Flexural Strength of Sewage Sludge Ash (SSA) Concrete

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Abstract. Studies about the sewage sludge becoming popular since the sewage sludge can be treated to produce sewage sludge ash (SSA) which has the potential to replace a percentage of cement. This study focuses on the flexural strength of the sewage sludge ash (SSA) concrete for 3, 7 and 21 days of curing relatively to its density. In this study 10 percentages of SSA was used as a replacement to cement and fine aggregates. SSA had known to exhibits pozzolanic properties similar to Ordinary Portland Cement (OPC). SSA was also used to replace the fine aggregates since by products of incineration as the particle size distribution has similar sizes to fine aggregates normally used in concrete mix. Besides, many studies also mention that SSA used in concrete may produce lightweight concrete. The SSA was incinerated at 1000°C for 2 hours followed by cooling in open air. Some of the SSA was sieved to be used as fine aggregates and some was grounded to be used as cement. Number of sample that was prepared for this study was 14 and it was design to achieve compression strength of 30MPa at 28 days based on DOE method. The flexural strength of concrete for cement replaced with SSA was lower than the control sample but it has an early flexural strength. The flexural strength of concrete for fine aggregate replaced with SSA was higher compared to the control sample.

1. Introduction

Environmental problem has become a global issue and lots of studies have being carried out as to identify possible and reliable ways in reducing the problem and improving ones way of life. Disposal of sewage sludge to the environment is a serious concern both in developing and developed countries. Studies about the sewage sludge became popular in recent years since the sewage sludge can be treated to produce sewage sludge ash (SSA) which has the potential to replace certain percentages of cement, which may reduce the environmental impact of disposing the sewage sludge. Besides, this may also contributes towards reducing cost of construction using Ordinary Portland Cement (OPC). The SSA is produce by incineration of the dried sewage sludge (DSS) and in past practice, it is disposed in a controlled landfills. Disposing SSA could result in increased amount of land required to dispose as well as ground contamination since it contains heavy metals. Therefore, as said earlier applying SSA to replace concrete to a certain amount may reduce these problems. SSA can be used as a cement replacement since its hydraulic properties and major elements are similar to cement i.e. silica, iron, calcium, aluminum, magnesium, phosphorus and oxygen. Numerous studies on the use of SSA as cement and fine aggregates (Sand) have been done [1]. Further study on SSA may lead to a breakthrough in the construction industry.

Concrete is the most preferred construction materials to build a structure since it is more economical, flexible, and durable compared to steel and timber. Concrete composed of water, cement, coarse and fine aggregates with a specific ratio of the components. Since one of the major component is cement
which is increasing in price, substitute materials to replace it has been done. Examples of cement substitutes are hydraulic fly ash, activated slag, and calcium sulfoaluminate which have been researched to be a great alternative to cement [2]. The use of incineration for sewage sludge has been rising since the volume of the waste is reduced, and pathogenic organisms and volatile contents can be eliminated which leads to the disposing of SSA to be a new problem [3]. Since SSA can be reused for concrete, it is essential to further the research on the material.

SSA was suggested to be included since it exhibits pozzolanic properties similar to cement. However, the pozzolanic properties are lower compared to Portland cement which will reduce the strength of the concrete. To counter the low pozzolanic properties, replacing a percentage of cement in SSA may prove beneficial not only in terms of the concrete performance, but also helping the environment by providing a way to recycle the SSA [4]. Sewage Sludge was traditionally used as a fertilizer in agriculture however many countries reconsider its use because concern of accumulation of heavy metals in soil and pathogenic organisms. The increase in the production of sewage sludge has many countries resort to incineration, which led to the problems of disposing the SSA since landfills becomes less abundant [3]. Including SSA in concrete may provide an alternative to reuse this materials as well as reducing the construction price since most of this waste material is free. Researches need to be done before SSA can be included in concrete to observe the negative or positive effects.

This study is to determine the flexural strength of concrete where the percentage of cement is modified with the inclusion of SSA. The SSA has been thermally and mechanically treated and an optimum percentage of cement replaced has been determine based on past research which is 10% SSA replace as cement by weight. The SSA concrete is tested for its flexural strength and to see whether it is cost effective to be implemented.

Since countries like Spain and United Kingdom has problem disposing the sewage sludge, many studies have been done to utilize the SSA such as in lightweight concrete [5], bricks [6] and aerated concrete [7]. In the future, Malaysia will face a similar problem since Malaysia will continue to be modernized. Another problem is the rising price of cement due to the high demand of the construction industry [8]. The optimum SSA replace in cement and the behavior of SSA such as water absorption, density and weight class has been studied. Question that needs to be answered are: what is the flexural strength of SSA replacing a percentage of cement? What is the flexural strength of SSA replacing a percentage of fine aggregates? Does SSA concrete will affect the concrete performance?

Thus, the objectives in this study are to determine the density and flexural strength of the concrete with 10% of the weight replace with cement and fine aggregate at 3, 7 and 21 days.

![Figure 1](image1.png)

**Figure 1.** Process of preparation of SSA.
2. Methodology

2.1. Preparation of SSA

Figure 1 show the processes involved in SSA preparation. The Dried Sewage Sludge (DSS) was collected from Sewage Treatment Plant (STP). The collected DSS was incinerated using incinerator at 1000°C for 2 hours to produce the SSA and fast cooling in an open air. Then, some of the SSA was ground using the Ball Mill Machine for 12 hours at the speed of 30 rpm. Six (6) numbers of large size and fourteen (14) numbers of small sizes of ball mills was used. The grounded SSA will be used to replace a percentage of cement while the ungrounded SSA will be sieved and used to replace a percentage of sand during the preparation of the concrete beam. The SSA will be stored in separate containers until further testing.

2.2. Preparation of concrete sample

The concrete beam was designed according to British (DOE) method where the mix will be mixed using Concrete Mixer. The size of the beam used was 100mm x 100mm x 500mm. The design mix was calculated based on weight in accordance to DOE method and summarized in Table 1 and 2. The beam mould was cleaned properly and a layer of grease is smeared in the mould before concrete is to be poured. The concrete was poured in a mould and vibrated using a vibration table. The sample was stored in the laboratory for 24 hours until transfer to the curing tank.

\[ \text{Table 1. Concrete mix design per m}^3 \text{ and per trial mix (water-cement ratio=0.47)} \]

| Quantities                  | Cement(kg) | Water(kg) | Fine aggregate(kg) | Course Aggregate (kg) (Size =10mm) |
|-----------------------------|------------|-----------|--------------------|-------------------------------------|
| Per m\(^3\) (nearest 5 kg)  | 436        | 205       | 587                | 1192                                |
| Per trial mix of 0.005 m\(^3\) | 2.18       | 1.03      | 2.94               | 5.96                                |

\[ \text{Table 2. Concrete sample mix design (w/c ratio = 0.47)} \]

| Sample | No. of Sample | Cement (kg) | Water (kg) | Fine aggregate (kg) | Course Aggregate (kg) (Size =10mm) | SSA (kg) |
|--------|---------------|-------------|------------|--------------------|-------------------------------------|----------|
| C0     | 9             | 19.62       | 9.27       | 26.46              | 53.64                               | -        |
| C1     | 3             | 5.88        | 3.09       | 8.82               | 17.88                               | 0.66     |
| C2     | 2             | 4.36        | 2.06       | 5.29               | 11.92                               | 0.59     |
| Total  | 14            | 29.86       | 14.42      | 40.57              | 83.44                               | 1.25     |

(C0: Control concrete beam sample, C1: 10% of cement replaced by SSA concrete beam sample, C2: 10% of sand replaced by SSA concrete beam)

2.3. Concrete testing

2.3.1. Density test. The concrete beam size 100mm x 100mm x 500mm will be used in determining the density of the samples as in [9]. The mass of each concrete beam is determined by using weighing machine. The volume of the test specimen which is concrete beam should not less than 40d\(^3\), where d is the nominal size of the aggregate. The size aggregate used in this study is 10mm which means the concrete beam should not less than 40 000 mm\(^3\). The actual volume of the concrete beam is 5 000 000 mm\(^3\) which is more than 40d\(^3\). The density value will be determined by using Density equation (1) below.
2.3.2. Flexural test. The concrete beam size 100mm x 100mm x 500mm will be used in determining the flexural strength of the samples as in [10]. There are nine (9) samples for each type of concrete beam (3 types of concrete beam) and three (3) specimen of each beam will tested at 3, 7, and 21 days of curing time. Force (F) is applied to the concrete beam at an increment of 0.06 ± 0.04 N/(mm.s) as in BS 1881 Part 118 using the Universal Testing Machine until crack appears on the concrete or until the universal testing machine stopped. The flexural strength of each concrete can be calculated using the equation (2). Finally, the average flexural strength of each concrete beam tested is calculated and recorded.

\[
\text{Flexural Strength} = \frac{F \times 1}{w \times d^2} \left( \frac{N}{\text{mm}^2} \right) \tag{2}
\]

3. Result and Discussion

3.1. Density of concrete

The average density of the control sample at 3, 7 and 21 days is 2412 kg/m³, 2402 kg/m³ and 2344 kg/m³ respectively. The density for the concrete with 10% cement replaced with SSA at 3, 7 and 21 days is 2436 kg/m³, 2376 kg/m³ and 2398 kg/m³ respectively. The density for the concrete with 10% fine aggregate replaced with SSA at 3 and 7 days is 2456 kg/m³ and 2464 kg/m³ respectively. Figure 2 shows the densities of the different types of concrete for the specified curing time.

From this result, it is analysed that there is a small variation in the concrete density of the different types of concrete. It is to be expected that the density of the SSA concrete will be similar or higher compared to the control sample since the optimum incineration time of 1000°C was selected. The increase in density of SSA is directly proportional to the incineration temperature but drops off after the temperature exceeds 1000°C [7]. It is concluded that the concrete replaced with SSA incinerated at 1000°C has an insignificant impact in density.

![Figure 2](image-url)
3.2. Flexural Strength

The average flexural strength of the controlled sample for 3, 7 and 21 days is 3.62 MPa, 4.78 MPa and 4.84 MPa respectively as shown in Figure 3. The flexural strength of concrete with SSA replace 10% of cement for 3, 7 and 21 days is 4.63 MPa, 4.67 MPa and 4.73 MPa respectively. The flexural strength of concrete with SSA replace 10% of fine aggregate for 3 and 7 days is 5.20 MPa and MPa respectively.

From the results, it is analysed that concrete replaced 10% of cement with SSA has a high early flexural strength with 4.63 MPa at 3 days compared to the control sample with a flexural strength of 3.62 MPa. The longer the curing time, the flexural strength of the SSA concrete increases rate has slowed down as shown in figure 4.2. The concrete control sample flexural strength surpasses the SSA concrete at 7 day onwards. This means that concrete replaced with 10% of cement with SSA has a high early flexural strength but lower flexural strength at increase curing time compared to a normal concrete.

Moreover, concrete replaced with 10% of fine aggregate with SSA has a higher early flexural strength compared to the control sample. The flexural strength of the SSA concrete at 3 day is 5.20 MPa surpasses the flexural strength of the concrete control sample for 21 day which is 4.84 MPa. This may have been a result of increase in density during the incineration process which results the SSA being more compact thus increase in strength. Besides, the different chemical composition of the SSA may result in the increase in strength of the concrete [11].

![Flexural Strength of Concrete Beam](image)

**Figure 3.** Relationship between flexural strength and curing time.
(C0: Control concrete beam sample, C1: 10% of cement replaced by SSA concrete beam sample, C2: 10% of sand replaced by SSA concrete beam)
(P0: Prediction of control concrete beam sample, P1: Prediction of 10% of cement replaced by SSA concrete beam sample, P2: Prediction of 10% of sand replaced by SSA concrete beam)

The results of SSA as cement may be lower since the SSA has a low pozzolanic activity compared to Ordinary Portland Cement (OPC). SSA as fine aggregate may produce different result due to the particle differs in size during sieving compared to the powdery SSA after grounding. The finer SSA
reacts with water to become a cementitious material compared to the large particle size of the ungrounded SSA which is used as fine aggregates which limits its interaction with water. It can be concluded that SSA used to replace 10% of cement in concrete has a higher early flexural strength but lower end flexural strength. SSA used to replace 10% of fine aggregate in concrete has high flexural strength compared to the control sample. For this study, we have limited time and resources therefore the flexural strength at 28 days for concrete with 10% cement replaced by SSA and flexural strength at 21 and 28 days for concrete with 10% fine aggregate replaced by SSA was predicted based on normal concrete behaviour which increases linear-elasticly by a small amount nearing the end strength.

4. Conclusion and Recommendations

4.1. Conclusion

From the investigation carried out, it can be concluded that:

1. The results obtained showed that the density of the concrete increase slightly or almost similar to the control sample. It can be concluded that SSA incinerated at 1000°C for 2 hours have an insignificant effect on the concrete.
2. The flexural strength of 10% of cement replaced with SSA in concrete shows a high early strength at 3 days with 1.01 MPa compared to the control sample but low strength with increase in the curing duration. The difference in the strength value of both of this concrete is very small that it can be concluded that the decrease in strength for the SSA as cement in concrete should be considered during design calculations but it does not affect the performance of the concrete.
3. The flexural strength of 10% of fine aggregates replaced with SSA in concrete shows high strength at any curing duration. This shows that the potential of SSA incinerated at 1000°C for 2 hours and sieved to the right particle size could be used to make concrete in the industry. The SSA as fine aggregate in concrete surpasses the flexural strength of the control sample with 1.58 MPa at 3 days and 0.49 MPa at 7 days. Therefore it can be concluded that there is an increase in the concrete performance with SSA replacing 10% of fine aggregates.

As a conclusion, all the objective of this study has been obtained to explain SSA as a partial replacement in concrete.

4.2. Recommendation

Based on the results obtain from this study, the followings are recommended for future study to enhance the knowledge on SSA as a partial replacement in concrete:

1. It is recommended that future studies should be carried out to verify the prediction of the SSA concrete for 28 days of curing time.
2. Future studies can try using incineration temperatures ranging from 900°C - 1000°C to obtain a less dense concrete with the benefit of increase concrete strength.
3. Future studies to determine the relation and find the optimum of incineration temperature, density and increase in concrete strength.
4. It is recommended that finding the relation of the chemical composition of sludge with the increase in concrete strength when SSA is used as fine aggregates should be carried out.

5. References

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