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# Compressive Strength of Concrete with Sewage Sludge Ash (SSA)

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**Abstract.** This study was carried out to determine the density and compressive strength of concrete using Sewage Sludge Ash (SSA) as combination of cement and fine aggregate replacement. The SSA suggested replacing the cement in the concrete because it has similar Pozzolanic properties of Ordinary Portland cement (OPC). Besides that, the particle size of the SSA after incineration process is similar to the fine aggregate that used in the concrete. The incineration process of the SSA takes 2 hours at the temperature of 1000°C. The sieving process will take place after incineration process and the SSA will be used as fine aggregate replacement. The remaining SSA will be grounded with ball mill and used as cement replacement. In this study, the compressive strength design by using DOE method to achieved 30 MPa (target mean strength of 46 MPa) at 28 days. The density of the SSA concrete has higher value compare to control sample because the incineration at 1000˚C will increase the density of SSA. Previous study shows that 10% of SSA replaces cement in a concrete give same compressive strength value as control sample and the acceptable percentage of fine aggregate is between 10 to 25 percentages. Comparatively, the compressive strength of concrete when SSA used as combination of cement and fine aggregate replacement also give higher value compare to control sample.

## 1. Introduction

Sludge is an inevitable by-product of wastewater treatment [9]. Based on the perspective Sludge Production Factor (SFD), about 5.3 million $m^3$ per year of sewage sludge was produced by national sewage company such as Indah Water Konsortium [11]. The projected sludge generation in the year of 2035 is estimated at 10 million $m^3$ per year with average 2% of solid content [11]. Based on the Indah Water [11], the sludge reuse options in Malaysia are land reclamation, composting, building materials, reforestation, and power generation.

Common methods of disposal are by land filling, ocean dumping, and spreading on reclaimed land. However, these common methods of disposal of sludge are poses complex problem since it can affect the environment such as air, land and water pollution. One of the options to minimize these problems is by applying the Sewage Sludge Ash (SSA) to replace certain percentage of cement and aggregate in the concrete. Therefore, many researchers have carried out the study on utilization of wasted materials as building and construction materials in order to reduce the environmental problem. The study on the possible use of the of sewage sludge ash as building and construction materials have been carried out by various researchers. This study is very useful in order to minimize the environmental problems.

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Besides that, the SSA will have a useful value or commercial value when it can be used to minimize the environmental problem and used as a useful material.
Since the methods of the disposal of sludge can affect the environment as well as the materials' cost of the construction project, there is a need for alternatives to solve these problems. Disposal of sludge is an unsatisfactory solution especially when it disposes directly into landfill [13]. Therefore, there are studies carried out about the possible use of the sludge and sludge ash as building and construction materials by various researchers. The reuse of sewage sludge into construction materials not only minimize the disposal problem but also economic, ecological and energy saving advantage [9].
The behaviours of concrete when SSA used to replace cement and its optimum percentage have been studied. Besides that, the acceptable percentage of fine aggregate used in a concrete also have been studied. However, the behaviours of concrete such as its density and compressive strength when the optimum percentage (10%) of SSA used as cement replacement combine acceptable percentage of SSA used as fine aggregate replacement are not clearly study. Apart from minimize the environmental problems, this study will help to reduce the usage of cement and fine aggregate in a concrete as well as reduce the cost of the materials. Therefore, these behaviours of the concrete will be determined in this study.
The strength of concrete is defined as the maximum load or stress that can carry by the concrete [5] [10]. Strength in compression is one of the important behaviour in cement-based materials. Based on the study that carried out by [1], the 10% of the SSA replace cement in concrete conformed to design 28 days compressive strength when cured more than 28 days. [1] conclude that 10% of the SSA replace cement in concrete could apply to unreinforced concrete to reduce the use of cement. [9] also concludes that compressive strength of concrete cubes with 10% of SSA to replace cement was about same strength as control strength. Therefore sludge ash could be recommended for non structural use such as walkways, pavements and also drains [9]. Based on the studied that have been carried out by many researchers, 10% of SSA can be used to replace cement in concrete because the compressive strength shows the little decrease at 28 days. Increasing the SSA percentage as cement replacement in a concrete mix design will decrease the compressive strength of the concrete [12]. [12] concluded that there is potential of domestic waste sludge powder or SSA used as partial cement replacement.
In this study, the SSA was used as combination to replace cement and fine aggregate (sand) in one concrete sample. Therefore, the objectives in this study are to determine the density and compressive strength of the concrete when 10% of SSA replacement of cement and adding 10% of SSA replacement of fine aggregate.


**Figure 1.** Process of production of SSA.

## 2. Methodology

### *2.1. Production of SSA*
Based on studies done previously by many researchers [2], the temperatures of 1000$^{o}$C and above are mostly used. The lower temperature induces slow and low strength development because of low of CaO, $SiO_2$ and $Al_2O_3$[8]. In this study, Dried Sewage Sludge (DSS) was collected from Sewage Treatment plant and was incinerated at 1000$^{o}$C for 2 hours at the furnace to produce sewage sludge ash (SSA) (Figure 1). The process follows with fast cooling in an open air. After which some of SSA was sieved and used as replacement of fine aggregate in the concrete cube. Remaining amount of SSA was then grinded using ball-mills inside the Ball Mill Machine for 12 hours at a speed of 30 rpm. The number of ball-mills used in this study was six (6) of large size and fourteen (14) of small sizes. The grinded SSA was used as 10% replacement of cement and the ungrounded SSA of 10% was used as replacement to fine aggregate.

### *2.2. Preparation of Concrete Cube*
In this study, the concrete mixture was designed (Table 1 & 2) according to [4] British Standard (BS 1881) to achieve the target mean strength of 46 MPa at ages of 28 days using 0.47 water cement ratio. Cube mould of 150mm×150mm×150mm was used to cast the concretes following standard procedures. These concrete samples were left for 24 hours in the laboratory for ambient drying process before placing them in curing tank.

**Table 1:** Concrete Mix Design per m$^3$ and per Trial Mix (water-cement ratio=0.47)

| Quantities | Cement (kg) | Water (kg) | Fine Aggregate (kg) | Course Aggregate (kg), Size of 10 mm |
|---|---|---|---|---|
| Per m$^3$ (nearest 5 kg) | 436 | 205 | 587 | 1192 |
| Per trial mix of 0.00375 m$^3$ | 1.64 | 0.77 | 2.20 | 4.47 |

**Table 2:** Concrete Sample Mix Design (w/c ratio = 0.47)

| Sample | No. of Sample | Cement (kg) | Water (kg) | Fine Aggregate (kg) | Course Aggregate (kg), Size of 10 mm | SSA (kg) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Grounded | Ungrounded |
| S0* | 9 | 14.76 | 6.93 | 19.80 | 40.23 | - | - |
| S1* | 2 | 2.96 | 1.54 | 3.96 | 8.94 | 0.32 | 0.44 |
| **Total** | **11** | **17.72** | **8.47** | **23.76** | **49.17** | **0.32** | **0.44** |

- S0*: Concrete sample contained 0% of SSA
- S1*: Concrete sample contained 10% of grounded SSA (cement replacement) and 10% of ungrounded SSA (fine aggregate replacement)

### *2.3. Concrete Testing*

*2.3.1. Density Test.* After the concrete samples reach their curing time, their density was determined according to [3] BS 1881: Part 114: 1983 (Method for determination of density of hardened concrete) using equation (1). The value of the density of each sample was calculated and recorded. Finally, its average value was determined accordingly.

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$$\text{Density} = \frac{\text{Mass of Concrete}}{\text{Volume of Concrete}} \left(\frac{\text{kg}}{\text{m}^3}\right) \quad (1)$$

*2.3.2. Compressive Strength Test.* Compressive strengths of the concrete samples were determined according to BS: Part 116: 1983 (Method for determination of compressive strength of concrete cubes). Compression Machine Test was used to obtain the maximum loads and compressive strength. The loading to the concrete samples, were applied continuously at nominal rate within the range 0.2 $N/mm^2.s$ to 0.4 $N/mm^2.s$ until no greater load can be sustained. By using the compressive Machine Test, the maximum load is obtained and is recorded. By using equation (2), the compressive strength of each sample was determined. The average of the concrete cube samples also was calculated and recorded.

$$\text{Compressive strength} = \frac{\text{Maximum load}}{\text{Cross Sectional Area of Cube Sample}} \left(\frac{\text{kN}}{\text{m}^2}\right) \quad (2)$$

## 3. Result and Discussion

### *3.1. Density of Concrete*

The relationship of density of concrete cube and curing time is expressed in Figure 2 below.

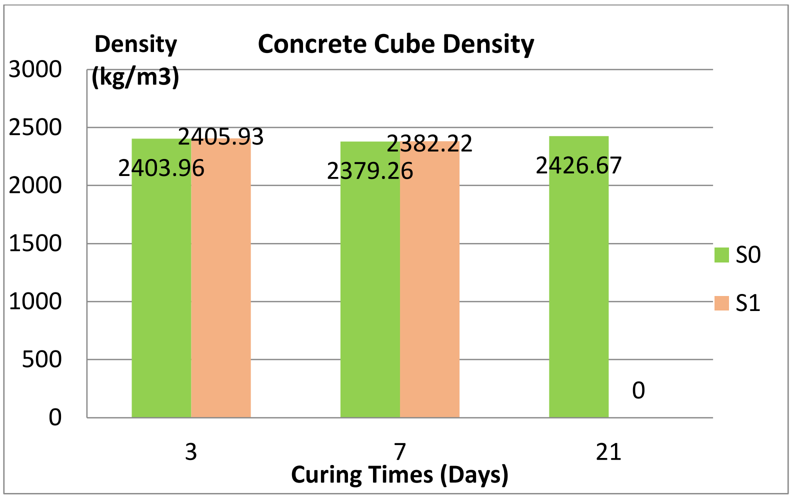


**Figure 2:** Relationship between concrete cube density and curing time.

For the control sample of the cube, the average mass is calculated. The average density of the control sample at curing time of 3, 7 and 21 days is 2 403.96 $kg/m^3$, 2 379.26 $kg/m^3$ and 2 426.67 $kg/m^3$ respectively. The density value for the concrete cube that contain combination of 10% of SSA to replace cement and 10% of SSA to replace fine aggregate at 3 and 7 days is 2 405.93 $kg/m^3$ and 2 382.22 $kg/m^3$ respectively.

The density of control samples fall between 2379 $kg/m^3$ to 2426 $kg/m^3$. The densities of SSA concrete samples fall between 2380 $kg/m^3$ and 2426 $kg/m^3$. Based on [7], the density of SSA concrete may be influenced by incineration temperature. Since the incineration temperature used in this study was 1000°C, the density values of the SSA concrete samples were found to be slightly higher than control samples. Therefore, the result may conclude that the usage of SSA in concrete may increase the density of concrete.

### *3.2. Compressive Strength*

The relationship of compressive strength of concrete cube and curing time is expressed in Figure 3 below.

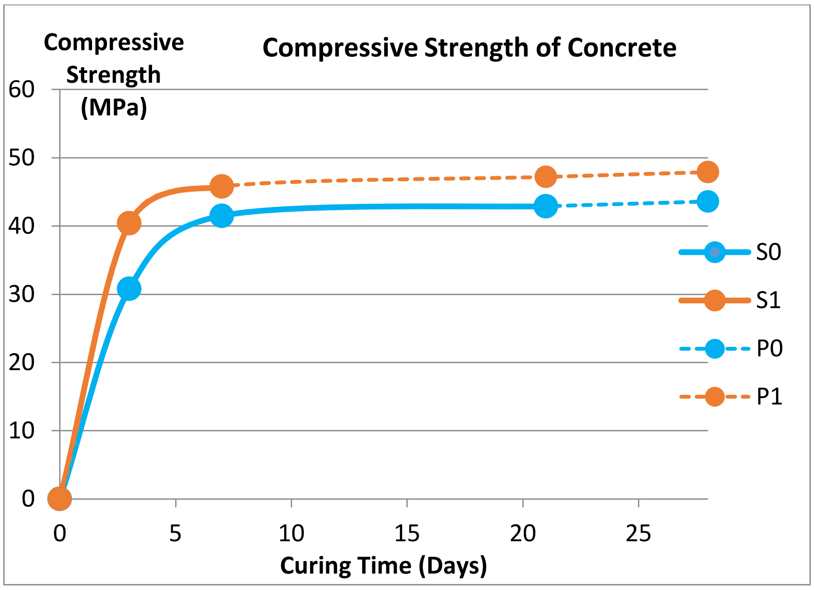


**Figure 3:** Relationship between compressive strength and curing time.

- S0: Concrete sample contained 0% of SSA
- S1: Concrete sample contained 10% of grounded SSA (cement replacement) and 10% of ungrounded SSA (fine aggregate replacement)
- P0: Prediction of concrete sample contained 0% of SSA
- P1: Prediction of concrete sample contained 10% of grounded SSA (cement replacement) and 10% of ungrounded SSA (fine aggregate replacement)

For the control sample, the average of maximum load is calculated. Compressive strength of concrete cubes is obtained using Compressive Strength Formula, where the parameter needed is average of maximum load and cross sectional area. The compressive strength of the control sample at curing time of 3, 7 and 21 days is 30.8 MPa, 41.5 MPa and 42.9 MPa respectively. The compressive strength value for the concrete cube that contain combination of 10% of SSA to replace cement and 10% of SSA to replace fine aggregate at 3 and 7 days is 40.4 MPa and 45.8 MPa respectively.
Based on the result obtained at 3 and 7 days of curing time, the compressive strength of concrete cube that contain SSA as cement replacement and fine aggregate replacement is higher compared to control sample. The compressive strength of concrete cubes with 10% of SSA as cement replacement was about same strength as control strength [9]. The optimum percentage of SSA to replace cement is 10% was used to combine with 10% of SSA to replaced fine aggregate. Referring to [6], the acceptable replacement percentage of SSA to replace fine aggregate in the concrete is up to 25%.
According to the available data, prediction was done for projected strength of SSA concrete (figure 3). The P0 and P1 are referring to the prediction value of compressive strength for concrete sample and SSA concrete respectively. The projected value for concrete sample at 28 days reaches 43.6 MPa. The projected compressive strength value for the SSA sample is 47.2 MPa for 21 days and 47.9 MPa for 28 days respectively. The projected values of the SSA sample found to be attaining the target mean strength at 21 days.
Therefore, it can concluded that the combination of 10% SSA used as cement and fine aggregate replacement in the concrete may give significantly higher compressive strength value compared to control sample. Besides that, the combination of 10% SSA used as cement and fine aggregate replacement in the concrete also were found to be attaining higher projected value of strength compared to control sample at 28 days of curing.

## 4. Conclusion and Recommendations

### *4.1. Conclusion*

From the study carried out, it may be concluded that:

1. Based on the result obtained, the density value of concrete cube that contained combination of SSA has insignificant differences or almost of the same as control sample. It shows the incineration temperature at 1000°C for 2 hours have insignificant effect on the concrete cube density.
2. Besides that, the compressive strength of combination 10% of cement and 10% of fine aggregate replacement is significantly higher than control sample. The concrete cube sample that contained SSA reached target mean strength value at 21 days. This shows that SSA may have potential to be used in a concrete with incineration temperature of 1000°C for 2 hours. The usage of SSA in a concrete will be beneficial since it can replace two materials in a concrete which is cement and fine aggregate.

As a conclusion, the density and the compressive strength value of the concrete have been determined and analyzed. Therefore, the objective of this study has been achieved.

### *4.2. Recommendation*
Based on the results obtained in this study, the following recommendations are suggested in order to improve and further enhance the outcome of studies related to SSA concrete;

1. Studies can be conducted by increasing the number of sample for each curing time in order to obtained more reliably accurate result.
2. Compressive strength test to be carried out for samples of 28 days curing time in order to verify the projected value.
3. Studies to be conducted to determine the optimum percentage of SSA replacement for fine aggregate when it combines with 10% of SSA as replacement in the concrete.
4. Further studies can be conducted using different incineration temperature and the duration in order to obtain less dense concrete.

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