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Effect of Dried Sewage Sludge on Compressive Strength of Concrete

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Abstract. Sewage sludge is a waste product generated from the wastewater treatment process at the treatment plant. The amount of sewage sludge produced is increases every year as the population increased. Poor management of sewage sludge will give negative impact to the environment. Replacing cement with sewage sludge ash is more significant to reduce the amount of waste material from sewage treatment plants. In this study, the various percentage of dried sewage sludge (DSS) has been added to replace the cement. Sewage sludge was dried in the oven with 100°C for 24 hours, then sieve through the sieve size 300 µm. Then, DSS was used in the concrete instead of cement with the replacement percentage of 0%, 5%, 10%, and 15% by weight. The compressive strength of concrete cube specimens was investigated after 7 and 28 days of curing. The results showed that the compressive strength of concrete specimens increased with the replacement of cement in concrete with 5 % to 10 % DSS, but the achieved maximum strength still lower compared to the control sample. However, the compressive strength of concrete specimens decreased when the DSS replacement of cement is more than 10 % by weight. The result of XRF test also showed that DSS has good potential to replace cement in concrete.

1. Introduction

It is estimated that the population in Malaysia is increasing to 32.5 million in the year on 2019. The increasing of the total population will automatically increase the amount of wastewater generated by the people. Normally, the wastewater from the residential building and the commercial building will be treated before it is released to the natural waterways that are called effluent. The quality of the effluent must be controlled in order to ensure the quality of the natural water resources in good condition for the population in Malaysia. According to the Department of Environment Malaysia, the standard effluent must be at Standard A and B. Thus, the process to control the quality of effluent is started at the sewage treatment plant. Sewage sludge is a waste product generated from the wastewater treatment process at the treatment plant. Most of the wastewater treatment plants in Malaysia are managed by Indah Water Konsortium (IWK). According to IWK, about $5.3 \times 10^6 \text{ m}^3$ was produced every year and the amount of sewage sludge is still increasing annually [1]. A large amount of sewage sludge produced every year will affect the environment and also social development[2,3]. Thus, the sewage sludge will be sent to the landfill for disposal process. Besides, the common methods of sewage sludge disposal are ocean dumping, landfilling and also spreading on reclaimed land [1]. However, these methods of disposal of sewage sludge will affect to the environment such as water



contamination, air, and land pollution because the sewage sludge contains toxic material and heavy metal. The disposal of sewage sludge at landfill area also can cause problem to the soil due to leachate that contains high potentially toxic and heavy metal produced by the sewage sludge[2,4,5,6,7]. Thus, studies have been done to utilize the sewage sludge ash as a partial replacement in the concrete mix. The incinerated sewage sludge with 600°C to 900°C will produce the sewage sludge ash and minimized the volume of sludge up to 50 %.

Different researchers use different temperatures to produce sewage sludge ash (SSA). A study was done by M. Cyr et al., the temperature of 850°C was used to burn the sewage sludge in order to produce SSA [8]. Monzo et al reported that incinerating the sewage sludge (SS) up to 800°C can produce an amorphous SSA [9]. It was suggested that the sludge should be burnt to a temperature of 550°C for 3 hours to produce SSA as cement replacement [10]. Lin and Weng also incinerate the sludge at 800°C in the combustion chamber to remove the organic substance then was used as a clay substitute in brick manufacturing [11]. Kartini et al in their study, domestic waste sludge was burnt under uncontrolled burning in a ferro cement furnace for 72 hours to produce residue ash that was used in the concrete mix [12]. The temperature used to produce sewage sludge ash does not exhibit any significant effect on chemical properties of the ash but slightly affect the physical shape of the SSA. The study conducted by Siew et al shows that the sludge burnt at 600°C exhibited needle-shaped particles whereas a smooth structure was found in sludge burnt at 800°C due to the pozzolanic reaction which filled the void and pores in the mortar [13]. Moreover, sludge burnt at 800°C also provides additional strength to the mortar where the compressive strength has increased after 28 and 90 days [13]. An investigation done by Doh et al found that the SSA produce at the temperature of 600°C for the duration of three hours has the potential to be used as partial cement replacement in concrete since there are high similarities in the major chemical component of SSA compared to cement [14]. Sharif and Attom used burned sludge ash as soil stabilizing agent. They burned the sewage sludge at 550°C and mix with the different type of clay soil. From the test result, they suggested that the burned sludge ash can be used as soil stabilizer[15]. Carriona et al in his study on using SSA to manufacture pre-cast concrete block burned the SS at 800°C to produce fine SSA [16]. This fine SSA material then was found out apt to be used in pre-cast concrete block manufacturing. Donatello et al in his investigation, the temperature from 800°C to 900°C is used to develop sustainable and low energy constructions product incorporated incinerated sewage sludge ash. Franz in his study conducted in Switzerland used temperature of 830°C to 850°C to produce SSA. From the study, he found that SSA can be used as an effective phosphate fertilizer that meets the demands of the agriculture industry. While Jamshidi et al used 650°C temperature in his study to investigate the mechanical performance of concrete with partial replacement of sand by SSA [17]. However, Kazberuk used two different temperature of the furnace chamber wherein the bottom section the temperature is above 600°C and the upper section is more than 850°C to produce sewage sludge ash [18].

Apart from that, the use of SSA as a partial replacement of cement can be seen as a better solution to overcome the problem of disposal of sewage sludge. Using SSA as a partial replacement of cement has the potential to improve the mechanical performance of concrete. The workability and compressive strength of concrete after 28-days were improved with the addition of SSA [10,14] and lower the water absorption [14] compared to the control samples. According to [14,17,19] the optimum amount of SSA is 5 % by weight of ordinary Portland cement to promote the highest performance of compressive strength of concrete after 28 days. However, the high temperature for the combustion process to produce sewage sludge ash contributed to the increase of energy consumption. The manufacturing of ordinary Portland cement also requires a high degree of temperature in the burning process. Thus, by using sewage sludge ash to replace the cement is still increasing energy consumption. Based on the previous study, it found that the researchers burn the sewage sludge to form ash as a cement replacement in the concrete mix. Limited study has been conducted incorporating dried sewage sludge as a partial replacement of cement in the concrete mix. Therefore, this study aims to investigate the compressive strength of concrete containing dried sewage sludge as a partial replacement of cement by weight in concrete.

2. Materials

2.1. Sewage Sludge

Sewage sludge was collected from wastewater treatment plant at student's hostel, UiTM Pahang, Malaysia. The sewage sludge collected from the sludge dry bed at the wastewater treatment plant. Then, sewage sludge is oven dried at a temperature of 100°C for a period of 24 hours to ensure that the samples are dried [14]. The oven drying process is needed in order to remove up to 90% of its moisture content in the sewage sludge [14]. The impurities such as plastics, woods, and trash in the sludge were removed to ensure the best quality of sewage sludge. The dried sewage sludge was sieved passing 300µm. The process to produce dried sewage sludge was shown in Figure 1. In this research, 0%, 5%, 10% and 15% of the dried sewage sludge were added as a partial replacement of cement in the concrete mix. Then, the compressive strength of the 100 x 100x 100mm concrete cubes were measured and compared to the control samples. The control samples were prepared with 0% dried sewage sludge. Table 1 shows the complete concrete mix design according to the percentage of dried sewage sludge. The weight of aggregates, water, and cement obtained according to 0.008 m³ of the total concrete mix volume.

2.2. Course and Fine Aggregates

Crushed granite aggregates were used to include in the specimen mixture. The sources of aggregate were obtained from the Sungai Jan Kuari Sdn Bhd, Jerantut, Pahang. The coarse aggregates were graded in a range of 20 mm to 5 mm nominal size. While the fine aggregate or sand were sieve passed 5mm opening sieve size. Meanwhile, the fine aggregates or sand were graded is passing 5mm sieve size.

2.3. Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV)

The durability of the aggregate samples was tested in order to obtain the ACV and AIV. The ACV and AIV test is based on the BS 812 Part: III. The result obtained that the ACV and AIV is 25% and 17% respectively.

2.4. Cement

Type 1 ordinary Portland cement was used in this study as a binder material in the concrete preparation process. The cement was produced by YTL Cement Bhd. This particular cement was used for entire experimental work in this study.

3. Experimental Procedure

3.1. Sample Preparation

The concrete mix design consists of coarse aggregate, fine aggregates, ordinary Portland cement added with dried sewage sludge with four different weights as a partial replacement of cement which is 0%, 5%, 10%, and 15% respectively. A control mix was prepared using ordinary Portland cement with 0% dried sewage sludge as a replacement of cement in the concrete mix. Then, the dried sewage sludge was blended with cement and mixing with aggregates and water. Then the mixture was cast in the 100 mm x 100mm x 100mm steel mould. Six (6) specimens were prepared for each content of dried sewage sludge to measure the compressive strength after 7 days and 28 days. After the specimens cast in the steel mould, the specimens were kept for 24 hours. Then the specimen was removed from the mould and sank in the water for curing process.

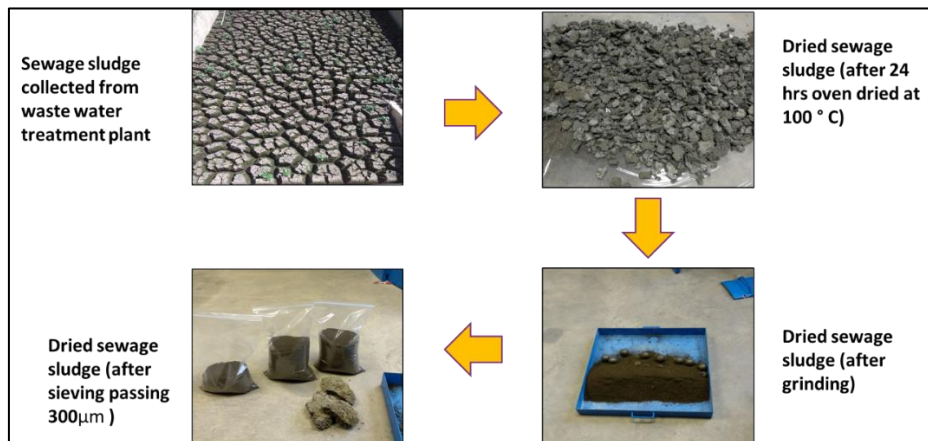


Figure 1. Process of Production of Dried Sewage Sludge

Table 1. Mix proportion of concrete containing dried sewage sludge

DSS (%)	w/c	Cement (kg)	DSS (kg)	Water (kg)	Aggregates		
					Fine (kg)	10mm (kg)	20mm (kg)
0 %	0.54	3.112	0	1.68	4.322	3.362	6.724
5 %	0.54	2.956	0.156	1.68	4.322	3.362	6.724
10 %	0.54	2.801	0.311	1.68	4.322	3.362	6.724
15 %	0.54	2.645	0.467	1.68	4.322	3.362	6.724

3.2. Curing Condition

The specimens were placed in the clean water after removing from the mould. The period of the curing process is 7 days until 28 days. After the curing period, the specimens were drained and ready for the compressive strength test.

3.3. Compressive Strength Test

One of the performance characteristics of concrete is compressive strength. 100 x 100 x 100 mm cube specimen was prepared to measure the compressive strength of concrete. The specimens were compressed using a compression strength test machine. The specimens were tested with a loading rate of 3.0kN/s according to British Standard Test method BS EN 12390:2009.

4. Results and Discussion

4.1. X-Ray Fluorescence Test (XRF)

Based on the oxide content in SSA, it is suitable to replace the Portland cement content in normal concrete. The XRF result in Table 2 shows that the major oxide of DSS (Fe₂O₂, SiO₂, P₂O₅, CaO, Al₂O₃). According to D. F. Lin et al., the major oxide component in Portland cement is SiO₂, CaO, and Al₂O₃ [11]. The production of DSS is easier and save-energy compared to the production of sewage sludge in the ash form. Thus, it will promote a great potential to reduce the carbon emission to the environment. According to the result of XRF test, it shows that the DSS also consist of the high content of oxide component and potentially to replace the cement content in concrete. Furthermore, the DSS form is more environmentally and considered a feasible alternative solution to the sludge disposal problem [14].

Table 2. Oxide content in DSS and Portland cement

Oxides	DSS	Portland Cement[14]
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Iron Oxide (Fe ₂ O ₂)	15%	2.3 %
Silicon Dioxide (SiO ₂)	14.9%	21.0%
Phosphorus Pentoxide (P ₂ O ₅)	6.03%	0%
Calcium Oxide (CaO)	1.81%	66%
Aluminium Oxide (Al ₂ O ₃)	7.34%	4.6%

4.2. Concrete Density

The density of concrete specimens were measured for each curing dates and percentages of DSS added as a cement replacement. The result of the concrete density for each percentage of DSS is shown in Figure 2. The density of concrete specimens for 7- and 28-days curing dates is lower compared to the density of the control sample (0% DSS). After 28 days curing period, the maximum density of concrete is 2350 kg/m³ was recorded compared to the 7 days curing period, the maximum density is 2290 kg/m³. However, the density of concrete started to drop after 5% of DSS was added for each curing periods as compared to the control sample. Based on the results obtained, it can be noted that the density of concrete decreased when the DSS with 300 µm were used to replacement the cement content in concrete.

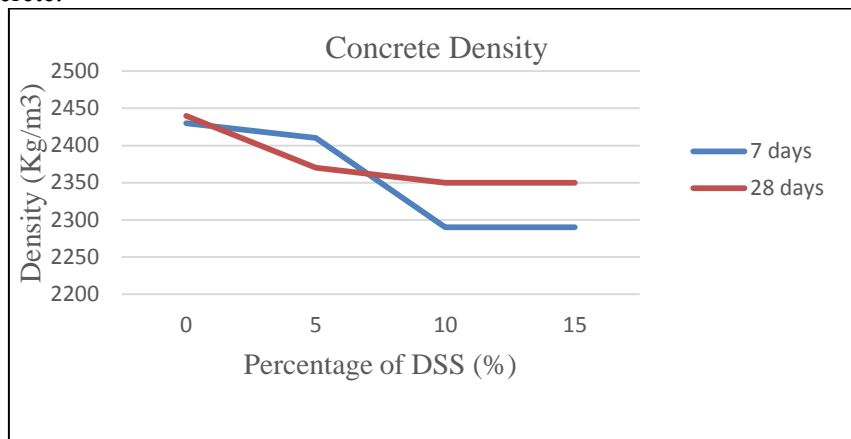


Figure 2. Concrete Density for Various DSS Content

4.3. Compressive Strength

In this study, the test age of concrete is 7 days and 28 days and 3 cubes were tested for each of the same proportion in order to obtain the average data. The results of the compressive strength of each mix are shown in Table 3 and Figure 3. As can be seen, the compressive strength of concrete is higher after 28 days compared to the 7 days curing periods. The result obtained indicates that the compressive strength of concrete is increased when the DSS was added as a cement replacement up to 10 %. Then, the compressive strength of concrete was starting to decrease when the content of DSS is more than 10 %. It also noted that the concrete mixture with DSS have a lower value of compressive strength compared to a control mixture.

Table 3. Compressive strength of various mix design

No.	Sample	Compressive Strength (N/mm ²)	
		7 Days	28 Days
1	0%	13.10	16.72
2	5%	8.00	9.33
3	10%	8.30	11.74
4	15%	5.86	9.95

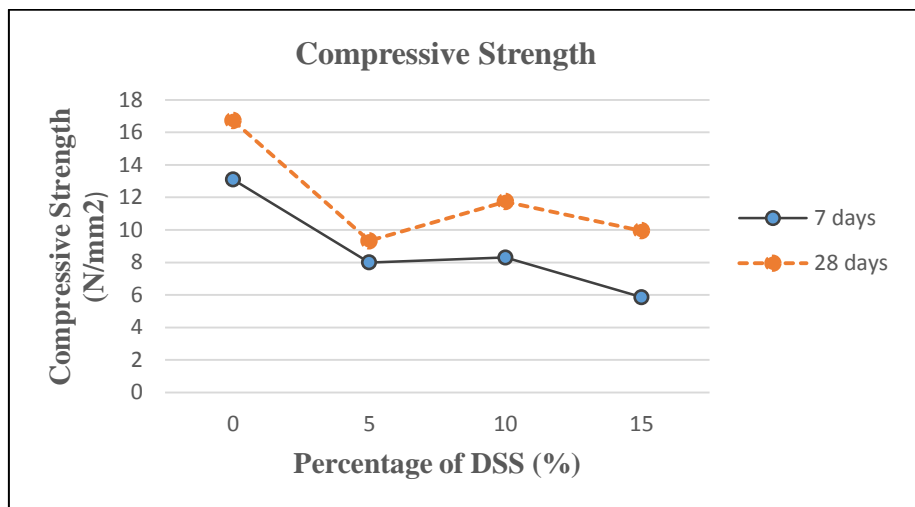


Figure 3. Compressive strength of various mix design

5. Conclusion

This study was done to assess the compressive strength of concrete containing DSS as a partial replacement of cement by weight in the concrete mixture. Results showed that the use of DSS as cement replacement in concrete resulted in good compressive strength compared to the control samples. The compressive strength of concrete increased when the DSS was added as a cement replacement up to 10 % in the concrete mixture. However, compressive strength of concrete was starting to decrease when the content of DSS is more than 10 %. Meanwhile, the density of concrete was decreased when the DSS with 300 μm particle size were used to replacement the cement content in concrete. Based on XRF result, it was found that the major oxide of DSS (Fe_2O_2 , SiO_2 , P_2O_5 , CaO , Al_2O_3) is approximately similar to the Portland cement. Thus, the use of DSS in concrete production has great potential to reduce the amount of sewage sludge at the disposal area. The possibilities to reuse of sewage sludge in other applications also can be explored such as for road and highway construction, ceramic or glass production and brick production. Thus, reuse of sewage sludge also encourages the public or stake holders to save the environment by using the sustainable materials.

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