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# Mechanical properties of concrete containing microwaved sewage sludge ash as partial cement replacement

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**Abstract.** The production of sewage sludge waste from waste water treatment plant is increased every year as it is also only dumped in selected dumping area without maximize the utilization of the waste. As we are towards the process of developing our country, the demand of cement in construction industry was also increased. The problem stated has spark the idea of this research is to study the mechanical properties of the concrete that using different percentage of Microwaved Sewage Sludge Ash (MSSA) as partial cement replacement. Other objectives of this research are to determine the optimum percentage of the replacement of the MSSA in the concrete. Microwave heating method with two different temperature which are Medium and Medium High temperature were used to study the effect of different burning temperature of the Microwaved Sewage Sludge Ash (MSSA) to the concrete. The content percentage of MSSA used was tested with 0%, 5%, 10% and 15% respectively. The MSSA concrete undergo curing day for 3, 7 and 28days were then test with Compressive Strength test, Flexural Strength test and Ultrasonic Pulse Velocity (UPV) test. Based on the result, MSSA concrete with 5% replacement and heated with Medium High Temperature shows the best in result which is 44.52 MPa, with 1.25% higher in compressive strength compared to normal concrete. The Flexural Strength test shows that the 5% MSSA-Medium High temperature concrete is higher than normal concrete which is 7.79 MPa. It is also shown that UPV value for 5% MSSA-Medium High Temperature had lower value than control sample, 4.640 km/s at the age of 28days curing. As conclusion, concrete that contains 5% of MSSA replacement and burned with Medium High temperature show the best result among other sample.

## 1. Introduction

The rapid urbanization and increasing urban population leads to increase numbers of construction activities. Central Intelligence Agency reported that Malaysia population annual rate of change is growing by 2.66% from 2010 to 2015 [1]. Hence, concrete production materials, especially cement are highly demand due to growing numbers of construction activities [2]. However, cement composition is made up from non-renewable resources and also the production of cement acquires high usage of energy consumption due to its burning process. Due to the problem statement, the usage of waste to partially replace cement is the environmental-friendly solution to reduce the usage of cement [3]. In this research, sewage sludge is the waste that has potential to partially replace cement due to its inorganic components including  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$  and in flux (i.e.,  $\text{Fe}_2\text{O}_3$ ,  $\text{FeO}$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$ ) that can be used to improve the performance of construction materials [4 – 6]. It is reported by Indah Water Consortium Sdn. Bhd that the production of sewage sludge waste is drastically increase annually [7], [4]. Estimated in the year of 2020, 7 million cubic meter of sewage sludge waste will be produced [8]. In recent years, the increasing amount of sewage sludge waste also lead to high usage of landfills [9]. Burning process is a necessary process to remove the heavy metal from the sewage sludge. Microwave heating process were chosen to be applied in this research to burn the sewage sludge due to its potential technique that will supplies a volumetric heating process. The energy transferred during the heating process also directly transferred to the sewage sludge by using electromagnetic field [4]. The heating process also will uniformly distribute to whole materials as the



heat is generated volumetrically. Furthermore, microwave heating technique may require less energy and time consumption [10]. In the production of MSSA concrete in this research, the MSSA were burned using two different heating temperature, which are Medium and Medium High temperature to study the effect of different heating temperature to the mechanical properties of the concrete. Furthermore, different percentages of MSSA composition in concrete mixture were also tested. Compressive strength test, flexural strength test and Ultrasonic Pulse Velocity test were used to measure the mechanical properties of the concrete. Other than that, X-Ray Diffraction test were also conducted to study the chemical composition of the Microwaved Sewage Sludge Ash.

## **2. Methodology**

### *2.1 Materials/Mixing Ingredients*

#### *2.1.1 Ordinary Portland Cement*

Ordinary Portland Cement (OPC) is used in this research as it contains zero additives in the constituent of the cement which suitable to study the effect of additional of the MSSA to the concrete mixture. Cement used is YTL Orang Kuat that certified to MS 522-1:2007 (EN 197-1:2000). The cement was stored at dry place in the laboratory to avoid dampness.

#### *2.1.2 Coarse aggregates*

Crushed granite was used as coarse aggregate in this research. The size of coarse aggregate that used in this research is in the range between 5mm and not exceeded to 10mm following standard BS812:Part103. Thus, the condition of the coarse aggregates also must free from any moisture and impurities. This is important to make sure the coarse aggregates will functionally act to provide durability and resist compressive strength of the concrete.

#### *2.1.3 Fine aggregates*

Fine aggregate that used in this research is from river sand type. The maximum size used for the fine aggregate is not exceeded 4.75mm following BS410:1986. The River sand is stored in dry condition in the laboratory before the mixing process to make sure its moisture content not affecting the concrete mixture.

#### *2.1.4 Microwave Sewage Sludge Ash (MSSA)*

Sewage sludge Ash obtained for this research were collected from Indah Water Consortium Waste Water Treatment Plant, Kuantan branch. The water treatment plant was located in the residential area and commercial lot. Therefore, the collected sludge was categorized as domestic sludge. The collected sludge then oven dried at the laboratory with 1050 °C for 24 hours to remove the moisture content. It was then burned by using Microwave oven following the temperature of Medium and Medium High temperature for 30 minutes to produced Microwaved Sewage Sludge Ash (MSSA). The MSSA was then grind to obtain fine particle size and sieved with 150µm sieve shaker. Only pass through MSSA will be used for the concrete mixture. This is important to make sure the consistency of the size.

Based on the initial experiments, X-ray Diffraction (XRD) patterns for Microwaved Sewage Sludge Ash that burned with Medium temperature of Microwaved consist mainly of quartz (Silicon dioxide, SiO<sub>2</sub>) and Cesium Niobium Sulfide. Silicon dioxide (SiO<sub>2</sub>) is one of the pozzolan which responsible for pozzolanic reaction in contributing to concrete's strength. It also consist high amount of quartz with the intensity of 1334 cps at 27.16° and 374 cps at 21.32°. The XRD pattern for MSSA which microwave heated to Medium High temperature show that the quartz contains in the MSSA, (2452cps at 27° and 1211cps at 68.64° SiO<sub>2</sub>). Medium high temperature MSSA consist high amount of quartz with the intensity of 627 cps at 21.24.

#### *2.1.5 Tap water*

Water was always functioned to grant cement to carry out hydration process and reacts as binder in the concrete production. The volume of water used was calculated in the concrete mix design. The water

cement ratio used in this research was 0.55. The quality of water is important to control the concrete quality. Supplied tap water must also clean and free from impurities for mixing and curing purposes.

### 2.2 Mix Proportions

Concrete mix design is important in controlling the uniformity of the concrete. The water/cement ratio used in this research is 0.55. The concrete grade used is Concrete Grade 30. Four different percentage of MSSA is used in the concrete mixtures which are 0%, 5%, 10% and 15%. Furthermore, two different microwave heating temperature were used in this research. The mix proportion of concrete specimen is tabulated in Table 1. Table 2 represent the name representation for each sample.

**Table 1.** Mix proportion table.

| Materials          | Quantity (kg/m <sup>3</sup> ) |
|--------------------|-------------------------------|
| Cement             | 390                           |
| Coarse Aggregate   | 1120                          |
| Fine Aggregate     | 690                           |
| Water-Cement Ratio | 199                           |

**Table 2.** Name representation for sample used.

| Sample    | Content Description                        |
|-----------|--|
| 0MSSA     | 0% MSSA                                    |
| 5MSSA-M   | 5% of MSSA heated at Medium Temperature    |
| 10MSSA-M  | 10% of MSSA heated at Medium Temperature   |
| 15MSSA-M  | 15% of MSSA heated at Medium Temperature   |
| 5MSSA-MH  | 5% of MSSA heated Medium High Temperature  |
| 10MSSA-MH | 10% of MSSA heated Medium High Temperature |
| 15MSSA-MH | 15% of MSSA heated medium High Temperature |

### 2.3 Specimen Preparation and testing.

#### 2.3.1 Slump test

Slump test, BS EN 12350-2 [11] was carried out to identify the workability and consistency of the fresh concrete. The workability of a concrete mix defined as the case where it being mixed, delivered, positioned and compacted in place. First, the apparatus for slump test were cleaned and damped. Then, fresh mixed concrete was filled into the slump cone until one-third of cone height was achieved. Next, the fresh concrete layer was stroked for 25 times by using a standard tamping rod with 16 mm diameter and 600 mm length. The procedures were repeated by filling the slump cone with second and third layers as well as the tamping process. Afterward, the slump cone was lifted gently in vertical direction. After the slumping of fresh concrete, the height between the slump cone and fresh concrete was measured.

#### 2.3.2 Compressive Strength test

For compressive strength test, continuous load is applied on the specimen until failure happened and the maximum load is recorded. To increase the accuracy, three specimens for each MSSA replacement are prepared to obtain the average result. Flexural strength test is used to measure the tensile strength of unreinforced concrete beam to resist failure in bending. The test are undergo according to BS EN 12390-3[12].

### 2.3.3 Flexural Strength test

Flexural strength test used to measure the tensile strength of concrete beam to resist failure in bending. The test is conducted according to BS EN 12390-5[13]. Continuous applied load are performed on the specimen until failure occurred and the maximum flexural is recorded. Three specimens for each MSSA replacement and each microwave temperature are obtained at respective curing date to obtain average result to increase the result accuracy.

### 2.3.4 Ultrasonic Pulse Velocity test

The Ultrasonic Pulse Velocity (UPV) test is a non-destructive test which is used to determine the concrete quality in term of density, uniformity and homogeneity. It will identify the failure, crack of physical deterioration in the concrete structure. The reference standard for UPV test is BS1881: part 203[14]. Travel period of ultrasonic wave penetrate through the concrete and dependent on the properties of material, dynamic modulus of elasticity, density of material and the frequency of ultrasonic wave.

## 3. Result and discussion

### 3.1 Slump test

The test is conducted according to BS EN 12350-2. The slump results of different MSSA percentage are shown in Table 3. All of the slump are classified as true slump, and fall within the range of 50mm to 100mm. 15% MSSA for both microwave heating temperature had the highest slump values which indicated that high workability in 15% replacement. Therefore, the slump value of the sample is increases with the increment of MSSA content. Thereby, the workability of fresh concrete is increases as the MSSA replacement percentage increase. This might due to the inert characteristic MSSA whereby the idle reaction between MSSA and water which made the fresh concrete watery, thus increase the workability of fresh concrete. The microwave heating temperature did not affect the workability of the concrete as the slump value achieved the true slump.

**Table 3.** Slump type

| Mix Type   | Water-Cement Ratio | Slump (mm) | Slump Type |
|------------|--------------------|------------|------------|
| 0 MSSA     | 0.55               | 50         | True slump |
| 5 MSSA-M   | 0.55               | 55         | True slump |
| 10 MSSA-M  | 0.55               | 55         | True slump |
| 15 MSSA-M  | 0.55               | 60         | True slump |
| 5 MSSA-MH  | 0.55               | 55         | True slump |
| 10 MSSA-MH | 0.55               | 55         | True slump |
| 15 MSSA-MH | 0.55               | 65         | True slump |

### 3.2 Compressive strength

The cube test was carried out to determine the compressive strength of the concrete specimens according to BS EN 12390-3. Compressive strength is conducted immediately after the curing period of concrete reached for designed age. Concrete cube size 100mm x 100mm x 100mm was used for this test. Table 4 shows the result of compressive strength result of different burning temperature and different proportion of MSSA concrete at different curing age. From the figure we can see at the ages of 3 days, control samples achieved highest value among other samples. This can be concluded that early strength of MSSA samples is lower than control sample. The early hydration process is delayed with the MSSA replacement which leads to reduction in early strength The formations of calcium

silicate hydrate which is responsible for the early strength development in cementitious materials become retarded with the increment of SSA replacements.. 5 MSSA-MH samples had the highest compressive strength among others which is 44.52 MPa, 1.25% higher than control samples. Meanwhile, the compressive strength of 15 MSSA-M and 15 MSSA-MH were the lowest strength which is 19.19 MPa and 13.84 MPa respectively. This indicated that 15% replacement of MSSA is unfavorable as it decreases the strength of concrete.

**Table 4.** Compressive strength result according to curing days

| Sample     | Compressive Strength (MPa) |        |         |
|------------|----------------------------|--------|---------|
|            | 3 days                     | 7 days | 28 days |
| 0 MSSA     | 31.39                      | 34.32  | 43.97   |
| 5 MSSA-M   | 23.48                      | 26.43  | 35.68   |
| 10 MSSA-M  | 17.15                      | 20.80  | 25.30   |
| 15 MSSA-M  | 13.79                      | 15.03  | 19.19   |
| 5 MSSA-MH  | 26.93                      | 37.57  | 44.52   |
| 10 MSSA-MH | 24.65                      | 30.67  | 35.82   |
| 15 MSSA-MH | 7.60                       | 11.14  | 13.84   |

### 3.3 Flexural strength

Concrete beam samples with size 100mm x 100mm x 500mm following BS EN 12390-5 were used for this testing. The concrete beam samples were tested at the age of 7 and 28 days only. Continuous applied load are performed on the specimen until failure occurred and the maximum flexural load is recorded. Three specimens for each MSSA replacement at the respective curing date are prepared and undergo flexural strength test to obtain the average results in order to increase the results accuracy. Average results tested for three beams tested were shown in Table 5 below to obtain the average results for every proportion.

**Table 5.** Flexural Strength Result

| Sample     | Flexural strength (MPa) |         |
|------------|-------------------------|---------|
|            | 7 days                  | 28 days |
| 0 MSSA     | 5.61                    | 7.78    |
| 5 MSSA-M   | 3.80                    | 5.97    |
| 10 MSSA-M  | 4.31                    | 5.41    |
| 15 MSSA-M  | 3.47                    | 4.74    |
| 5 MSSA-MH  | 5.64                    | 7.91    |
| 10 MSSA-MH | 5.21                    | 6.27    |
| 15 MSSA-MH | 3.95                    | 4.84    |

From Table 5, it is shows that the flexural strength of 5 % MSSA concrete heated with Medium High Temperature (5 MSSA-MH) was slightly higher than the control sample at the age of 7 and 28 days. The flexural strength of 5 MSSA-MH was 5.64 MPa at the age of 7 days curing and 7.91 MPa at the age of 28 days curing. The concrete with 15% of MSSA replacement show the lowest strength of flexural compared to other samples. 15MSSA-M flexural strength result was 39.07% lower than control samples at the age of 28 days.

### 3.4 Ultrasonic Pulse Velocity test

UPV is a non-destructive test undergo predict the concrete strength and detect the presence of internal flaws. The test conducted according to BS 1881: Part 203. Concrete specimens with size of 100 mm x 100 mm at 7 and 28 curing days are used for the test. Direct transmission method is used to measure the transit period of ultrasonic pulse between transducers on the concrete surface. Table 3 below shows the UPV results.

**Table 6.** Ultrasonic Pulse Velocity test results.

| Sample     | Pulse Velocity (km/s) |         | Concrete Quality |
|------------|-----------------------|---------|------------------|
|            | 7 days                | 28 days |                  |
| 0 MSSA     | 4.558                 | 4.640   | Excellent        |
| 5 MSSA-M   | 4.238                 | 4.392   | Good             |
| 10 MSSA-M  | 3.896                 | 4.226   | Good             |
| 15 MSSA-M  | 3.764                 | 3.950   | Good             |
| 5 MSSA-MH  | 4.461                 | 4.661   | Excellent        |
| 10 MSSA-MH | 4.399                 | 4.613   | Excellent        |
| 15 MSSA-MH | 3.667                 | 3.964   | Good             |

From the results shows in Table 6., the UPV value of control sample is 4.558 km/s at the age of 7 days and 4.640 km/s at the age of 28 days. Meanwhile, the UPV values for MSSA concrete was ranging from 3.667 km/s to 4.661 km/s. The 5% MSSA content which was microwaved heated to medium-high temperature (5 MSSA-MH) in concrete had the highest UPV value while 15% MSSA content microwaved with Medium temperature (15 MSSA-M) had the lowest UPV value. This indicated that 5 MSSA-MH concrete perform better pozzolanic reaction than controlled sample. The pozzolanic reaction in the 5 MSSA-MH was improving the density, uniformity and homogeneity of the concrete. Thus, the durability increased.

## 4. Conclusions

- The increase of slump value is attributed by the characteristic of MSSA. As the content of MSSA increases, the slump value increases. The slump value falls in the range of 50 mm to 60 mm with the water cement ratio of 0.55.
- 5% MSSA which microwave heated at medium-high temperature as partial cement replacement had higher compressive strength than conventional concrete G30. Increment approximately 1.25% in compressive strength compared to conventional concrete G30. Thus, it improved the compressive strength of the concrete. Further increment of MSSA content decreased the compressive strength of concrete.
- MSSA replacement in concrete also increased the flexural strength. 5% MSSA which microwave heated at medium-high temperature showed minor increment in flexural strength. The flexural strength of concrete decreases with the increment of percentage of MSSA replacement.
- The UPV value for 5% MSSA-B was the highest which indicated that it performed better pozzolanic reaction in concrete. Pozzolanic reaction is responsible to the strength development of concrete. Thus, 5% MSSA which is microwave heated to medium high temperature improved the uniformity and homogeneity of the concrete.
- MSSA consist high content of  $\text{SiO}_2$  after microwave heating.  $\text{SiO}_2$  is the pozzolan which is responsible to the strength development of concrete. MSSA which microwave heated to medium-high temperature contained higher intensity of  $\text{SiO}_2$  compared to the MSSA which microwave heated to medium temperature. Thus, it contributes to a higher pozzolanic activity in concrete.
- The optimum percentage of cement replacement in concrete is 5% MSSA which microwave heated to medium-high temperature as it performed a higher compressive strength and minor increment in flexural strength compared to conventional concrete G30.

- g) Microwaved Sewage Sludge Ash got the potential in replacing partially the cement usage in concrete production as it increases the strength of the concrete.

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