



THE USE OF SEWAGE SLUDGE ASH (SSA) AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

Doh Shu Ing¹, Siew Choo Chin¹, Tan Kim Guan¹ and Adilen Sui²

¹Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Gambang Kuantan Pahang, Malaysia

²Department of Civil Engineering, Politeknik Sultan Ahmad Shah, Kuantan, Malaysia

E-Mail: dohsi@ump.edu.my

ABSTRACT

The production of sewage sludge (SS) from waste water treatment plant is increasing all over the world. Disposal of sewage sludge is becoming a serious environmental issue to our society. Sewage sludge which contains high heavy metal is no longer suitable to be used as fertilizer. Besides, the land fill, which is the main disposal method, has also posed threat to leachate of heavy metal from the sewage sludge to the soil. Due to fast urbanization, the demand of cement has increased alarmingly. This will lead to increased cement production and emission of carbon dioxide because the cement industry one of the major contributor of carbon dioxide emission. Hence, the research for replacement of cement using sewage sludge ash is essential to reduce both the emissions of carbon dioxide and the disposal problem of sewage sludge ash. In this investigation, sewage sludge ash has been used as partial cement replacement in concrete. The sewage sludge is incinerated at the temperature of 600°C and duration of three hours. The incinerated sewage sludge ash is sieved through sieve size of 150 µm. Four different percentages of sewage sludge ash (SSA) is used to replace the cement in the concrete. XRD and XRF tests were carried to compare the result between SS, SSA and cement. The tests conducted on concrete in this investigation were slump test, water absorption and water absorption. Results show that SSA has the potential to replace cement since there are high similarities in major chemical component of SSA compared to cement. The replacement of cement in concrete with 5% SSA has shown lower water absorption and increase compressive strength of concrete up to 10% as compared with the control samples.

Keywords: sewage sludge, waste management, concrete replacement.

INTRODUCTION

Sewage sludge is a byproduct of wastewater treatment plant. Due to the urbanization and growth of population, the amount of sewage sludge has increased rapidly over the years and is expected to increase further. Higher amounts of sewage sludge may affect the environment. In current trends, the sewage sludge is disposed through land filling, ocean disposal, land application and agriculture use. Recent research has found that current disposal methods posed environmental issues such as water, air and air pollution (Jamshidi *et al.*, 2012).

Disposal of sewage sludge has become the financial burden of wastewater treatment companies. Siti Noorain (2013) has predicted that 7 million metric tons of sewage sludge will be generated annually in 2020 with the cost of management up to US\$ 0.33 billion per year. Among the methods of the disposal of sewage sludge, land disposal is the cheapest way as it enables crops to be grown on poor land. Sludge has the biggest proportion as compared to the other by-products generated during the process of sewage treatment, and it is found out that it contains heavy metals in its composition (Fontes *et al.*, 2004). Besides that, insoluble matter was also found in

sewage sludge such as organic matter, pathogens, nutrients, and metal. Sewage sludge also contains soluble substances such as minerals, salts and organic chemicals (Yip and Tay, 1990).

Incineration became one of the alternative solutions for the disposal of sewage sludge. The principal component of sewage sludge after going through the high temperature incineration such as SiO₂, CaO, Al₂O₃, are the components of ordinary cements (Tenza-abril *et al.*, 2011). The residue is practically inert and odourless, diverse solutions.

With the current rate of urbanization, it is expected that the demand of cement will increase further. An increase in the demand for cement shows that concrete structures are expected to increase in the similar trend (Jamshidi *et al.*, 2012). The largest carbon dioxide emission source is the cement industry. Almost 5-7% of global CO₂ emissions are caused by cement plants; 900 kg of CO₂ is emitted to the atmosphere for producing one ton of cement (Benhelal *et al.*, 2013). Thus further research should be conducted to study the potential of using SSA as cement replacement in concrete for structural use.



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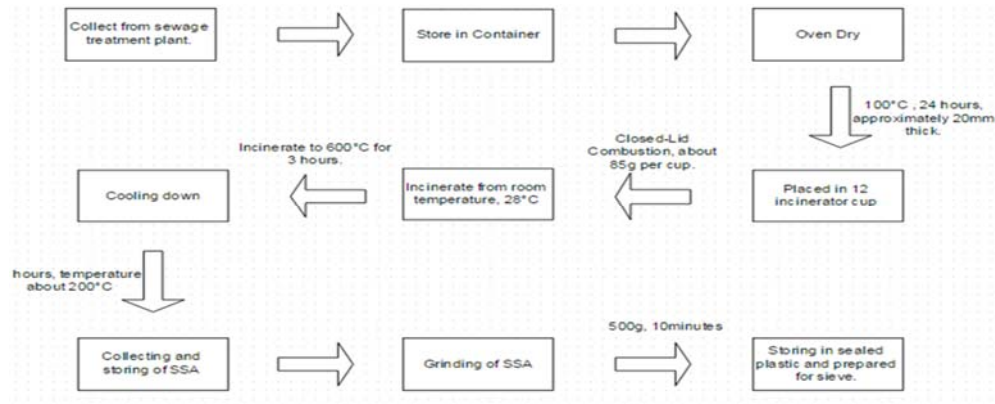


Figure-1. SSA incineration flowchart.

RESEARCH METHOD

Preparation of SSA

In order to ensure the consistency of samples, the sewage sludge is acquired from the same treatment plant. The sewage sludge is collected after 7 consecutive non-raining days for best quality control purposes and to ensure the sewage sludge is in dry condition. When collecting the sludge, impurities such as grass, roots and trash is filtered and removed. Only the top layer of sewage sludge is being collected to prevent over deep excavation which may cause the bottom sand layer of the drying beds to be mixed together with the sewage sludge. Before the oven drying and incineration process of sewage sludge, the sewage sludge was kept in a container to prevent the sewage sludge from contact with other impurities. The sewage sludge is oven dried at the temperature of 100°C for a period of 24 hours to ensure that the samples are dry prior to incineration process.

The sewage sludge is incinerated in a closed-lid method to make sure that all the sewage sludge ash is fully trapped inside the cup. The sewage sludge is incinerated from room temperature to the maximum temperature of 600°C for duration of 3 hours. Time taken to incinerate from room temperature to 600°C is approximately 15 minutes and cooling down duration from 600°C to 200°C is approximately 5 hours. The sewage sludge ash is removed from the incinerator at the lower temperature of about 200°C and stored in a container. The steps and procedures for preparation of SSA is shown in Figure-1.

RESULT

Yield of SSA

The average yielding percentage results obtained from 10 times of incineration at the temperature of 600 °C for the duration of 3 hours of sewage sludge ash is 47.45 %. This shows that the waste has been reduced by more than half and the left over residue, which is the sewage sludge ash, is a potential cement replacement material. Jamshidi *et al.* (2012) stated that the reduction in the

volume due to during the incineration process, the organic compounds and microorganisms been removed from the sludge. Two crystalline phases calcite and dolomite have been removed from the sludge.

X-Ray fluorescence test (XRF)

The XRF results in Table-1 show that the major oxide of SSA (Fe_2O_3 , SiO_2 , P_2O_5 , CaO , Al_2O_3) is approximately similar to the Portland cement based composites where SiO_2 , CaO and Al_2O_3 were the primary component found in the eco-cement clinker (Lin and Lin, 2007). According to Zhang *et al.*, (2013), by product with the high composition of CaO , SiO_2 and Fe_2O_3 can be used as calcium, silicates and iron sources in the production of cement clinker.

This indicates that incineration of sewage sludge to sewage sludge ash form is a feasible alternative solution to the sludge disposal problem (Tay and Show, 1994). Baeza *et al.*, (2014) stated that SSA has a significant amount of SiO_2 and Al_2O_3 , it can be considered as active mineral addition on Portland Cement based composites. The low content of chloride and sulphate which is potentially harmful to the strength and durability of concrete, it would not have a significant adverse impact on SSA concrete (Khanbilvardi and Afshari, 1995).

Table-1. Comparison of oxides between ss, ssa and portland cement.

	Oxides	SS	SSA	Portland Cement
1	Iron Oxide	14.6%	13.5%	2.3%
2	Silicon Dioxide	10.2%	36.4%	21.0%
3	Phosphorus Pentoxide	10.1%	13.0%	0.0%
4	Calcium Oxide	3.3%	4.4%	66.0%
5	Aluminium Oxide	3.1%	15.6%	4.6%



X-ray diffraction test (XRD)

The mineralogical composition and the crystalline phase of the sewage sludge incinerated at temperature of 600°C is shown in Figure-2. The XRD test was carried out at the duration time/scan speed of 1 degree/minutes, step/sampling step of 0.02 degree and scan range of 10-80 degree. The peak in XRD test shows the major mineral phases in the incinerated sewage sludge were quartz (SiO₂), magnesium oxide (MgO) and hematite (Fe₂O₃). The predominant crystalline constituents of all SSA samples are identically quartz and moganite (Pan *et al.*, 2003). Crystalline form of the major elements in incinerated sewage sludge ash are invariably quartz (SiO₂), whitlockite (Ca₃(PO₄)₂) and hematite (Fe₂O₃) (Donatello and Cheeseman, 2013). On the other hand, Amiralian *et al.*, (2015) state that the presence of oxygen atoms could suggest the availability of SiO₂, Al₂O₃⁻, and Fe₂O₃ as the basic oxides for creating the pozzolanic reaction.

Slump test

Workability is defined as the easement of the freshly mixed concrete can be placed, compacted and finished. In this study, slump test was chosen as the workability test for the fresh concrete. Every different batch of concrete was tested for slump test to ensure the workability of the concrete. Due to its simplicity and convenience, slump test was carried out before the

moulding of the fresh concrete. The slump test results are shown in Table-2.

Table-2. Result of slump test for various mix design.

Sample	W/C ratio	Slump (mm)	Slump Type
1	0%	70	True Slump
2	5%	60	True Slump
3	10%	55	True Slump
4	15%	50	True Slump
5	20%	50	True Slump

The results show that the type of slump for the different proportion of replacement of water-cement ratio 0.55 are in the category of true slump. It means that the fresh concrete is well mixed and the materials are well distributed since it did not tend to segregate and shear.

It is observed that the control sample shows the highest slump of 60 mm for control sample and 5% SSA concrete, the slump height decreasing as the percentage of replacement cement by sewage sludge ash increases and the slump remains unchanged at the percentage of 15% to 20% replacement. The slump for 5%, 10%, 15% and 20% were 60 mm, 55 mm, 50 mm and 50 mm respectively.

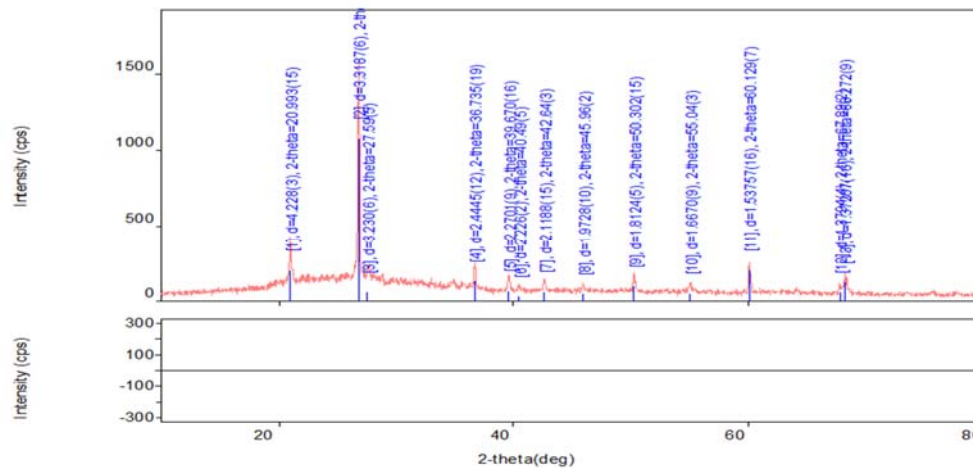


Figure-2. Mineralogical composition and the crystalline phase of SSA.

Sewage sludge which have the ability to absorb water compared to cement powder has slightly reduced the slump of the concrete mix. The decrease in workability can be explained by two factors, which is the irregular morphology of SSA particles and the high water absorption on SSA particle surfaces (Paya *et al.*, 2003). The shape of sewage sludge ash particles is not spherical which caused negative influence on workability (Monzo *et al.*, 1996). SSA could slightly decrease the workability and

strength of cement concrete due to high water demand of SSA.

Water absorption test

The durability of concrete near an exposed surface is largely determined by the rate at which harmful agents can penetrate into the concrete. The durability of concrete is due to the characteristic of its pore structure (De Schutter, 2004). The concrete was tested at the age of



28th day after removing from water curing tank. The water absorbed by the specimens was measured at 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 70, 80, 90, 100, 110, 120, 180, 240 minutes and 24 hours. The water absorption results is shown in Figure-3.

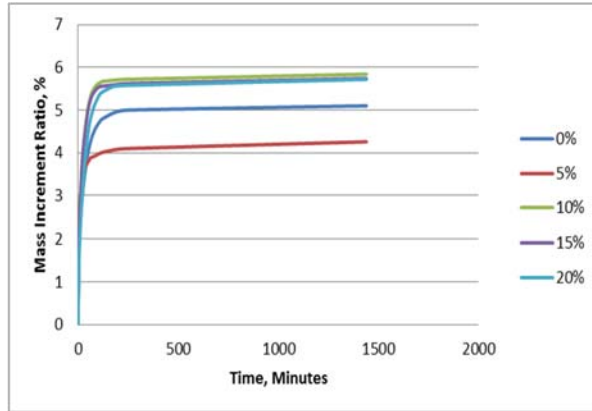


Figure-3. Water absorption test of various mix design.

Figure-4.8 shows the overall water absorption results for the 5 different proportion of SSA concrete. Based on Figure-4.8, the rate of water absorption of 10%, 15% and 20% of cement replacement by sewage sludge ash is the highest and almost similar among this 3 proportion. The control sample having the rate of water absorption lower than 10%, 15% and 20% but higher than 5% cement replacement sample. The sample with the 5% cement replacement shows the lowest absorption capacity where the average mass increment ratio is only 4.26 compared to 5.1 for the control sample. SSA mixtures with the smaller values of absorptivity are likely to have longer service life (Fontes *et al.*, 2004; Yagüe, 2005). In other words show that 5% SSA concrete would have a higher durability compared to control sample while 10-20% of SSA concrete would have a lower durability as it shows higher values in the water absorption test.

Compressive strength test

Compressive strength of concrete is the most common performance measure used by the engineer in designing building and other structures. In this study, the test age of the concrete was 1st, 7th, and 28th day and 3 cubes were tested for each of the same concrete proportion in order to obtain the average data. The compressive strength results of various mix design is shown in Table-3 and Figure-4.

Table-3. Compressive strength of various mix design.

Sample		1 day N/mm ²	7 days N/mm ²	28 days N/mm ²
1	0%	7.95	23.21	30.07
2	5%	7.39	21.22	33.09
3	10%	6.85	19.62	25.24
4	15%	6.07	17.03	23.16
5	20%	5.84	14.73	15.68

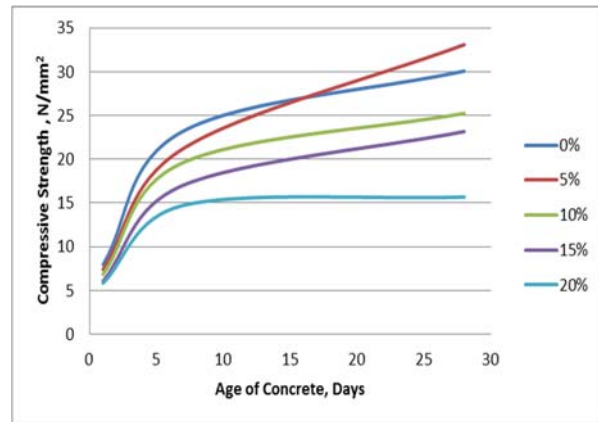


Figure-4. Compressive strength development of various mix design.

Based on the results shown in Figure-4, the mix design with SSA shown lower initial strength as compared with the control. The cement replacement of 5% SSA has shown the highest compressive strength of 33.09 N/mm² at 28 day while the lowest compressive strength is the 20% replacement of cement, which is 15.68 N/mm². The replacement of SSA at 5% has increase the compressive strength up to 10% as compared with the control concrete. The compressive strength decreases as the percentage of cement replacement by sewage sludge ash increases. The sewage sludge ash concrete shows increase compressive strength with curing time and the compressive strength loss is proportional to the percentage increment of sludge ash (Jamshidi *et al.*, 2012).

CONCLUSIONS

From the analysis of the results of this research, the following conclusion can be established:

- Incineration of sewage sludge at 600 °C reduces its volume to less than 50 %, which is a feasible solution to the land disposal problems. Besides that, incineration removed the organic compound and increases the composition of oxide element SiO₂, P₂O₅, CaO and Al₂O₃.



ii. Incinerated sewage sludge ash is a potential cement replacement as the major oxide of SSA (SiO_2 , CaO and Al_2O_3) similar to the Portland cement based composites where it is the primary component found in the cement clinker.

iii. The cement replacement of 5% SSA has shown improvement of compressive strength up to 10% as compared with the control. However, cement replacement with SSA more than 5% shows adverse result to the compressive strength.

iv. The replacement of sewage sludge ash in concrete of 5% SSA has the lowest water absorption value. Thus, 5% sewage sludge ash concrete has the lowest porosity and highest durability. The concrete with 5% of sewage sludge ash is the optimum mixture.

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