USE OF SEWAGE SLUDGE ASH AS A CEMENT REPLACEMENT IN CONCRETE: A REVIEW

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Abstract

Rapid industrial development and population growth in countries around the world have increased the production of sewage sludge. Sewage sludge is a waste product of the sewage treatment plant processes. The sewage treatment plants produce a large volume of wastewater every day in order to control the quality of the effluent released into a river or the sea. Instead of disposing of the sewage sludge at landfills, using sewage sludge as a recycle material could minimize the need for a new disposal area and consequently reduce the negative impact on the environment. Many studies have been conducted to examine the use of sewage sludge ash as a recycle material. This paper reviews the use of sewage sludge ash as a cement replacement in concrete production. Sewage sludge ash is a powdered material that contains a high percentage of SiO_2, Al_2O_3, Fe_2O_3, CaO, P_2O_5 and SO_3, and shows moderate reactivity in terms of pozzolanicity. Most of the researchers burned the sewage sludge at a temperature range of between 600°C - 900°C to produce sewage sludge ash. The partial replacement of cement with sewage sludge ash promoted an increase in the compressive and flexural strength of concrete. Meanwhile, the replacement of 5% sewage sludge ash by weight of cement was considered to be an optimum content in obtaining the best mechanical performance of concrete. Furthermore, the workability of concrete after 28-days was improved with the addition of SSA.

Keyword: Cement replacement, Pozzolanic, Sewage sludge

Introduction

Urbanization, industrialization and population growth have significantly increased the amount of sewage sludge (SS) produced. The modernization of wastewater management process has also contributed to the increase of sewage sludge. Sewage sludge is a waste product of the sewage treatment plants. The large amount of sewage sludge produced every year will affect the environment and also social development. Normally, sewage sludge will be incinerated, sent to landfills for disposal or used in agricultural applications (Zhang et al., 2018). However, the disposal of sewage sludge in landfills can cause problems to the soil due to the leachate generated by the sewage sludge, that contains potentially toxic heavy metals. In accordance with the global principles on sustainable development and stringent standards set by the governments, many countries are trying to find alternative environmental-friendly methods to dispose of the sewage sludge. Reuse of the sewage sludge and sewage sludge ash (SSA) in concrete is one of the best alternatives in reducing the amount of sewage sludge, and this can alleviate the impact of this waste material on the environment and human health.

SSA is primarily a silty material with 1 -100 µm particle size (Cyr et al., 2007). It is produced by the combustion process in an incinerator at a temperature range of between 550 °C - 850°C. Studies were conducted by Fontes et al. (2016), Cyr et al. (2007), and Ing et al. (2016) to examine the use of SSA as a cement replacement in concrete and mortar production. These studies showed that SSA reduced the workability of fresh concrete and mortar and tended to increase the setting time of cement. The replacement of blended cement by SSA increased the compressive strength at early and late ages of concrete (Oliva et al., 2019). Other studies were also carried out to explore the use of SSA in pavement construction industries and tile production processes. SSA is a polyphasic material made of several crystalline minerals such as silicon oxide, calcium oxide, iron oxide, calcium sulphate and other minerals (Cyr et al., 2007).

Production of Sewage Sludge Ash (SSA)

Sewage sludge ash (SSA) is a material obtained from the incineration of wastewater sludge. According to previous research, there was no specific temperature to burn the sewage sludge to form ash. However, Cyr et al. (2007), Monzó et al. (2003) and Fontes et al. (2004) burned the sewage sludge at temperatures ranging from 550˚C to 850˚C to produce sewage sludge ash that contained enough oxide components to be a cement replacement in concrete mixture.

Monzo et al. (2003) found that an amorphous SSA could be obtained after incinerating the sewage sludge (SS) at 800°C while Fontes et al. (2004) in their investigation on the potential use of sewage sludge ash suggested that the sludge should be burned at a temperature of 550°C for three hours for it to be used as a cement replacement. Lin and Weng (2001) incinerated the sludge at 800°C in combustion chamber to remove the organic substance which was then used as clay substitute in brick manufacturing. The temperature used to produce sewage sludge ash did not exhibit any significant effect on the chemical properties of the ash but slightly affected its physical shape. A study conducted by Chin et al. (2016) reported that the sludge burned at 600˚C exhibited needle-shaped particles whereas a smooth structure was found in sludge burned at 800°C due to the pozzolanic reaction which filled the void and pores in the mortar. Moreover, sludge burned at 800°C also provided additional strength to the mortar where the compressive strength had increased after 28 and 90 days (Chin et al., 2016).

However, SSA incinerated at more than 850°C can lead to low pozzolanic reactivity due to the crystallization of amorphous silica (Oliva et al., 2019). Besides, the higher incinerator temperature could also contribute to environmental problems and increase the carbon emissions. Thus, **Table 1** shows the optimum temperatures used by different researchers to produce SSA that provides a substantial pozzolanic activity in concrete mixture.

Table 1 Various temperatures used to produce SSA and effects on the cement-based materials

Researchers	Temperatures (°C)	Incineration Time (hours)	Method of Incineration	Research Findings
Cyr et al. (2007)	850	-	Fluidized Bed Combustor	Delay in setting and hydration of 1 hour and 30 minutes and 3 hours for 25 % and 50% SSA, respectively.
Monzo et al. (2003)	800	-	Fluidized Bed Combustor	Partial replacement of Portland cement with SSA produced a decrease in mortar workability.
Fontes et al. (2004)	550	3	Calcination	High strength mortar and concrete could be obtained using sewage sludge ash as a mineral additive
Lin and	800	-	Incinerated	The pulverized sludge

Weng (2001)				ash could be used as clay brick materials
Chin et al. (2016)	800	-	Incinerated	10 % replacement of 800 °C burnt SSA improved the compressive strength of mortar
Ing et al. (2016)	600	3	Incinerated	Lower water absorption and improved compressive strength of concrete up to 10% as compared to control sample after 5% replacement of cement with SSA.
Pérez et al. (2014)	800	-	Incinerated	Replacement of cement with 20% SSA proved to be suitable to produce precast concrete blocks
Jamshidi et al. (2012)	650	-	Incinerated	30 MPA concrete strength was achieved after replacement of sand with 20% SSA
Kazberuk. (2011)	850	-	Incinerated	The replacement of natural aggregate by 25% SSA provided adequate compressive strength, density and water absorption for concrete structures.

*Note (-) Not reported

Chemical Components of Sewage Sludge

The composition of sewage sludge (SS) generated in sewage treatment plants depends on the characteristics of raw wastewater and the procedures used to treat the wastewater (Perez et al., 2014). Since wastewater treatment process will concentrate the pollutants present in the sewage, the resulting SS contains a wide variety of suspended substances which have agricultural values such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The major elements in SSA are Si, Al, Ca, Fe and P. The Crystalline forms of these element are SiO_2, ($Ca_3(PO_4)_2$) and Fe_2O_3 (Cyr et al., 2007). The presence of these elements is also important when considering SSA as a pozzolanic additive in the blended cement. Based on the main oxide content in SSA, it is suitable to replace the Portland cement content in normal concrete with SSA because it is able to produce more silicon which is the main component in producing pozzolanic activity in cementitious materials (Ing et al., 2016). **Table 2** shows the main oxide content of SS, SSA and cement.

An effort was also extended by Lin et al. (2007, 2008) to reutilize sewage sludge ash by improving the properties of SSA incorporated nano-SiO_2 as an additive in tile manufacturing process. This study also found that the addition of nano-SiO_2 as an additive at the kiln temperature from 1000 °C to 1100 °C in the tile production could reduce the water absorption and abrasion. However, the bending strength of tiles was increased (Lin et al., 2007; Lin et al., 2008; Chen and Lin, 2009)

Table 2 Comparison of chemical composition of SS, SSA and Portland Cement

	Oxides	SS (%) (Franz2008)	SSA (%) (Franz2008)	Portland Cement (%) (Franz 2008)	Portland Cement (%) (Lin and Weng 2001)	SSA (%) (Lin and Weng 2001)	SSA % (Ing et al. 2016)	SSA % (Jamshidi et al. 2012)	SSA % (Kazberuk 2011)
1	Iron Oxide (Fe_2O_3)	14.6	13.5	2.3	3.86	8.06	10.0	15.6	8.5
2	Silicon Dioxide (SiO_2)	10.2	36.4	21.0	20.99	50.01	19.2	18.2	48.2
3	Phosphorus Pentoxide (P_2O_5)	10.1	13.0	0.0	-	1.03	12.3	8.9	5.6
4	Calcium Oxide (CaO)	3.3	4.4	66.0	65.96	4.75	30.6	22.8	4.1
5	Aluminium Oxide (Al_2O_3)	3.1	15.6	4.6	6.19	16.23	8.9	9.1	18.7

Note: (-) not reported

Physical Properties of Sewage Sludge Ash

Sewage sludge ash (SSA) is a silty-sandy material and its maximum particle size is 100 µm with a mean diameter of around 26 µm. A relatively large fraction of the particles is less than 0.075 mm (no.200) in size (Lin et al., 2008). Besides, SSA also consists of moderately low organic and moisture content. It is also a non-plastic material because some water is needed to obtain the satisfactory level of the plasticity (Anderson, 2002). Specific gravity of SSA was found by Lynn et al. (2015) ranging from 1.8 - 2.9. They also suggested that SSA was suitable to be used as a filler or fine aggregates in concrete. Furthermore, using SSA as a partial replacement of cement in concrete would increase the water absorption between 8 - 20% compared to 1 - 3 % when using natural sand due to the irregular particles with rough surface and a porous microstructure of SSA (Lynn et al., 2015). The existence of crystalline materials such as quartz (14%), felspar and micas (9%) and amorphous (77%) in SSA content influenced the pozzolanic activity of cement-based materials (Cyr et al., 2007).The amount of main oxide content in SSA such as SiO_2 and Al_2O_3 would also affect the pozzolanic activity of cement-based materials. The irregular and porous structures of SSA also lead to high water demand when used in concrete and mortar (Cyr et al., 2007).

The Use of Sewage Sludge Ash in Concrete

In construction industries, SS and SSA are normally used as partial replacements of sand or cement in concrete, mortar, ceramics and in the production of bricks and bio-bricks. 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 (Ing et al., 2016; Fontes et al., 2016) and this also lowered the water absorption (Ing et al., 2016) compared to the control samples. The compressive strength of pre-cast concrete block also increased after replacing 10% cement with SSA (Perez et al., 2014). Even though the compressive strength of pre-cast concrete block was not enhanced after replacing 20% cement with SSA, the production of the block would require less cement (Perez et al., 2014). A study was carried out to examine the use of SSA as a lightweight aggregate in concrete. It was found that the application of 25 % of natural aggregate volume provided compressive strength, density and water absorption values adequate for service condition of concrete structure (Kazberuk, 2011). Meanwhile, the partial replacement of cement with SSA promoted an increase in the total porosity and a reduction in the absorptivity values of the control mixtures (Fontes et al. 2004). In addition, the fire resistance of concrete also increased when the SSA content in concrete mixture increased (Chen et al., 2006). **Table 3** shows the optimum content of SSA used to replace the Portland cement as identified by several researchers.

Table 3 Optimum content of SSA as cement replacement in concrete

Researchers	Compressive Strength	Flexural Strength
Jamshidi et al. (2012)	5%	5%
Ing et al. (2016)	5%	-
Fontes et al. (2016)	5%	5%

Conclusion

Partial replacement of Portland cement with sewage sludge ash (SSA) can be considered as a viable alternative as it enhances the properties of concrete as well as reduces the amount of waste materials dumped at landfills. Based on the previous research reviews, the following conclusions can be established:

i. The optimum temperatures used by researchers to produce SSA that provide substantial pozzolanic activity in concrete mixture range between 550˚C to 850˚C.
ii. The replacement of SSA as a partial replacement of cement in concrete will increase the water absorption between 8- 20%.
iii. Sewage sludge ash is a powdered material that contains high percentage of SiO_2, Al_2O_3, Fe_2O_3, CaO, P_2O_5 and SO_3, and shows moderate reactivity in terms of pozzolanicity.
iv. The major oxide components of SSA (Fe_2O_2, SiO_2, P_2O_5, CaO, Al_2O_3) are quite similar to that of the Portland cement.
v. The optimum content of SSA as a cement replacement in concrete is 5 %.

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Conflict of interests

The authors declare that there is no conflict of interests with any organization or financial body for supporting this research.

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