INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
Vol. 13 No. 3 (2022) 174-182

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Flexural and Compression Superiority of Sewage Sledge Ash Concrete

Thevaneyan Krishta David, Renga Rao Krishnamoorthy[2*]

[1]School of Civil Engineering,
Universiti Teknologi Mara, Shah Alam, MALAYSIA

[2]Smart Manufacturing Research Institute (SMRI),
Universiti Teknologi Mara, Shah Alam, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2022.13.03.016
Received 11 December 2021; Accepted 13 March 2022; Available online 10 December 2022

Abstract: The sustainability of the environment has become a global issue, and several researches have been conducted in order to uncover possible and trustworthy solutions for lowering the problem and increasing one's quality of life. Wastewater treatment produces sludge, which is an unavoidable byproduct. Landfilling, ocean dumping, and spreading over reclaimed territory are all common ways of disposal. However, these popular sludge disposal methods represent a significant dilemma since they can pollute the environment, including the air, land, and water. Since sewage sludge can be treated to produce sewage sludge ash (SSA), which has the potential to replace certain percentages of cement, studies on sewage sludge have been popular in recent years. Many studies have been done to use the SSA in lightweight concrete, bricks, and aerated concrete because nations like Spain and the United Kingdom have problems disposing of sewage sludge. This study focuses on the flexural and compression strength of the sewage sludge ash (SSA) concrete for 3, 7, and 21 days of curing relatively to its density. In this study, 10 percent of SSA was used as a replacement to cement and fine aggregates. The flexural strength of concrete for cement replaced with SSA was lower than the control sample but it has a higher early flexural strength. The flexural strength of concrete for fine aggregate replaced with SSA was higher compared to the control sample. Comparatively, the compressive strength of concrete when SSA is used as a combination of cement and fine aggregate replacement also gives a higher value compared to the control sample.

Keywords: Sewage sludge ash, compression test, flexural test, incineration, sustainability

1. Introduction

The sustainability of environment has become a global issue, and several researches have been conducted in order to uncover possible and trustworthy solutions for lowering the problem and increasing one's quality of life. The environmental impact of sewage sludge disposal is a major concern in both developing and industrialized countries. Wastewater treatment produces sludge, which is an unavoidable byproduct. According to the Sludge Production Factor (SFD), national sewage companies like Indah Water Konsortium in Malaysia create roughly 5.3 million m^3 of sewage sludge each year. In the year 2035, sludge generation is expected to be 10 million m^3 per year, with an average solid content of 2% [1]. Land reclamation, composting, building materials, reforestation, and power generation are among the sludge reuse options in Malaysia, according to Indah Water. Landfilling, ocean dumping, and spreading over reclaimed territory are all common ways of disposal. However, these popular sludge disposal methods represent a significant

*Corresponding author: rao@salam.uitm.edu.my

dilemma since they can pollute the environment, including the air, land, and water. Since sewage sludge can be treated to produce sewage sludge ash (SSA), which has the potential to replace certain percentages of cement, studies on sewage sludge have been popular in recent years. This research may beneficial in reducing environmental issues. Aside from that, the SSA will have commercial worth if it can be used to reduce environmental problems while still serving as a valuable material. This research could potentially help to reduce the cost of construction by employing an alternative to Ordinary Portland Cement (OPC) to an appropriate percentage. Many studies have been done to use the SSA in lightweight concrete [2], bricks [3], and aerated concrete because nations like Spain and the United Kingdom have problems disposing of sewage sludge [4]. Malaysia may confront a similar dilemma in the future as the country continues to develop. Another issue is the rising cost of cement as a result of the construction industry's strong demand [5].

The reuse of sewage sludge as construction materials not only reduces the disposal problem, but it also saves money, energy, and the environment [3]. The SSA is made from the combustion of dry sewage sludge (DSS), which was previously disposed of in controlled landfills. Because SSA contains heavy metals, disposing of it could result in higher land requirements as well as ground contamination. As a result, as previously stated, using SSA to replace concrete to a certain extent may help to alleviate these issues. Because its hydraulic qualities and key constituents, such as silica, iron, calcium, aluminium, magnesium, phosphorus, and oxygen, are comparable to cement, SSA can be used as a cement substitute. There have been numerous researches on the use of SSA as cement and fine aggregates (sand) [6]. More research into SSA could pave the way for a breakthrough in the building industry.

Concrete is the most commonly used construction material because it is more cost-effective, flexible, and long-lasting than steel and timber. Concrete is made up of a specified proportion of water, cement, coarse, and fine particles. Because one of the main components, cement, is becoming more expensive, replacement materials have been used to replace it. Coal bottom ash, rice husk ash, hydraulic fly ash, activated slag, and calcium sulfo-aluminate are examples of cement substitutes that have been studied as a viable alternative to cement [7].

1.1 Objectives

The behaviour of concrete when SSA is used to replace cement, as well as the best amount to utilise, has been investigated. Aside from that, the allowable fine aggregate percentage in concrete has been investigated. However, the behaviour of concrete, such as density and compressive strength, when the optimal proportion (10%) of SSA is used as cement replacement combined with an acceptable percentage of SSA as fine aggregate replacement has not been well investigated. This research will not only assist to alleviate environmental problems, but it will also help to reduce the use of cement and fine aggregate in concrete, as well as the cost of the materials.

The greatest load or stress that concrete can withstand is defined as its strength [8] [9]. One of the most essential properties of cement-based materials is compression strength. The best SSA replacements in cement, as well as SSA characteristics such as flexural strength, water absorption, density, and weight class, have been investigated. According to a study conducted by [10], 10% of SSA can be used to replace cement in concrete that has been cured for more than 28 days and has a compressive strength of 28 days. Study by [10] concluded that 10% of the SSA could be used to substitute cement in unreinforced concrete in order to reduce cement use. Researcher [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 [3]. 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 [11]. Study by [11] concluded that there is potential of domestic waste sludge powder or SSA used as partial cement replacement. The following questions must be addressed: what is the flexural and compression strength of SSA when it replaces a percentage of cement? How strong is SSA when it replaces a percentage of fine aggregates in terms of flexural and compression strength? Will the use of SSA concrete have an impact on the concrete's performance? As a result, the concrete's behaviours will be determined in this study.

In this study, the SSA was used with cement and fine aggregate (sand) to substitute cement and fine aggregate (sand). As a result, the aim of this study are to assess the density, flexural strength, and compressive strength of concrete after 10 percent SSA replacement of cement and adding 10% SSA replacement of fine aggregate at 3, 7, and 21 days.

2. Methodology

2.1 Preparation of SSA

The stages involved in SSA preparation are depicted in Figure 1. The Sewage Treatment Plant provided the Dried Sewage Sludge (DSS) (STP). Temperatures of 1000ºC and beyond are commonly employed, according to investigations conducted by various researchers [2]. Because of the low levels of CaO, SiO_2, and Al_2O_3 [12], the lower temperature causes a slow and poor strength growth. Dried sewage sludge (DSS) was collected from a sewage treatment plant and burned for two hours at 1000ºC in a furnace to create sewage sludge ash (SSA) (Figure 1). After that, the process is finished with a quick chilling in the open air. After then, some of the SSA was ground for 12 hours at 30 rpm in a Ball

Mill Machine. A total of six (6) big ball mills and fourteen (14) tiny ball mills were used. During the preparation of the concrete beam, 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. Until further testing, the SSA will be kept in separate containers.

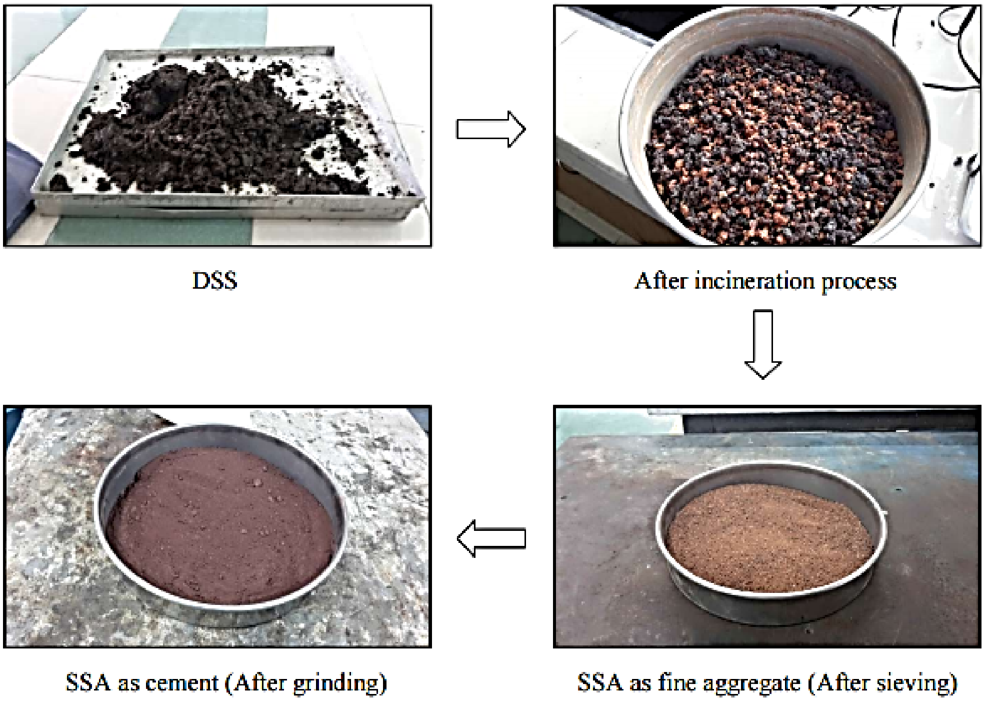

Fig. 1 - SSA preparation

2.2 Preparation of Concrete Sample

The concrete beam was intended to attain a goal mean strength of 46 MPa at 28 days using a 0.47 water cement ratio, according to [13] British Standard (BS 1881). The flexural beams utilised in the test were 100mm x 100mm x 500mm in size. The concretes were cast using a 150mm x 150mm x150mm cube mould for cube compression test techniques. Tables 1, 2, and 3 summarise the calculated design mixtures. Before concrete was poured, the beam and cube moulds were thoroughly cleaned and a layer of grease was put in the mould. A vibration table was used to vibrate the concrete after it was poured into a mould. Before being placed in the curing tank, these concrete samples were left in the laboratory for 24 hours to allow for ambient drying.

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 =10mm)
Per m^3 (nearest 5 kg)	436	205	587	1192
Per trial mix of 0.005 m^3 (Beam)	2.18	1.03	2.94	5.96
Per trial mix of 0.00375 m^3 (Cube)	1.64	0.77	2.20	4.47

Table 2 - Beam samples mix design (w/c ratio = 0.47) for flexural test

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	9	17.64	8.29	26.46	53.64	1.98
C2	9	19.62	9.27	23.81	53.64	2.66

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

Table 3 - Cube samples mix design (w/c ratio = 0.47) for compression test

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*	9	13.32	6.62	17.82	40.23	1.44	1.98

(S0: Concrete sample contained 0% of SSA and 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

To compare density and strength, the densities of the samples were calculated according to BS 1881: Part 114: 1983[14]. A weighing machine was used to determine the mass of each concrete sample. The volume of the concrete beam test specimen shall not be less than $40d^3$, where d is the nominal aggregate size. The aggregate size employed in this investigation was 10mm, implying that the concrete beam should be at least 40000 mm3. The concrete beam's actual volume was 5 000 000 mm^3, which is more than $40d^3$. Each cube sample's density was also calculated and documented. Finally, the average value was calculated as a result. Density equation (1) will be used to calculate the density value.

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

2.3.2 Flexural Test

The flexural strength of the samples was determined using concrete beams of 100mm x 100mm x 500mm, as specified in BS 1881: Part 118: 1983. There are nine (9) samples of beams for flexural testing, with three (3) samples from each category being evaluated at three (3), seven (7), and twenty-one (21) days of curing time. The Universal Testing Machine is used to apply force (F) on the concrete beam in increments of 0.06 ± 0.04 N/mm.s as per BS 1881 Part 118 until a crack shows on the concrete or the universal testing machine stops. Equation 2 can be used to compute the flexural strength of each beam sample. Finally, concrete beam's average flexural strength for respective categories were determined and documented.

$$\text{Flexural Strength} = \frac{\text{F x l}}{\text{w x d}^2}\left(\frac{\text{N}}{\text{mm}^2}\right) \qquad \text{(Eq. 2)}$$

2.3.3. Compressive Strength Test

The concrete samples' compressive strengths were evaluated using BS: Part 116: 1983. (Method for Determining Concrete Cube Compressive Strength) The maximum loads and compressive strength were determined using the Compression Machine Test. The loading was applied to the concrete samples at a notional rate ranging from 0.2 N/mm2.s to 0.4 N/mm2.s until no more loads could be tolerated. The maximum load is obtained and recorded using the compressive Machine Test. Each sample's compressive strength was calculated using equation 3.

$$\text{Compressive strength} = \frac{\text{Maximum load}}{\text{Cross Sectional Area of Cube Sample}} \left(\frac{\text{kN}}{\text{m}^2}\right) \quad \text{(Eq. 3)}$$

3. Result and Discussion

3.1 Density of Concrete

At 3, 7, and 21 days, the average density of the beam control sample was 2412 kg/m^3, 2402 kg/m^3, and 2444 kg/m^3, respectively. At 3,7, and 21 days, the density of the concrete beam with 10% cement replaced with SSA was 2436 kg/m^3, 2476 kg/m^3, and 2 476 kg/m^3, respectively, while the density of the concrete beam with 10% fine aggregate replaced with SSA was 2456 kg/m^3, 2464 kg/m^3, and 2471 kg/m^3, respectively. The concrete cube samples' average densities were also recorded. The average densities of concrete beam and cube samples are shown in Table 4.

Table 4 - Density of the samples

Sample	Density (kg/m^3)		
	3 days	7 days	21 days
CO	2412	2402	2444
C1	2436	2476	2476
C2	2456	2464	2471
SO	2403	2411	2426
S1	2405	2389	2395

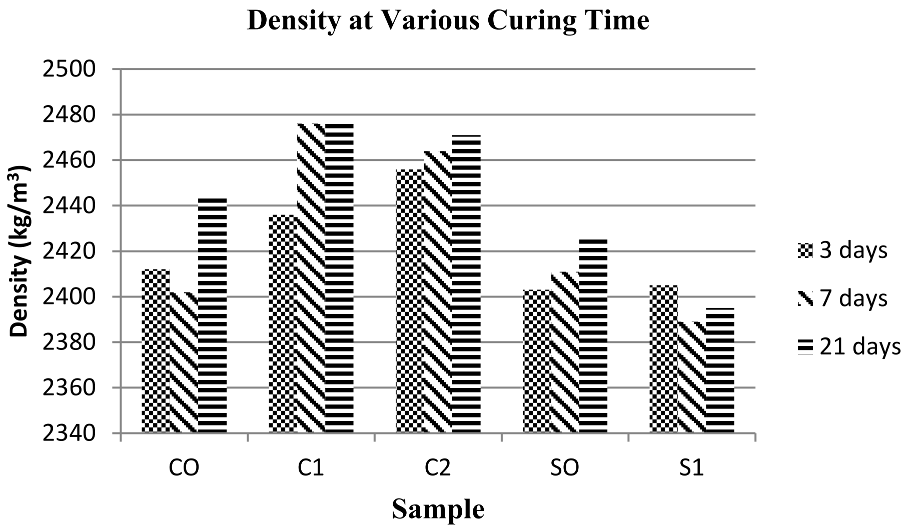

Fig. 2 - Comparison of the concrete samples densities for the specified curing time

Since the optimum incineration time of 1000 C was chosen, it is expected that the density of the SSA concrete will be similar to or higher than that of the control sample. The concrete densities for the concrete beam and cube samples were found to vary insignificantly for a given curing time as a result of this. Figure 2 shows the comparison of the concrete beams (CO, C1 and C2) and cubes (SO and S1) samples densities for the specified curing time. According to [4], the density of SSA increases in direct proportion to the incineration temperature, although it begins to decline once the temperature approaches 1000°C [4]. Since the incineration temperature used in this study was 1000ºC, 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 which agrees well with the findings of [4].

3.2 Flexural Strength

Table 5 shows that the average flexural strength of the controlled sample after 3, 7, and 21 days is 3.62 MPa, 4.78 MPa, and 4.84 MPa, respectively. For 3, 7, and 21 days, the flexural strength of concrete with SSA replacing 10% of the cement is 4.63 MPa, 4.67 MPa, and 4.73 MPa, respectively. For 3, 7, and 21 days, the flexural strength of concrete with SSA replacing 10% of the fine aggregate is 5.20 MPa, 5.27 MPa, and 5.29 MPa, respectively.

Table 5 - Flexural strength at various curing duration

Sample	Flexural Strength (MPa)		
	3 days	7 days	21 days
CO	3.62	4.78	4.84
C1	4.63	4.67	4.73
C2	5.20	5.27	5.29

According to the findings, concrete containing 10% SSA has a high early flexural strength of 4.63 MPa at 3 days, compared to the control sample, which has a flexural strength of 3.62 MPa. The rate of growth in flexural strength of SSA concrete has slowed as the curing time has increased, as illustrated in Figure 3. At 7 days, the flexural strength of the concrete control sample exceeds that of the SSA concrete. This means that SSA-replaced concrete has a high early flexural strength but a reduced flexural strength as the curing period increases, compared to regular concrete.

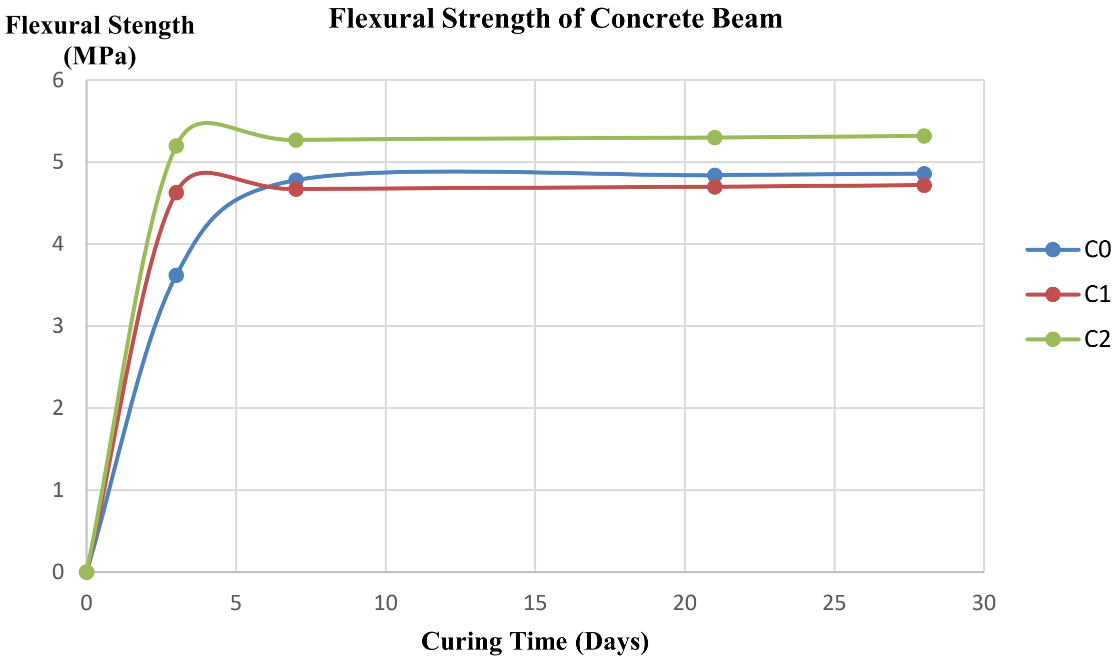

Fig. 3 - Relationship between flexural strength and curing time

Conversely, SSA-replaced concrete with 10% fine aggregate has a higher early flexural strength than the control sample. The flexural strength of the SSA concrete at 3 days is 5.20 MPa, which is higher than the 4.84 MPa flexural strength of the concrete control sample at 21 days. This could be due to an increase in density during the incineration process, causing the SSA to become more compact and thus stronger. Furthermore, the SSA's different chemical composition may lead to increases in concrete strength [15].

Since SSA has a lesser pozzolanic activity than Ordinary Portland Cement, the outcomes of using it as a cement may be lower (OPC). Due to particle size differences during sieving compared to powdery SSA after grinding, SSA as fine aggregate may provide different results. In comparison to the large particle size of the ungrounded SSA used as fine aggregates, which limits its contact with water, the finer SSA reacts with water to create a cementatious substance. It may be inferred that when SSA is used to replace 10% of the cement in concrete, the early flexural strength is higher but the final flexural strength is reduced. In comparison to the control sample, SSA utilised to replace 10% of fine aggregate in concrete has a high flexural strength.

For this study, the flexural strength at 28 days for concrete with 10% cement replaced by SSA and for concrete with 10% fine aggregate replaced by SSA was predicted as depicted in Figure 3 based on concrete behaviour which increases linear-elastically by a small amount nearing the end strength.

3.3 Compressive Strength

The average of maximum load is determined for the control sample and presented in table 6. The Compressive Strength Formula is used to calculate the compressive strength of concrete cubes, with the parameter needed being the average of maximum load and cross sectional area. The compressive strength of the control sample is 30.8 MPa, 41.5 MPa, and 42.9 MPa after 3, 7, and 21 days of curing, respectively. At 3, 7, and 21 days, the compressive strength of the concrete cube containing a mixture of 10% SSA to replace cement and 10% SSA to replace fine aggregate is 40.4 MPa, 45.8 MPa, and 46.1 MPa, respectively.

Table 6 - Compressive strength at various curing duration

Sample	Curing Duration (Days)	Compressive Strength (MPa)
SO	3	30.8
	7	41.5
	21	42.9
S1	3	40.4
	7	45.8
	21	46.1

The compressive strength of concrete cubes containing SSA as cement replacement and fine aggregate replacement is higher than the control sample, according to the results obtained at various curing times. It is noted that the differences between the controlled samples and samples with 10% replacements of SSA to cement and fine aggregate contains is significant for tested duration of curing. At 3 days curing variation up to 25% is noted. However, this variation decreases to 10% and 7% for 7 and21 days respectively.

According to [3] concrete cubes with 10% SSA as cement substitute had a compressive strength that was similar to the control strength [9]. SSA replacement to cement of 10%, combining with 10% SSA replacement to fine aggregate may indicate that concrete with higher strength could be produced. It noteworthy that according to [15] the optimal percentage of SSA that can be used to replace fine aggregate in concrete is up to 25% in an effort to produce higher strength concrete compared to the conventional concrete.

The predicted strength of SSA concrete was calculated based on the available data (Figure 4). The S0 and S1 correspond to the compressive strength prediction values for concrete sample and SSA concrete, respectively. The concrete sample's anticipated value at 28 days is 43.6 MPa. For the SSA sample, the anticipated compressive strength value is 47.9 MPa for 28 days. The SSA sample, on the other hand, was found to be achieving the required mean strength after 21 days.

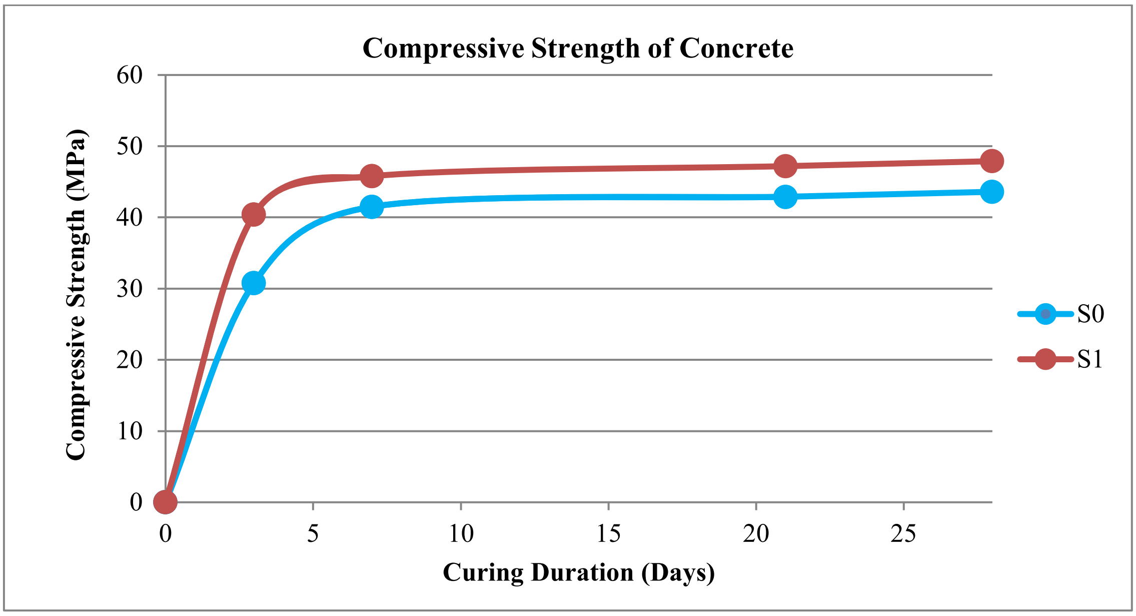

Fig. 5 - Compressive strength of samples

As a result, it can be inferred that using 10% SSA as a cement and fine aggregate substitute in concrete can result in a significantly better compressive strength value when compared to the control sample. Furthermore, when compared to the control sample after 28 days of curing, the combination of 10% SSA employed as cement and fine aggregate replacement in the concrete achieved a higher anticipated value of strength.

4. Conclusion and Recommendations

4.1 Conclusion

The objective of this study was to determine the density and flexural strength of concrete with 10% SSA replacement of cement (S1) and fine aggregate (S2) at 3, 7, and 21 days, as well as the compressive strength of concrete after 10% SSA replacement of cement combined with 10% SSA replacement of fine aggregate at 3, 7, and 21 days. It is possible to draw the following conclusions from the research:

1. The density of the concrete with SSA replacement varies somewhat or is practically identical to the control sample, according on the results. This could indicate that SSA incinerated at 1000°C for 2 hours has a negligible effect on concrete density.
2. The flexural strength of concrete with 10% cement substituted by SSA showed a high early strength at 3 days, with a 25% increase in strength over the control sample. This variance, however, lessens as the curing time increases.
3. Flexural strength of concrete containing 10% fine aggregates substituted with SSA demonstrates good strength at any curing time. This demonstrates that SSA might be used to build concrete in the industry if it was burned at 1000°C for 2 hours and sieved to the proper particle size. At 3 days (5.20 MPa), the flexural strength of concrete with 10% SSA as fine aggregate exceeds the flexural strength of the control sample at 21 days (4.84 MPa). As a result, it can be stated that the concrete with SSA replacing 10% of the fine aggregates has superior strength performance than the control sample and the sample with SSA replacing 10% of the cement.
4. The compressive strength of the 10% cement combining with 10% fine aggregate replacement sample is significantly higher than that of the control sample. At 21 days, the concrete cube sample containing SSA had reached the intended mean strength value. This suggests that SSA might be employed in a concrete with a 1000oC incineration temperature for 2 hours. The use of SSA in concrete is advantageous since it may replace two elements in a concrete, namely cement and fine aggregate.

4.2. Recommendation

Based on the findings of this study, the following suggestions are made in order to improve and enhance the outcomes of investigations involving SSA concrete:

1. Studies will be carried out to establish the best proportion of SSA replacement for fine aggregate when combined with 10% SSA as a cement replacement in concrete.
2. In order to generate less dense concrete, more research can be done utilising different incineration temperatures and durations.
3. Finding the relationship between the chemical composition of sludge and the increase in concrete strength when SSA is used as fine aggregates is advised.

Acknowledgement

The completion of this study would have been not possible if not dependent on the support of my undergraduate students Alister Saba anak Johnny and Sumba anak Ensanum from the School of Civil Engineering, Universiti Teknologi MARA, Shah Alam. They hence paid equal contribution to the study for which I always feel profound gratitude in my heart.

References

[1] Zaini, U., & Salmiati. (2011). *Management of Sludge in Malaysia.* Institute of Environmental and Water Resource Management.

[2] Cheeseman, C. R., & Virdi, G. S. (2005). Properties and Microstructure of Lightweight Aggregate Produced from Sintered Sewage Sludge Ash. *Resources, Conservation and Recycling 45* , 18-30.

[3] Tay, J. H., & Show, K. Y. (1992). Utilization of Municipal Wastewater Sludge as Building and Construction Materials. *Resources, Conservation and Recycling* , 191-204.

[4] Lynn, C. J., Dhir, R. K., Ghataora, G. S., & West, R. P. (2015). Sewage Sludge Ash Characteristics and Potential for Use in Concrete. *Construction and Building Materials 98* , 767-779.

[5] Adnan, H. (2014, August 9). *Business News: Cement Prices Go Upwards*. Retrieved April 12, 2016, from The Star Online: http://www.thestar.commy/business/business-news/2014/08/09/cement-prices-go-upwards-current-prices-pegged-at-rm380rm400-per-tonne/

[6] Smol, M., Kulczycka, J., Henclik, A., Gorazda, K., & Wzorek, Z. (2015). The Possible Use of Sewage Sludge Ash (SSA) in the Construction Industry as a Way Towards a Circular Economy. *Journal of Cleaner Production* , 44-45.

[7] Thevaneyan Krishta David & Siva Sankaran Nair (2018). *Flexural Strength of Sewage Sludge Ash (SSA) Concrete* - 2018 3rd International Conference on Building Materials and Construction (ICBMC 2018), Nha Trang, Vietnam, 23-25 February, 2018 (2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **371** 012010 https://doi.org/10.1088/1757-899X/371/1/012010)
[8] Jackson, N., & Dhir, R. K. (1996). *Civil Engineering Materials* (Vol. V). New York: Palgrave
[9] Teychenne, D. C., Franklin, R. E., & Erntroy, H. C. (1997). *Design of Normal Concrete Mixes.* London: Bulding Research Establishment.
[10] Chang, F. C., Lin, J. D., Tsai, C. C., & Wang, K. S. (2010). Study on Cement Mortar and Concrete made with Sewage Sludge Ash. *Water Science and Technology* .
[11] Kartini, K., Dahlia Lema, A. M., Dyg., S. Q., A., A., Anthony, A. D., Nuraini, et al. (2015).Incinerated Domestic Waste Water Sludge Powder as Sustainable Replacement Material for Concrete.

[12] Naamane, S., Rais, Z., & Taleb, M. (2016). The Effectiveness of the Incineration of Sewage Sludge on the Evolution of Physicochemical and Mechanical Properties of Portland Cemeny. *Construction and Building Materials* , 783-789.
[13] British Standard- BS 1881: Testing Concrete. *Part 116: Method for Determination of Compressive Strength.* London: British Standard Institution.
[14] British Standard- BS 1881: Testing Concrete (1983). *Part 114: Method of Determination of Density of Hardened Concrete.* London: British Standard Institution.

[15] Kazberuk, M. K. (2011). Application of SSA as Partial Replacement of Aggregate in Concrete. *Polish J. of Environment Stud. Volume 20* , 365-370.