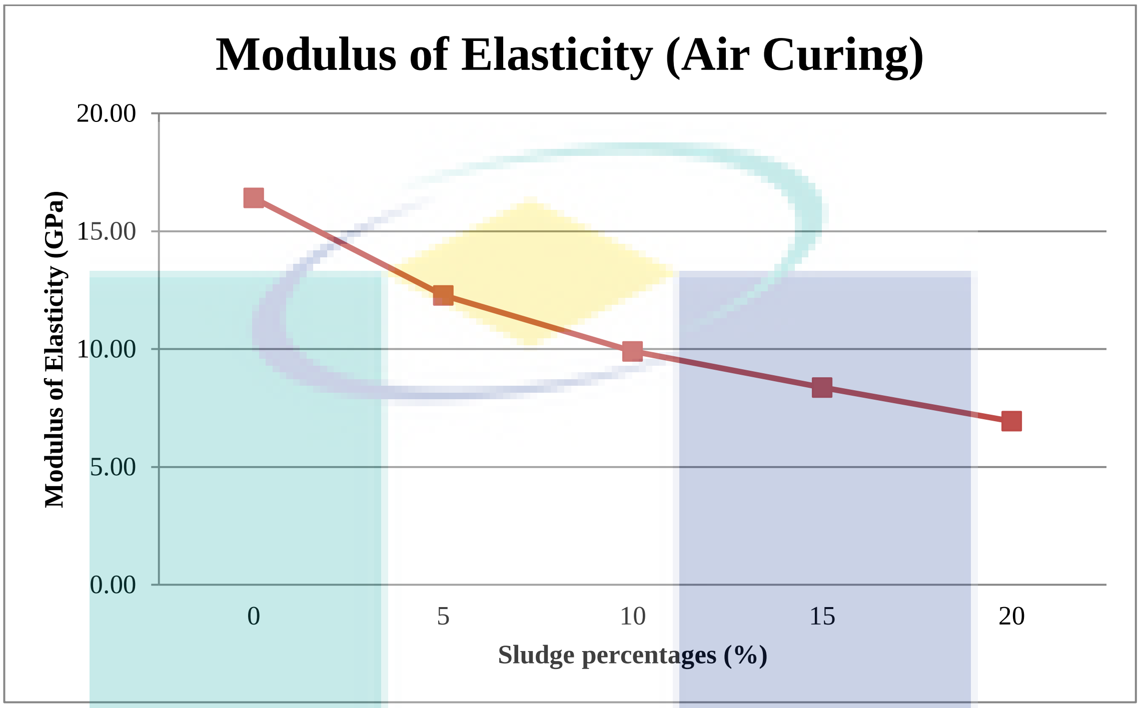

Figure 5.7 Modulus Elasticity of air cured MSSA concrete.

5.4 Summary

Based on the research for the mechanical properties of the Microwaved Sewage Sludge Ash (MSSA) concrete, curing method used will certainly affect the sample properties in term of the mechanical strength. All of the specimens tested were also to be likely higher in strength when the curing period were increase. The presence of water in the development of the concrete strength increases the hydration process and pozzolanic reaction to make it more dense than usual. The experiment shows that 5% addition of MSSA in the concrete mixture may produce good quality of MSSA concrete compared to control specimen.

CHAPTER 6

DURABILITY ANALYSIS OF MSSA CONCRETE

6.1 Introduction

This chapter will discuss oh the durability analysis of the concrete containing Microwaved Sewage Sludge Ash (MSSA) as additional material to the concrete mixture. Durability properties of the concrete will be tested by acid resistance test, sulphate resistance test and water absorption test. All of the testing is analysed and discussed below.

6.2 Water Absorptions Results

Water absorption is one of the factors to be considered in studying the durability properties of the concrete. It is measured by recording the mass change rate percentage of the concrete sample within the time it is in contact with water. According to the paper studied by Medina, Zhu, Howind, Sánchez De Rojas, & Frías, 2014, concrete samples with below 10% of water absorption rate were considered as high quality concrete. As shown in the Figure 6.1 and Figure 6.2 below, the percentage of water absorption for both curing method MSSA concrete were below 10%. Thus, both were meet the requirement.

The results for water cured MSSA concrete samples that illustrated in Figure 6.1 shown that the water absorption percentage for water cured samples were lower than air cured samples shown in Figure 6.2. This proves that curing regime will affect the water absorption rate. This were also agreed by Herki, 2020. Water curing samples undergo continuous hydration process of cement in concrete, thus providing $Ca(OH)_2$ in the pozzolanic reaction that refines the internal structure of the concrete.

Based on the graph, the controlled specimens were higher in rate of water absorption than the MSSA concrete specimens in both condition of curing. The results shown also illustrate that the rate of water absorption for 5% MSSA is the lowest among others and starting to increase as the percentages of MSSA is increased. This is due to the ability of the samples to absorb water when the percentages of MSSA usage increased (Nazierah, Kartini, Hamidah, & Nuraini, 2016). Furthermore, the graph shown that all of the result for MSSA concrete samples is lower than control sample. This showed that MSSA concrete has high resistance against durability.

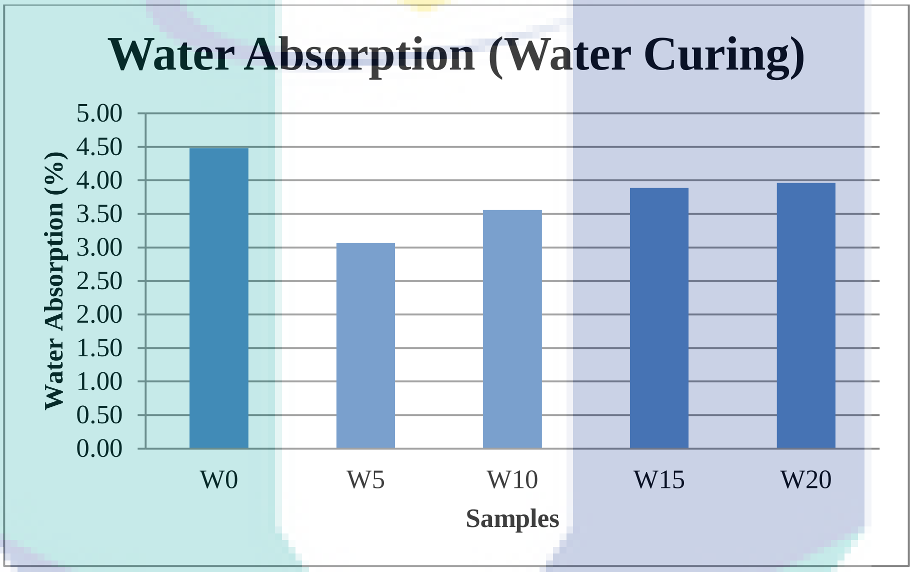

Figure 6.1 Water Absorption of Water cured MSSA concrete

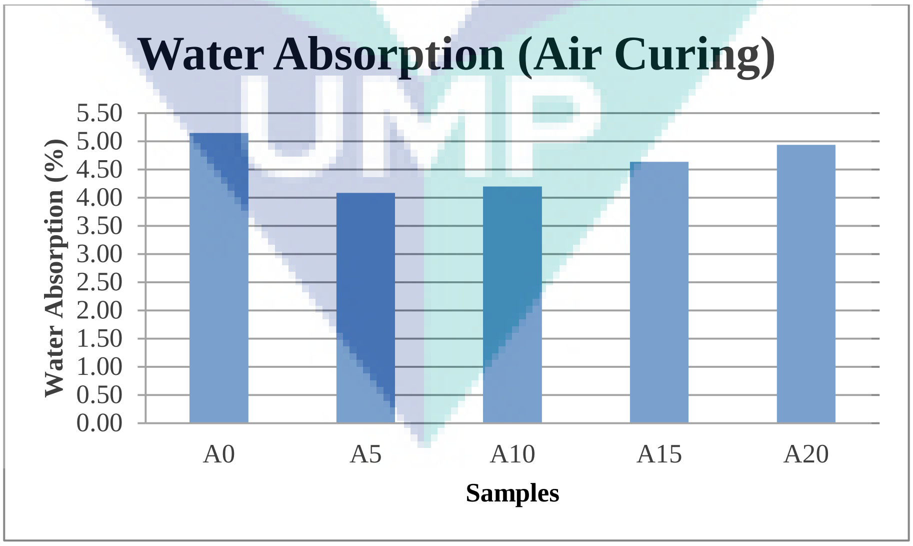

Figure 6.2 Water Absorption of Air cured MSSA Concrete

6.3 Acid Attack on MSSA Concrete

This part will discuss on the effect of MSSA concrete samples subjected to Sulphuric Acid solutions up to 1800 hours. The analysis of the samples involved visual observation, residual mass and the compressive strength of the concrete samples.

6.3.1 Visual Observation

The acidic solution were always renewed and controlled to make sure the pH values were maintain at its acidic state along the experiment. The physical changes of the MSSA were identified along the immersion time of the samples with the Sulphuric Acid solution towards the end of 1800 hours. During the early stage of the immersion, the visual observation on the samples shows that the MSSA concrete do not exhibit any form of changes in their shape. However, the fine aggregate of the samples is slowly showing the deterioration on the external surface of the samples. The deterioration process occur when the hydrochloric acid react with Calcium Hydroxide $Ca(OH)_2$ in the cement that resulting the cement structure became loose and make it detached from its original state (Miyamoto, Minagawa, & Hisada, 2014).

After 1800 hours of immersion in the sulphuric acid solution, the control specimen and the concrete mixture with 5% of MSSA almost not showing any deterioration to the samples, compared to specimens contains high amount of MSSA. Figure 6.3 demonstrate the deterioration occurs to the specimens containing 20% of MSSA. This is due to the roughness and irregularity of MSSA particles that increase the absorption of the acid solution to penetrate the concrete faster. The irregular particle shape increases the voids in the concrete samples (Vouk, Nakic, Stirmer, & Cheeseman, 2017).

Figure 6.3 Surface Appearance of 20% MSSA Concrete

6.3.2 Residual Mass

The results for the mass loss of Microwaved Sewage Sludge Ash (MSSA) concrete specimens containing different percentages of MSSA immersed in the hydrochloric acid are showed in Figure 6.4 and 6.5. The weights of all specimens start to lose as it is the effect from the immersion of specimen in the acid that cause the aggregate detached. Concrete will tend to swelling, expansion and cracks as result of internal pressure due to the chemical reaction of sulphuric acid and lime in the cement (Umara, Warid, & Ahmad, 2016).

Towards the end of the immersion of acid, MSSA concrete outer layers surface becomes more loosen. More fine aggregates dropping from the specimens and larger void are exposes. From the graph, it is shown that air cured concrete exhibit higher mass loss compared to water cured concrete. This is due to the denser structure of the water cured concrete due to the better hydration process. Concrete contains 5% of MSSA shows the lowest percentages in the mass loss followed by control specimen. While the 20% MSSA concrete shows the highest in mass loss.

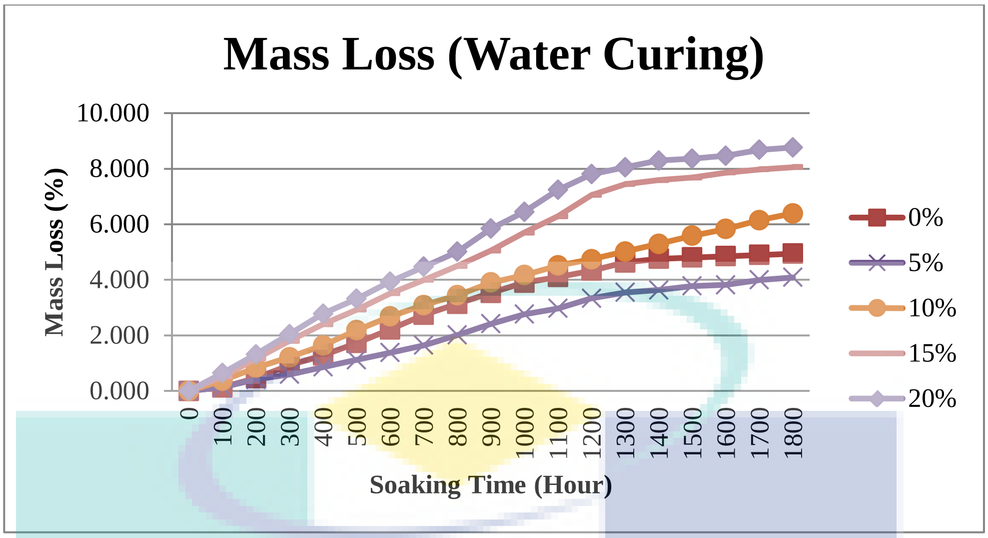

Figure 6.3 Mass loss percentage MSSA Concrete water cured immersed in hydrochloric acid for 1800hours

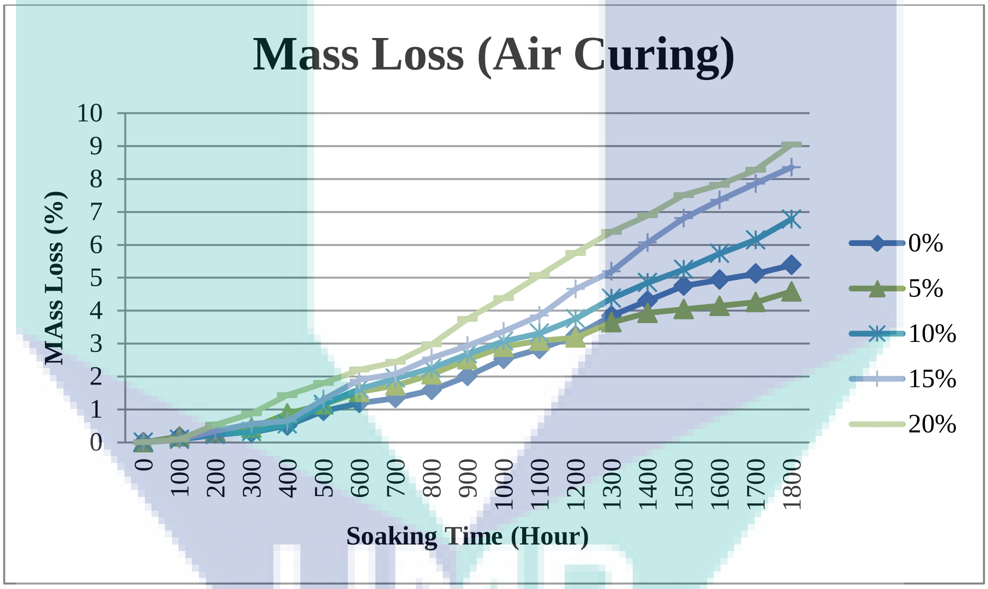

Figure 6.3 Mass loss percentage MSSA Concrete air cured immersed in hydrochloric acid for 1800hours

6.3.3 Compressive Strength

After the immersion periods end at 1800hrs, all specimens were tested for compression test to measure the residual strength. Figure 6.4 and Figure 6.5 shown the results for residual strength for water cured MSSA concrete and air cured MSSA concrete respectively. The water cured MSSA concrete specimens shows the best in results as the percentage of the deterioration observed range from 19% to 28% only, compared to air cured MSSA concrete specimens with range of 26% to 36% of deterioration strength percentage. This proves that air cured MSSA concrete has lower durability against acid attack compared to water cured MSSA concrete. This may due the compactness of water cured specimens as higher amount of C-S-H gel form from the undisturbed hydration during the curing period.

Sample for 5% MSSA content in water cured specimens shows the best in result as the strength deterioration rate percentage was only 19.88%. This was due to the denser effect, hydration process and pozzolanic effect of the 5% MSSA that enhanced the resistance of concrete against acid attack. Therefore, suitable amount of MSSA, and application of water curing method contributes to the denser concrete compared to control specimen. So, it led to the good resistance of concrete towards acid attack.

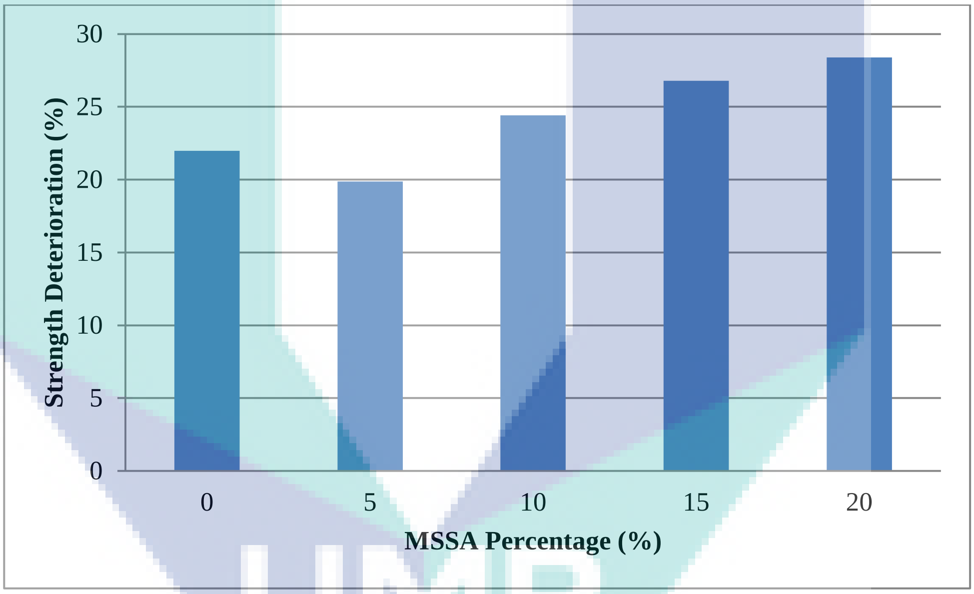

Figure 6.4 Strength deterioration for water cured MSSA Concrete immersed in hydrochloric acid for 1800hours

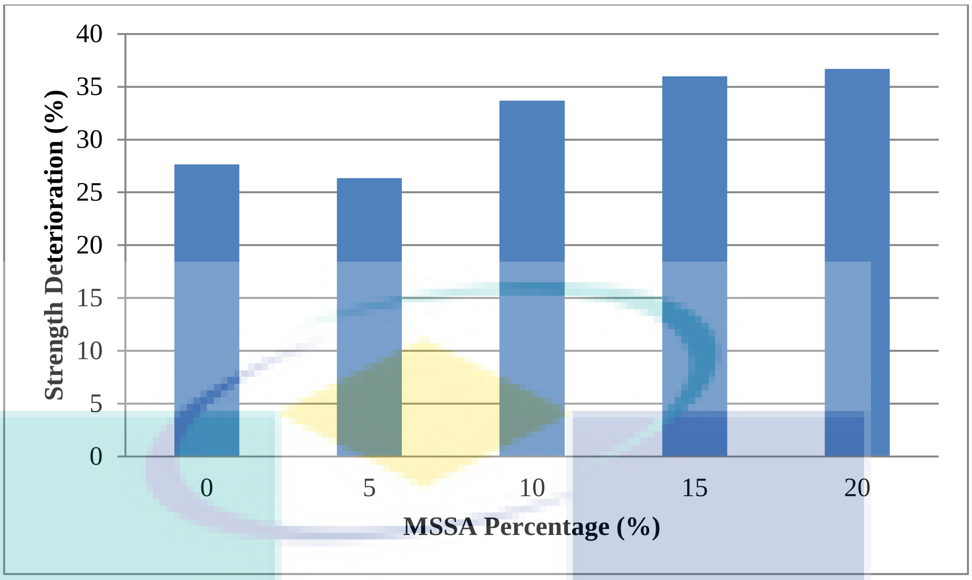

Figure 6.4 Strength deterioration for air cured MSSA Concrete immersed in hydrochloric acid for 1800hours

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APPENDIX A
SAMPLE APPENDIX 1

For Appendices Heading, use TITLE AT ROMAN PAGES style.

APPENDIX B
SAMPLE APPENDIX 2

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