

Properties of concrete containing microwaved sewage sludge ash

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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 m³ of sewage sludge annually. Normally all of this waste is disposed by landfill. 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. 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. The MSSA samples were also tested with water absorption test to evaluate the quality of concrete in term of porosity and permeability. Water curing sample with 5% of MSSA (W5) had the best in results compared to other specimens. The mechanical properties of W5 content in concrete shows the most optimum samples due to the densification of pozzolanic reaction and filler effect of 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. 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 waste on dumping site and improves the quality performances of the concrete.

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INTRODUCTION

Malaysia is one of the developing countries that have rapidly growing number of population through the urbanization phenomenon. In 2020, urban population of Malaysia is stated as 77.2 % of its total population and growing from 2015 to 2020 with annual rate of change of 2.13% [1] With this growing number of population, the waste generated every year has also gradually increased and be one of the major concern in term of environmental pollution in many developing country [2]. 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 [3]. High moisture, complex constituents and characteristic are the difficulties faced in handling and managing the wastewater sewage sludge [4]. 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, odor emission and also soil contamination that gives threat to pollution problems [3]. 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 [5].

Previous studies had shown that the use of Incinerated Sewage Sludge Ash (ISSA) in concrete production is a success as its properties improve the performance of the concrete [6, 7]. The new method introduce, burning the sewage sludge by using microwave heating process producing Microwave Sewage Sludge Ash (MSSA) was looking forward to have the same result. The usage of waste material as additional material used in the concrete mixture has been explored by many researcher [8, 9]. Some of the researcher has investigate the additional material functioned as binder or filler to the concrete mixture. This will help in improves the properties of the mixture in term of physical and mechanical properties,

as well as the internal properties. Using MSSA as additional material in this research were seek to improve the quality of the concrete.

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 [10]. 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 [6]. 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. The method of burning the sewage sludge ash by using microwaved method in this research can be the new exploration that may help researchers produce more quality of sewage sludge ash with the least usage of energy and time.

MATERIALS

Ordinary Portland Cement

Ordinary Portland Cement (OPC) are used 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. The cement used was stored at dry place in the laboratory to protect it from dampness, which can cause hydration process of the cement.

Coarse Aggregates

Crushed granite aggregates available from local sources are used for this research. The aggregate used is in the range between minimum of 5mm and not exceeded maximum size of 10mm. Thus, the conditions of the coarse aggregates need to be dust clean before used in the concrete mixing.

Fine Aggregates

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 4.75mm is considered as fine aggregate. Hence, the fine aggregate was prepared by passing through 4.75mm sieve.

Tap 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.

Microwave Sewage Sludge Ash (MSSA)

The sewage sludge was collected from the sewage treatment plant owned by Indah Water Consortium (IWC), Kuantan branch. The treatment plant was encompassed by private and business region and categorized as domestic sludge. To further remove the moisture content, the raw sewage sludge was oven dried at the laboratory for 24 hour at 105°C. Next, the oven dried sewage sludge then burned with microwaved high temperature mode for 30 minutes. The product of sewage sludge from the microwave burning process was then grind into powder form with sieved passed through 150µm to produce Microwaved Sewage Sludge Ash (MSSA).

METHODOLOGY

Casting of Specimens

Concrete mix design is important in controlling the uniformity of the concrete. The water/cement ratio used in this research is 0.50. The concrete grade used is Concrete Grade 30. Five different percentage of MSSA is used in the concrete mixtures which are 0%, 5%, 10% , 15% and 20%. Table 2.0 represent the name representation for each sample.

Table 1. Name representation for sample used

Sample	Sample Description
W0	Water Cured controlled sample
W5	Water Cured sample contains 5% of MSSA
W10	Water Cured sample contains 10% of MSSA
W15	Water Cured sample contains 15% of MSSA
W20	Water Cured sample contains 20% of MSSA
A0	Air Cured controlled sample
A5	Air Cured sample contained 5% of MSSA
A10	Air Cured sample contained 10% of MSSA
A15	Air Cured sample contained 15% of MSSA
A20	Air Cured sample contained 20% of MSSA

The concrete cube with size of 100mm x 100mm x 100mm in accordance to BS 1881: Part 108:1983 [11] was used for compressive strength test and water absorption test. While non-reinforced concrete beam with the size of 100mm x 100mm x 500mm were casted by using steel mold were used for flexural strength test accordance to BS 1881: Part 118:1983 [12]. The cylinder concrete with diameter of 100mm and tallness of 200mm were utilized for Modulus of Elasticity test.

During the casting process, all of the specimens were compacted by tamping rod three layers with each layer was stroked for 25 times to reduce the voids in the specimens. The specimens were left to set in laboratory for 24 hours before demold. After removal of specimens from molds, the specimens were cured in water and air curing method for 3, 7, 28, 60, 90 and 180 days.

Compressive Strength Test

Compressive strength test is conducted to determine the strength of concrete under crushing loads. The specimen was place at the centre of the machine with the valve closed as shown in Figure 1. The compression test was automatically terminated when the specimen reach it maximum strength. The maximum load was recorded. Three specimens for each series of the concrete mixed design were tested to provide more accurate data. The test was carried out by following the standard of BS EN 12390-3 (2002) [13]. The specimens are placed in two types of curing, air and water curing for 7, 28, 56, 90 and 180 days. Firstly, on the testing day, the weight of each MSSA concrete 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.

**Figure 1.** Compressive testing machine

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) [14]. This test was

performed by using UTest machine with two points of loading as shown in Figure 2. The loading rate of the UTest machine was 0.5kN/s. Concrete beam with size 100mm x 100mm x 500mm at 3, 7, 28, 60, 90 and 180 days of water and air curing used in this experiment to compare their performance when different percentage of Microwave Sewage Sludge Ash (MSSA) were added. This test was performed by using UTest machine with two points of loading. The loading rate of the UTest machine was 0.5kN/s. Three specimens are prepared for each particular proportion of material in the specimens at the respective curing date and flexural strength tests are performed to achieve the average result in order to improve the result accuracy.



Figure 2. Flexural strength test machine

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) [15]. This test was conducted to determine the ability of concrete to maintain its original form when it is stretched. The static modulus elasticity in compression of the concrete sample was calculated using equation showed in (1) following BS 1881-121 (1983).

$$\Delta\sigma/(\Delta\varepsilon) = (\sigma_a - \sigma_b)/(\varepsilon_a - \varepsilon_b) \quad (1)$$

Where;

σ_a = upper loading stress (N/mm²)

σ_b = basic stress (0.5 N/mm²)

ε_a = mean strain under the upper loading stress

ε_b = mean strain under the basic stress

Water Absorption Test

The water absorption test is conducted based on ASTM C 642 (2006) [16]. Water absorption tests were done to measure the amount of water absorbed by the concrete sample. Furthermore, this test was evaluated the quality of concrete as it is highly related to concrete porosity and permeability. Initial weight of the specimen was recorded before all of the specimens submerged in the water. After submerged the specimen for 48hours, the mass of the specimens were recorded. The water absorption by mass is calculated as equation (2).

$$\text{Absorption \%} = (W_s - W_d)/W_d \times 100\% \quad (2)$$

Where;

W_d = dry weight of the specimen

W_s = saturated weight of the specimen after submersion in water

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X-ray Diffraction (XRD)

X-Ray Diffraction test used to identify the chemical composition of the Microwaved Sewage Sludge Ash (MSSA). The chemical phase of the component was identified from the pattern graph and indicates the amount of components present in the sample. The peak on the graph indicates the intensity of the element in the samples. Figure 3 presents the XRD result for MSSA. From the graph, it is indicated that only Silicon Dioxide (SiO₂) exists in the specimens. High Temperature Mode of burning MSSA consist high amount of Silicon Dioxide with intensity of 627cps at 31.42°, 2452cps at 27° and 1211cps at 68.64°.

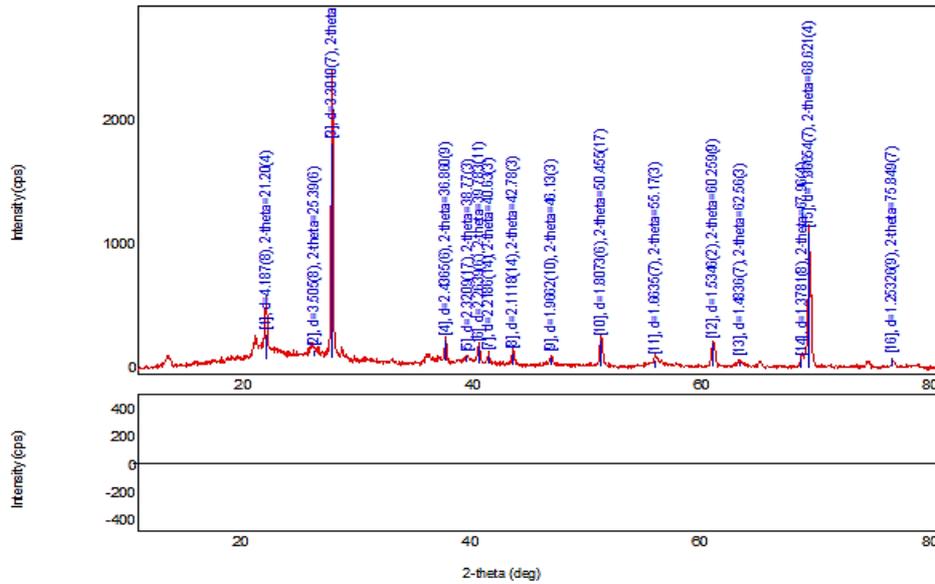


Figure 3. X-Ray diffraction of microwave sewage sludge ash

X-Ray Fluorescence (XRF)

The chemical composition of Microwaved Sewage Sludge Ash (MSSA) that burned in high mode temperature that resulted from the X-ray Fluorescence test was summarized in Table 1. The main oxide group found in the Microwaved Sewage Sludge Ash (MSSA) was Silicon Oxide (SiO₂), Sulphur Trioxide (SO₃) and Iron Oxide (Fe₂O₃). There was a high content of Silicon Oxide after the microwave burning process. 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. Significant amount of SiO₂ can be considered as active mineral addition on cement mixture composite [17]

Table 2. X-Ray fluorescence result for MSSA

Oxide Group	Percentage Content (%)
SiO ₂	14.94
Fe ₂ O ₃	11.14
SO ₃	6.86
CaO	5.36
Al ₂ O ₃	2.57
MgO	0.34
TiO ₂	0.76
ZnO	1.16
K ₂ O	0.84
P ₂ O ₅	3.57

Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) of MSSA mortar was carried out to analyze the morphology of the samples. Figure 4 shows the micrograph of the MSSA. From the micrograph, it was obtained that the MSSA has the smooth surface structure. 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. The porous structure were also produced due to the process of sintering and densification from the burning process and also consistent finess of the MSSA [18]. This proven that MSSA can increase the strength of the mortar.

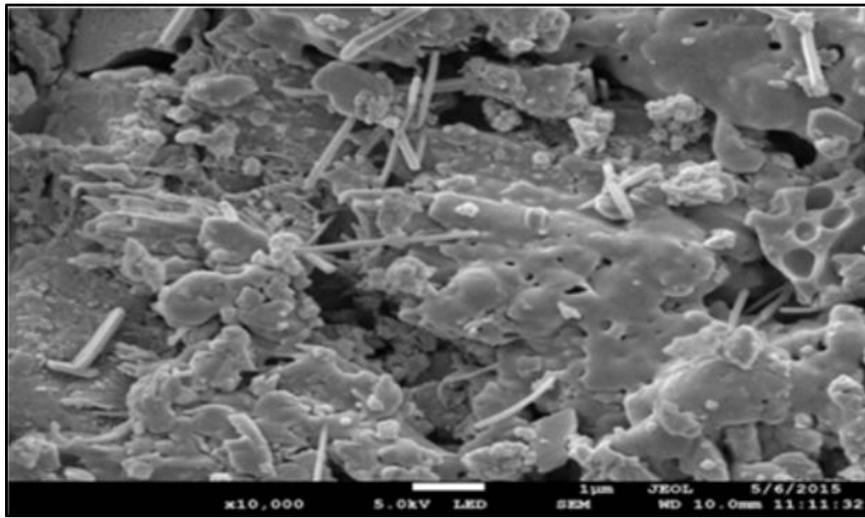


Figure 4. Scanning electron microscope of MSSA

RESULTS AND DISCUSSION

Compressive Strength Test

Compression test is one of the most important aspects in analyzing 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 and Figure 6.

From the graph, it is shown that the highest strength was achieved by W5 concrete with 55.85 MPa at the age of 180 days, 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 180 days. 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 was influenced by 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 favorable moist conditions will control the hydration process of the concrete [19]. 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 $\text{Ca}(\text{OH})_2$ 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.

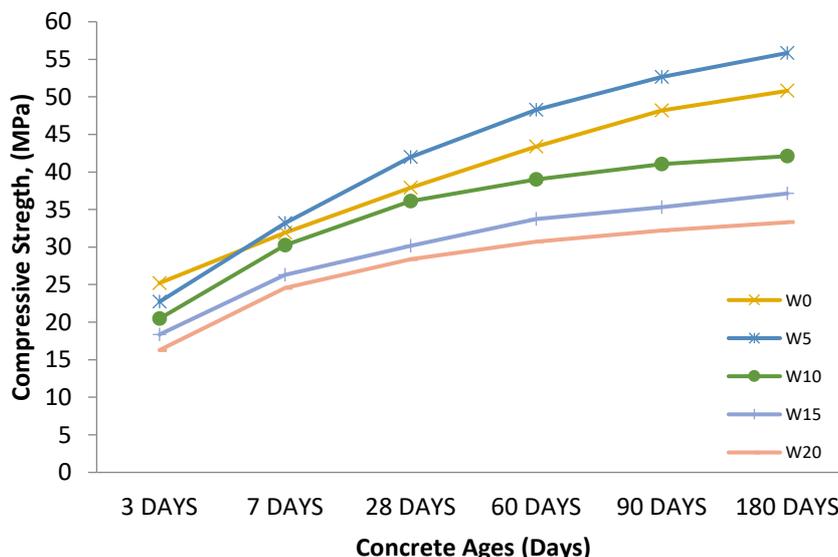


Figure 5. Compressive strength result for water cured MSSA concrete

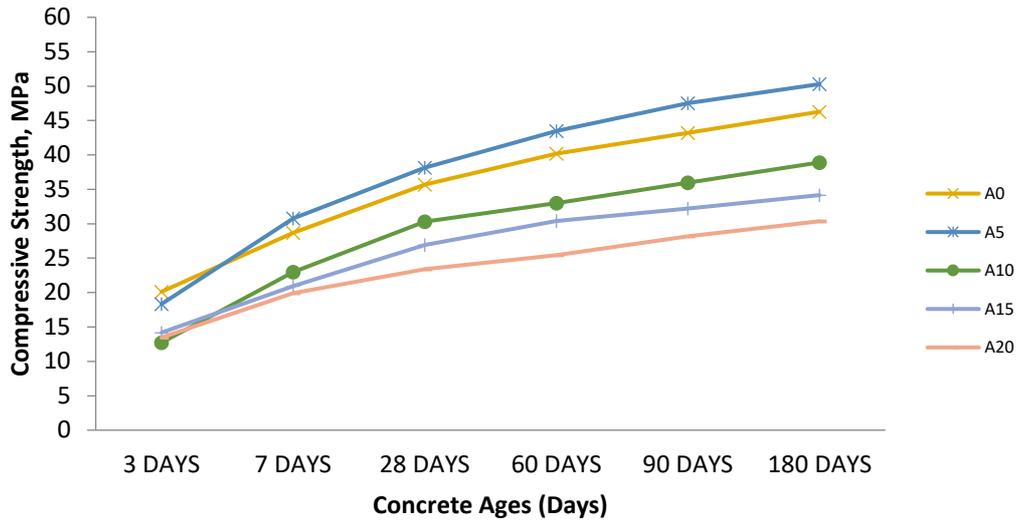


Figure 6. Compressive strength result for air cured MSSA concrete

Flexural Strength Test

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 7 for water cured concrete, and Figure 8 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 [20].

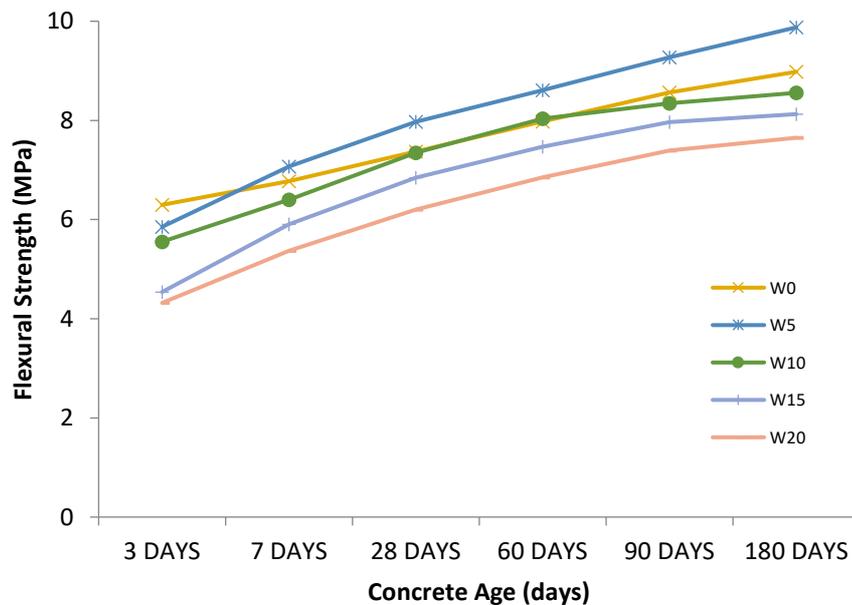


Figure 7. Flexural strength result for water cured MSSA concrete

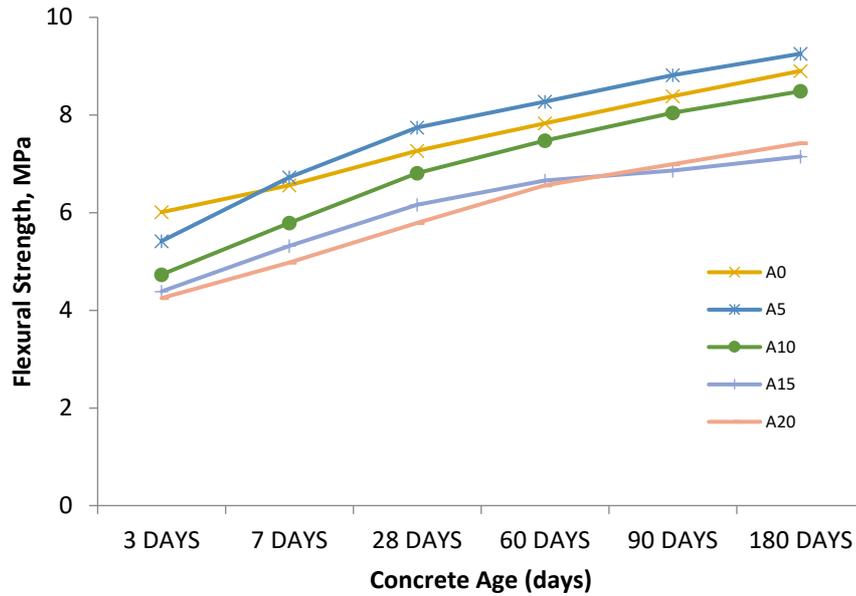


Figure 8. Flexural strength result for air cured MSSA concrete

Modulus of Elasticity Test

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 9 and Figure 10. The results indicate incorporation of suitable percentage of MSSA at 5% increase the stiffness of the concrete. The result also 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 was also shown in the report by [21]. 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 [22].

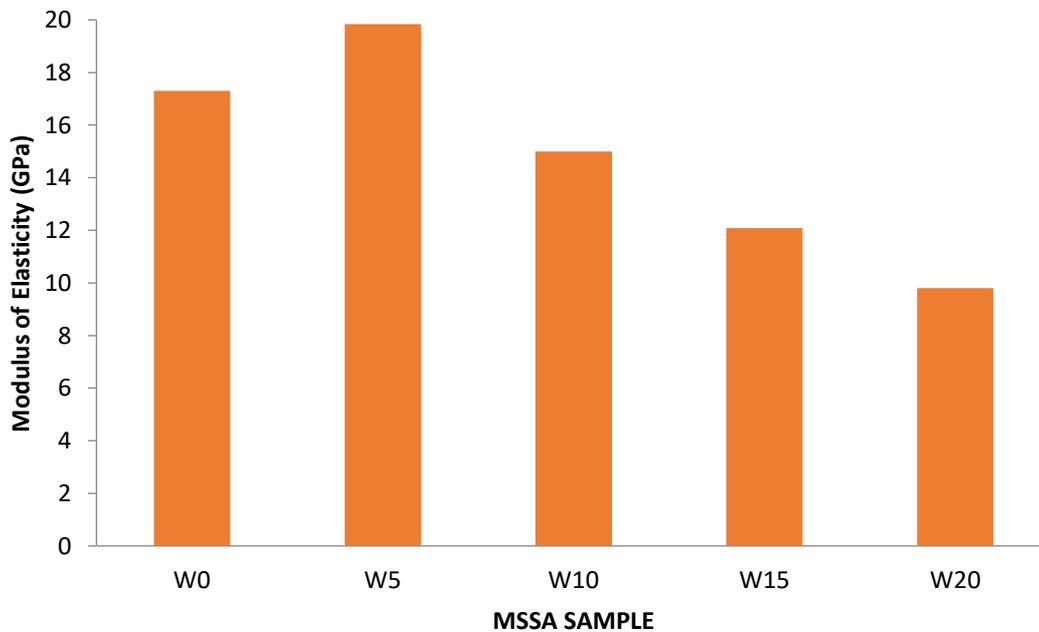


Figure 9. Modulus of elasticity for water cured MSSA concrete

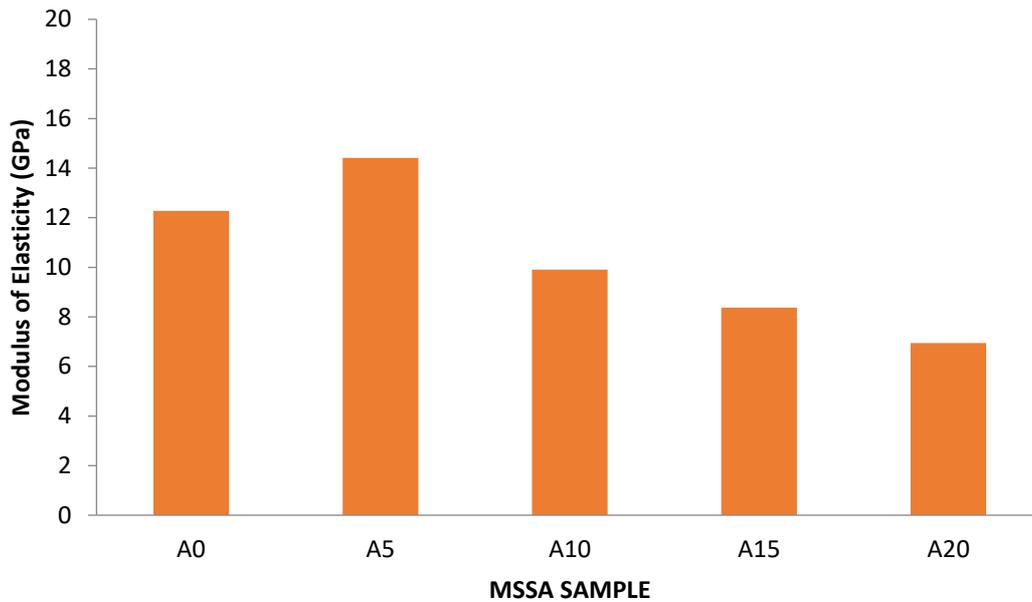


Figure 10. Modulus of elasticity for air cured MSSA concrete

Water Absorption Test

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 [23], concrete samples with below 10% of water absorption rate is considering as high quality concrete. As shown in the Figure 11 and Figure 12 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 11 shown that the water absorption percentage for water cured samples were lower than air cured samples shown in Figure 12. This proves that curing regime affect the water absorption rate of MSSA concrete in which this effect is similar to other concretes with local materials as replacement or additional materials [24]. Water curing samples undergo continuous hydration process of cement in concrete, thus provides $\text{Ca}(\text{OH})_2$ 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 W5 sample 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 [25]. Irregular particle and porous microstructure of sewage sludge ash increase the water demand when usage of sewage sludge ash increased in the concrete mixture [26].

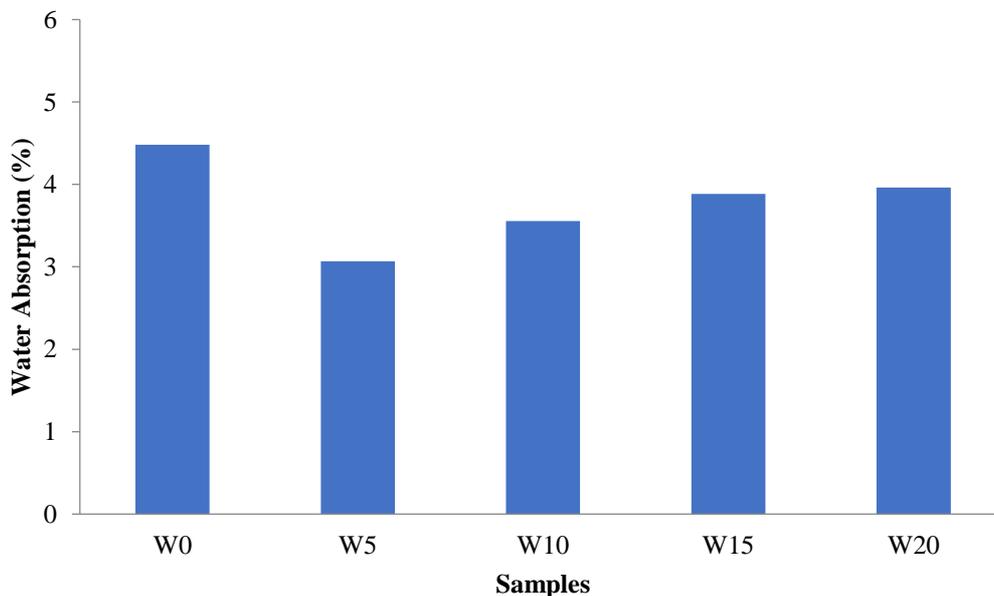


Figure 11. Water absorption result for water cured MSSA concrete

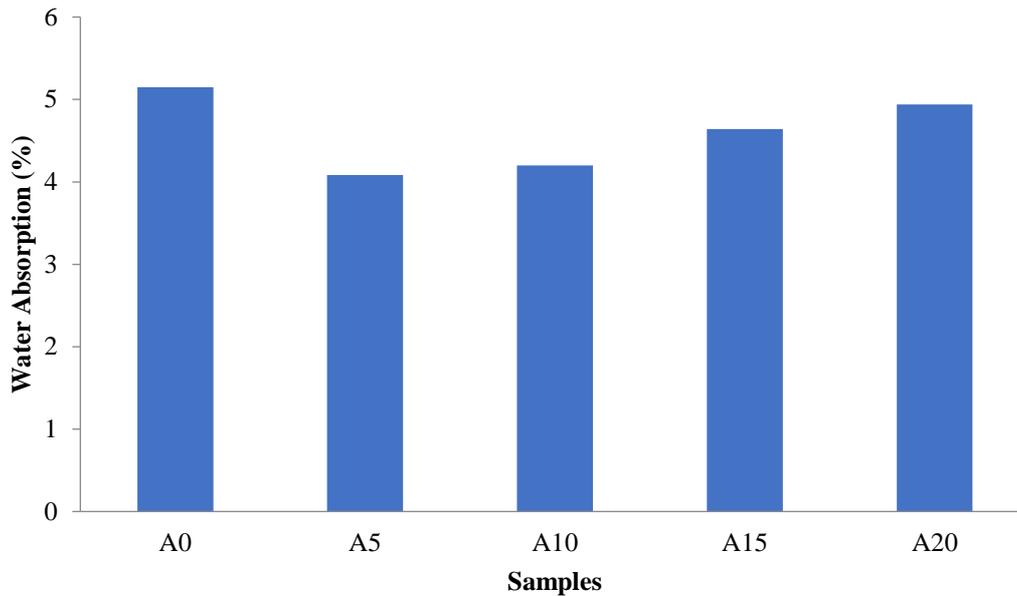


Figure 12. Water absorption result for air cured MSSA concrete

CONCLUSION

1. From the XRF analysis, 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. 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.
2. The formation of smooth structure found through SEM analysis, high content of SiO_2 and Fe_2O_3 through XRF analysis, and SiO_2 found as major component in XRD analysis has proved that High Temperature Mode of Microwave when burning the Microwaved Sewage Sludge Ash (MSSA) have shown that it will help in increasing the quality of concrete.
3. The mechanical properties concrete testing for MSSA concrete shown that water curing method is more suitable than air curing method in resulting good quality of concrete. The continuous water supply provided to the concrete specimen will ensure in generation of larger amount of C-S-H gel. Production of binding gel along with pozzolanic reaction and filler effect of MSSA makes the concrete denser and able to sustain larger load than air curing specimens.
4. Optimum percentage of using MSSA in concrete mixture is 5%. Based on the compressive strength test, water cured of 5% MSSA concrete (W5) shows the best in result at 180days of curing, which is 55.85 MPa. This is 9.94% higher than control specimen, and 9.95% higher than A5 specimen. In term of flexural strength, W5 specimen reached 9.98 MPa, while A5 reached, 9.26 MPa which is 7.78% in difference. Eventually, similar trend happening in modulus of elasticity test for the MSSA concrete. W5 achieved 19.84GPa, 37.68% higher than air curing MSSA concrete.
5. Additional of MSSA to concrete mixture for both air and water cured specimen has meets the requirement for good quality of concrete as it was below 10% of absorption. The rate of water absorption for water cured specimens were range from 3% to 4.5%, while air cured were 4% to 5.15%. Additional of MSSA to the concrete mixture has greatly reduce the water absorption due to its filling effect has fill up the voids in the concrete.

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