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THE USE OF SEWAGE SLUDGE AND ITS ASH IN CONSTRUCTION AND AGRICULTURE INDUSTRY: A REVIEW

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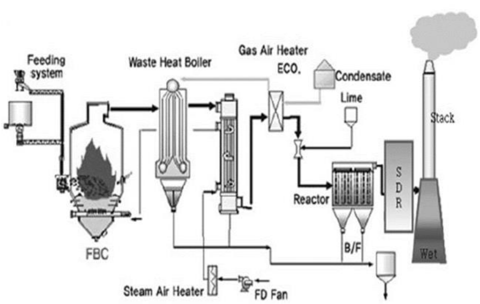
Graphical abstract



Abstract

Harmful sewage sludge generated from wastewater treatment plant being disposed to landfill has long caused major anxiety in local municipalities around the world. In line with the concept of sustainable development practice being adopted around the world, more efforts has looked deeper into ways to reuse this waste material and one of it was the ash generated from this material. This paper review the use of sewage sludge and sewage sludge ash (SSA) in construction and agriculture industry through a multi-faceted review of previous researches done in various industries. Besides reducing the amount of waste in landfill, this solution can also contribute to the reduction of natural resources consumption. It examines in detail how the various burning temperature can affect the sewage sludge ash as well as the potential usage of this ash in asphalt, concrete and cement mixture, soil stabilization and agriculture either as a substitute material, or as a raw and enhancement material. The various chemical composition in this ash enable the SSA to be used in application in multiple industry as each of the respective chemical composition bring enhancement to the end product respectively.

Keywords: Waste, sewage sludge, ash, disposal, reused

Abstrak

Enapcemar kumbahan berbahaya yang terhasil dari loji rawatan air kumbahan dan dilupuskan ke tapak pelupusan sampah telah menimbulkan kebimbangan di kalangan pihak berkuasa tempatan di seluruh dunia sejak sekian lama. Selaras dengan konsep amalan pembangunan mampan yang digunapakai di seluruh dunia, banyak usaha telah dilakukan untuk mengguna semula bahan buangan ini dan salah satu daripadanya ialah dengan mengguna semula abu yang terhasil daripada enapcemar kumbahan tersebut. Kertas kajian ini bertujuan untuk mengulas tentang penggunaan semula sisa enapcemar dan abunya dalam industri pembinaan dan pertanian melalui kajian semula kertas-kertas penyelidikan yang telah dilakukan oleh para penyelidik terdahulu. Selain daripada mengurangkan jumlah sisa enapcemar ditapak pelupusan, penggunaan semula sisa enapcemar ini turut mengurangkan penggunaan bahan-bahan semulajadi dalam industri pembinaan. Dalam kertas kajian ini juga, ia mengkaji secara terperinci bagaimana suhu pembakaran boleh memberi kesan kepada abu enapcemar kumbahan yang dihasilkan serta potensi penggunaan abu ini dalam campuran asfalt, konkrit, campuran simen, penstabilan tanah dan industri pertanian samada sebagai bahan pengganti, atau sebagai bahan mentah dan bahan peningkat. Komposisi kimia yang pelbagai yang terdapat didalam abu enapcemar ini telah membolehkan abu enapcemar digunakan dalam pelbagai industri kerana setiap komposisi kimia itu membawa kepada peningkatan kualiti terhadap produk akhir yang dihasilkan.

Kata kunci: Bahan buangan, enapcemar, abu enapcemar, pelupusan, penggunaan semula

1.0 INTRODUCTION

Sewage sludge is a by-product material generated from sewage treatment plant that contain harmful element to the environment. The amount of sewage sludge produce increase day by day all over the world due to ongoing industrialization and increased in living standard and its bring a huge disposal problem to the local municipalities. Statistic shows that, in Spain, 1.2 million tons of sewage sludge were generated annually [1]. According to Ministry of Interior, Taiwan, in 2003, 180000 m^3 of sewage sludge was produced daily [2]. To reduce the sludge waste, 70 percent of sewerage sludge in Japan was incinerated and it was reported that, in 2011 alone, 221000 tons of sewage sludge ash was produced [3]. In United States and the European Union countries, the total production of sewage sludge approaches 17 million tons (Mt) of dry solids per year [4]. In Malaysia, about 3 million metric tons of sewage sludge was produced annually and it has been predicted to rise up to 7 million metric tons in the year of 2020 [5]. The cost to manage the sewage sludge would be up to US$0.33 billion per year. This amount would impose a huge financial burden to sewage and wastewater treatment companies [6]. Majority of the country use the land fill as the main disposal method for sewage sludge as it is the easiest way and involve a cheaper cost. It is estimated that, a ton of sludge deposited in landfill can cost around US$40 to US$60 [7].

In some countries, sewage sludge has been reused as fertilizer in agriculture industry. For country with limited land space, ocean is the best choice for sewage sludge disposal. However, disposal of sewage sludge in landfill or ocean is not considered as a sustainable waste management practice and not in line with worldwide trends. Moreover, from environmental point of view, landfill and ocean disposal can cause environmental problem due to the leachate release by the sludge. Leachate that contain heavy metal materials could contaminate underground and surface water and consequently can harm the aquatic life in the ocean. In 1996, London Protocol has prohibited sewage sludge ocean disposal [8]. Similar in Europe, ocean disposal has been banned since 1998 [9]. To overcome this problem, some countries perform incineration as an intermediate sewage sludge treatment prior disposing it into landfill. Incinerating sewage sludge will produce an inert ash that has much less volume than the original volume hence reduce the amount of sewage sludge to be deposited in landfill. Studies shows, incineration could reduce the mass and volume of sewage sludge up to 70 and 90 percent respectively [9-10]. However, incineration of sewage sludge will create another environmental issue such as air pollution where some hazardous substances in exhaust gas was released during the burning process [11].

In order to reduce the amount and combat the problem related to sewage sludge and sewage sludge ash disposal, simple rule of 3R: reuse, reduce and recycle can be implemented. Recently, a lot of researches has been conducted regarding the use of sewage sludge and sewage sludge ash as part of the construction materials. From the studies, it shows that sewage sludge and sewage sludge ash is a useful materials that can be utilized in construction industry. Reuse of sewage sludge in construction industry not only significantly reduce the amount of sewage sludge in landfill, it also can reduce the consumption of natural resources thereby reduce the cost of construction materials. This paper attempt to review the potential that sewage sludge and sewage sludge ash have which can be used in construction and agriculture industry.

2.0 EFFECT OF BURNING TEMPERATURE AND BURNING DURATION ON SSA PROPERTIES

Sewage sludge ash (SSA) is an inert materials produce by combusting the dewatered sewage sludge in an incinerator at high temperature. The temperature, combusting duration, types of incinerator, source of sewage sludge (domestic or industrial) and chemical additives used in sewage treatment plant will greatly influence the particle size and chemical properties of sewage sludge ash [12-15]. Fluidization bed combustion (FBC) is one of the widely used technologies to burn sewage sludge. Figure 1 shows the schematic diagram of the burning process using FBC sludge incinerator. FBC has several advantages compare to other methods that including the complete combustion at relatively lower temperature and a longer residence time of sludge in the hot bed.

Perez *et al*. investigated the potential use of SSA as a cement replacement in precast concrete blocks used maximum temperature of 800°C to produce SSA using fluidized bed incinerator [10]. Martyn *et al.* also using fluidized bed combustor at temperature of 850°C to burn sewage sludge in their study to investigate the behavior of SSA in cement based materials [15]. Various temperature ranging from 800°C to 900°C has been used by previous researcher to incinerate sewage sludge and usually the burning periods is around 1 to 2 hours. However, there are studies that used the burning period more than 2 hours to produce SSA. For example, Kartini *et al.* in their study burnt domestic waste sludge powder under uncontrolled burning in ferrocement furnace for 72 hours to produce ash that has been used as partial material replacement for concrete [16].

In other study, Lin *et al.* used temperature of 800°C with burning period of 20 hours to produce SSA, which was then used in glazed tiles manufacturing [17]. Munjed and Mousa burned the wastewater sludge at temperature of 550°C in their study using SSA as a soil stabilizing agent [18]. Marta used two different temperature for upper (>850°C) and bottom (>600°C) furnace chamber to burn sewage sludge [13]. Monzo *et al*. used temperature of 800°C to burn sewage sludge in their study to investigate the effect of SSA and SSA particle size on the workability of cement mortar [19].

Lin and Weng examined the possibility of using SSA as a brick materials also incinerated the sewage sludge at 800°C in a combustion chamber to remove the organic substance. The SSA then was used to produce bricks without any further treatment [20]. While, Siew *et al*. investigate the properties of cement mortar using SSA that was incinerated at two different temperatures (600°C and 800°C). The FESEM test results show that SSA samples burnt at 600°C exhibited needle-shaped particles whereas a smooth structure was found in SSA burnt at 800°C due to the pozzolanic reaction which filled the void and pores in the mortar. Even though the early strength of mortar using both types of SSA (burnt at 600°C and 800°C) were reduced, the results of compressive strength at 90 days shows that the replacement of 10 percent of 800°C SSA in cement mortar exhibited better performance compared to 600°C SSA and control sample [12].

Table 1 XRF Analysis for chemical composition in sewage sludge and SSA burning at 600°C and 800°C

Element	SS	600°C SSA	800°C SSA
	Percentage (%)		
Silicon (Si)	4.82	18.49	18.66
Iron (Fe)	12.07	14.44	14.30
Aluminium (Al)	1.59	7.95	7.55
Phosphorus (P)	4.85	6.56	6.32
Calcium (Ca)	2.76	4.20	4.12
Sulphur (S)	1.35	1.44	0.69
Potassium (K)	0.49	1.13	1.08
Titanium (Ti)	0.36	0.99	0.96
Magnesium (Mg)	0.17	0.91	0.82
Zinc (Zn)	0.40	0.81	0.79
Barium (Ba)	0.12	0.13	0.13
Copper (Cu)	0.05	0.13	0.11
Manganese (Mn)	0.05	0.09	0.09
Tin (Sn)	-	0.06	0.06
Zirconium (Zr)	0.03	0.05	0.04
Chlorine (Cl)	0.14	0.05	-
Lead (Pb)	0.04	0.03	0.03
Bromine (Br)	0.04	0.02	-
Chromium (Cr)	0.03	0.02	0.02
Strontium (Sr)	0.03	0.02	0.02
Nickel (Ni)	0.01	0.02	-
Vanadium (Nb)	-	-	0.01
Rubidium (Rb)	0.01	-	-

In Japan, sewage sludge usually incinerated at temperature of 800°C or higher. Kenichiro and Tsutomu used three different temperature (800°C, 900°C and 950°C) with three different burning duration ranging from 0.5 to 1.5 hours to incinerate sewage sludge. As a result, it was found that roughness structure on the SSA surface decayed as the incineration temperature level advanced from 800°C to 950°C and specific surface area was also reduced by the same rise in temperature [11]. In study conducted by Lin *et al.* to improve the stabilization of soil, they incinerate dewatered sewage sludge at temperature of 900°C to 1000°C to produce SSA. Then, SSA was ground using multi-spinning roller powder-grinding machine to get average particle size of 0.0137mm before applying it to soft subgrade soil [21]. Others, Tashima *et al.* use maximum temperature of 775°C to burn sewage sludge and used it in mortars, Georg *et al.* use temperature of 850°C, Deepak *et al.* use average temperature of 900°C to incinerate the sludge and Ewelina use temperature of 815°C [8, 22-24].

Based on study conducted by Lin and Weng and Kenichiro and Tsutomu using four different burning temperature (600°C, 800°C, 900°C and 950°C), it can be concluded that, the higher the temperature used to burn sewage sludge, the fine the particles of sewage sludge ash will be produced [11-12].

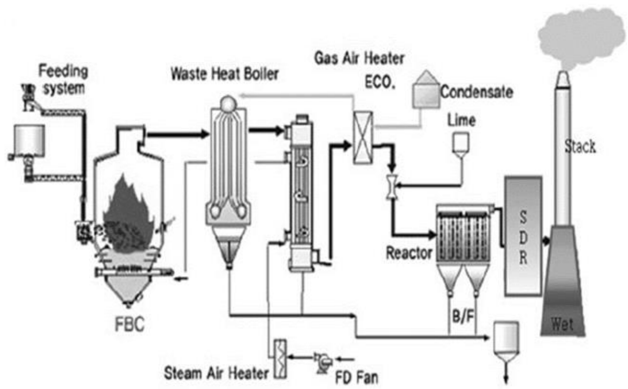
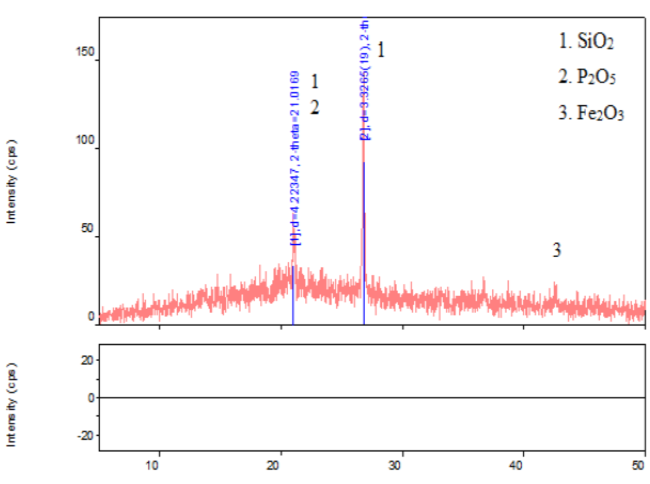


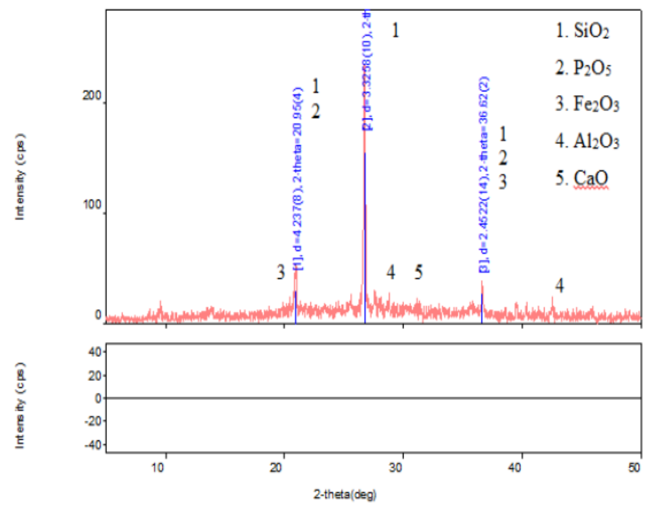
Figure 1 Schematic diagram of the process configuration of a FBC sludge incinerator [8]

2.1 Chemical Properties of Sewage Sludge and Sewage Sludge Ash

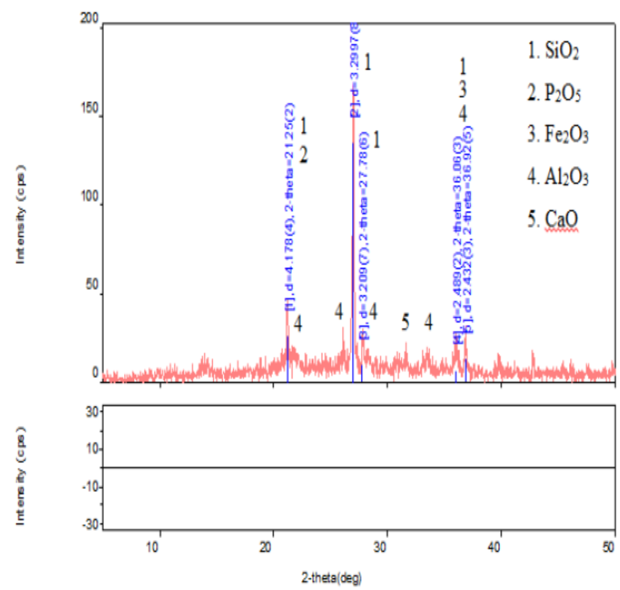
Chemical compositions of sewage sludge and sewage sludge ash greatly depends on the chemical additives used during the treatment of sewage and wastewater in plant [15]. However, as noted previously, the temperature used to incinerate sewage sludge also play a significant role in determine the amount of chemical and trace element in SSA. In study conducted by Siew *et al.*, more quartz (silicon dioxide (SiO_2)) and aluminum oxide are found in SSA burn at 800°C than 600°C [12]. Normally X-ray diffraction (XRD) and X-ray fluorescence (XRF) analysis are conducted to determine the chemical composition of sewage sludge and sewage sludge ash. Figure 2 shows the XRD pattern of raw sewage sludge and sewage sludge ash incinerate at two different temperature (600°C and 800°C) and Table 1 shows XRF analysis for chemical composition in sewage sludge and sewage sludge ash incinerate at 600°C and 800°C [12].



(a) Raw sewage sludge



(b) 600°C SSA



(c) 800°C SSA

Figure 2 XRD Pattern of (a) raw sewage sludge (b) 600°C SSA (c) 800°C SSA [12]

Table 2 Chemical composition of SS and SSA

Oxides	SS (%) [6]	SSA (%) [6]	SSA (%) [25]	SSA % [10]	SSA % [2]
Iron Oxide (Fe_2O_3)	14.6	13.5	8.06	10.0	6.81
Silicon Dioxide (SiO_2)	10.2	36.4	50.01	19.2	63.31
Phosphorus Pentoxide (P_2O_5)	10.1	13.0	1.03	12.3	7.02
Calcium Oxide (CaO)	3.3	4.4	4.75	30.6	1.80
Aluminium Oxide (Al_2O_3)	3.1	15.6	16.23	8.9	15.38
Magnesium Oxide (MgO)	-	-	1.68	2.7	1.03

Oxides	SS (%) [6]	SSA (%) [6]	SSA (%) [25]	SSA % [10]	SSA % [2]
Sulfur Trioxide (SO_3)	-	-	3.33	11.1	1.02
Natrium Oxide (Na_2O)	-	-	0.92	0.8	0.70
Potassium Oxide (K_2O)	-	-	2.61	1.4	1.51
Chlorine(Cl_2)	-	-	-	-	
Titanium Dioxide (TiO_2)			-	1.0	

Table 2 shows the difference in percentage of chemical composition and trace element in sewage sludge and sewage sludge ash used by previous researcher in their study. The difference in amount of chemical composition probably due to the source of sewage sludge (domestic or industry), burning temperature and the chemical used in sewage treatment plant. However, it can be seen that, most of the sewage sludge and sewage sludge ash mainly contain of iron oxide (Fe_2O_3), silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), phosphorus pentoxide (P_2O_5), calcium oxide (CaO) and sulphur trioxide (SO_3). Silicon dioxide is the main components that make sewage sludge a suitable raw material in ceramic manufacturing industry. High aluminium oxide content may also benefit in resistance to the chloride attack in concrete application due to chloride binding capacity of amorphous alumina [9]. Besides, silicon dioxide, aluminum oxide, and calcium oxide are the main elements in cement that used in construction industry hence make SSA as a useful waste material to be used as partial replacement for cement in mortar and concrete. Sulphur trioxide is used to retard quick setting in cement and phosphorus pentoxide is the element that will control the quality of cement [16]. In agricultural industry, phosphorus element ensure that SSA can be utilized as fertilizer.

2.2 Sewage Sludge and Sewage Sludge Ash in Asphalt Mixture

Due to its subtle size, most of the study used sewage sludge and sewage sludge ash as a partial replacement of fine aggregate or as a filler in asphalt mixture. Figure 3 show the comparison of particle size distribution of SSA and other types of filler used by previous researcher [1]. From the figure, it can be seen that about 90% of SSA has particle size smaller than 60μm. According to Malaysia Specification for Road Works, filler can be defined as particle size that passing through 75μm sieve size.

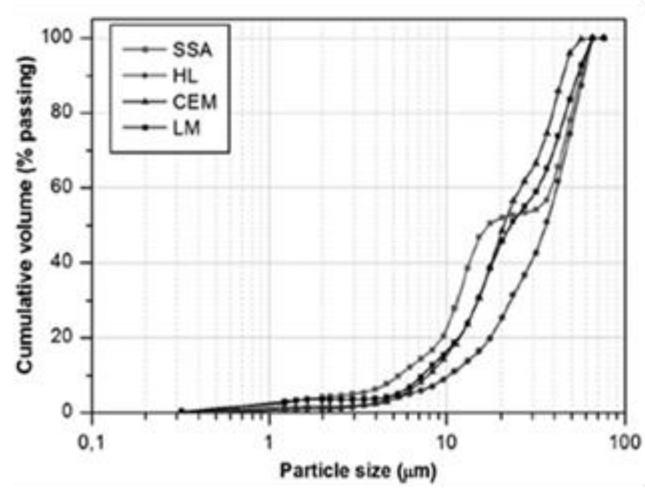


Figure 3 Comparison of particle size distribution of sewage sludge ash (SSA), hydrated lime (HL), cement (CEM) and limestone (LM) filler [1]

Study conducted by Sato *et al.* pulverized the SSA before it was utilized as a filler in asphalt mixture. From the study, it was found that, pulverized SSA has improved the Marshall stability of asphalt mixture compare to unpulverized SSA. Moreover, the amount of pulverized SSA that can be mixed in asphalt mixture also increase. Besides that, due to the porous property that belongs to SSA, pulverizing SSA become much easier than the mineral filler (limestone) [3]. Other study show that, replacement of 50 percent of mineral filler with dry sludge has increase the stability, flow and air voids of Marshall sample [26].

Khyati *et al.* investigate the usage of SSA in asphalt concrete using disk shape compact tension testing. From the fracture energy measured, it was found that the asphalt concrete with 2 percent SSA has similar performance with control sample (0 percent SSA). Therefore, they conclude that SSA has a good potential to be used effectively in asphalt concrete and 2 percent reduction in the use of virgin aggregates would lead to significant preservation of environment and natural resources [27]. Al Sayed *et al.* used municipal sewage sludge to examine the suitability of SSA as filler in asphalt concrete wearing course. From Marshall stability result, asphalt concrete with SSA has lower value compare to the asphaltic mix using limestone (control sample). However, both mixtures are acceptable to be used as wearing course according to Bahrain Specifications. Stability test was conducted at elevated temperature (70°C and 80°C) to represent hot region temperature in Gulf country, asphaltic concrete mix with SSA show different pattern where its stability value are greater than control sample. This result suggested that SSA are suitable to be used as a filler in hot environments [32].

Table 3 Comparison of chemical composition of sewage sludge and sewage sludge ash with cement and other type of ash

Oxides	SS (%) [6]	SSA (%) [10]	POFA (%) [28]	OPC (%) [29]	Rice Husk Ash (%) [30]	Fly Ash Class		
						F (%) [31]	C (%) [31]	F (%) [25]
Iron Oxide (Fe_2O_3)	14.6	10.0	1.1	3.86	0.10	14.4	5.4	2.33
Silicon Dioxide (SiO_2)	10.2	19.2	53.5	20.99	80.20	49.9	32.9	54.22
Phosphorus Pentoxide (P_2O_5)	10.1	12.3	-	-	0.35	-	-	-
Calcium Oxide (CaO)	3.3	30.6	8.3	65.96	0.55	3.23	28.9	2.81
Aluminium Oxide (Al_2O_3)	3.1	8.9	1.9	6.19	0.14	24.0	19.4	31.39
Magnesium Oxide (MgO)	-	2.7	4.1	0.22	0.23	0.98	4.8	0.59
Sulfur Trioxide (SO_3)	-	11.1	2.4	-	0.26	0.88	3.8	0.01
Natrium Oxide (Na_2O)	-	0.8	-	0.17	0.37	-	-	0.21
Potassium Oxide (K_2O)	-	1.4	-	0.60	1.3	2.46	0.30	1.16
Chlorine (Cl_2)	-	-	-	-	0.17	-	-	-
Titanium Dioxide (TiO_2)	-	1.0	-	-	-	-	-	1.42

Similar study (investigate on the suitability of using SSA as a filler in asphalt mixture) has been conducted by Zachary and Donald. Stability test results shows similar pattern where asphalt mixture using SSA as a filler (filler contribute 6% from the total weight of aggregate in asphalt mixture) has lower value compare to the mixture using lime and cement. The same findings has been previously revealed by Al Sayed *et al.* Even though the stability result of SSA asphalt mixture is lower, the value is still in the acceptable range set by the Kenyan Standard Asphalt Concrete Properties Specification and therefore SSA was recommended to be used in the asphalt mixture as binder course and wearing course for low volume traffic roads [33].

Besides using SSA as fine aggregates and filler replacement in asphalt mix, some study used SSA to produce molten slag before used it in asphalt mix as aggregate substitute. Study conducted by Jakarni *et al.* shows that sewage sludge molten slag fulfill almost all standard requirements for aggregates to be used in road constructions (LAAV, AIV, PSV and soundness) except flakiness. Therefore, they concluded that sewage sludge molten slag can be utilized as aggregate substitute where aggregate constitute about 94% to 95% in asphalt mixtures [34].

2.3 Sewage Sludge and Sewage Sludge Ash in Cement Mixture

Due to its content that has similarity in terms of major chemical components with Ordinary Portland Cement (OPC) such as SiO_2, CaO, Al_2O_3, Fe_2O_3 and MgO, sewage sludge and sewage sludge ash are used in various applications in construction industry including as raw feed cement clinker production, as partial cement or aggregate replacement in concrete mix, as partial cement replacement for bricks and precast concrete blocks manufacturing, as mineral additive in cement mortar and as raw materials in glass-ceramic productions. Table 3 show the comparison of chemical composition of sewage sludge and sewage sludge ash with cement and other type of ash that normally used in cement mixture. Piasta and Lukawska investigated the effect of sewage sludge ash in cement mortar. From the results obtained, the cement mortar incorporated with SSA has longer setting time and it may be attributed by the presence of phosphorus in SSA. Even though there was metal elements in SSA, the effect is not significant due to low contents and it was suggested, 10% of SSA could be a safe amount to be added in cement binder composites [35].

Doh *et al.* used waste water treatment plant sludge ash as partial replacement of cement in concrete mixture. XRF test result shows, the oxide component of SSA is approximately similar to the OPC based composites where SiO_2, CaO and Al_2O_3 are the primary components. From water absorption and compressive strength test, it was found that 5 percent of SSA-cement replacement has the lowest water absorption and highest compressive strength. Thus, 5 percent SSA-cement replacement was suggested as the optimum mixture design where it has lowest porosity and highest durability [6]. Study conducted by Marta using SSA as partial replacement of aggregate in concrete mix found that SSA strongly influenced the technical properties of the concrete. The test result showed 25 percent SSA was suggested as an optimum amount to replace natural aggregate by volume in concrete structural application where the concrete mix produce an acceptable compressive strength and water absorption. However, for non-structural application where the high strength concrete is not crucial, the amount of sewage sludge ash to be added can be more than 25 percent of the volume of natural aggregate as long as it is not affect the quality of the concrete [13].

2.4 Sewage Sludge and Sewage Sludge Ash in Soil Stabilization

In soil stabilization application, most of the studies use sewage sludge ash to enhance the engineering properties of soft soil. Gullu and Girisken used industrial wastewater sludge to investigate the performance of treated fine-grained soil. Using the sludge to soil proportions up to 80%, they found that the internal friction angle of untreated soil is significantly enhanced at most of the sludge dosages ($p < 0.05$) and 50% sludge dosage can improve the soil to "good" rating quality to be used as base layers [36]. Lin *et al.* conducted a study to compare the improvement in strength of soft soil using sewage sludge ash and fly ash. From the result of UCS, CBR and triaxial compression test, they found that both ash (sewage sludge ash and fly ash) can effectively improve the strength of soft cohesive subgrade soil and suggested the optimum amount of sludge ash to be added is around 8 percent [25].

Munjed and Mousa examined the application of burned wastewater sludge ash in soil stabilization. The results show that the addition of 7.5% of the burned sludge ash by the dry weight of the soil will increase the unconfined compressive strength and maximum dry density and also decrease the swelling pressure and the swell potential of the soil. The addition of percentage higher than 7.5% by dry weight of the soil decreases both the maximum dry density and the unconfined compressive strength. As a result it showed less effectiveness in stabilizing the soil [18]. In another hand, some researcher used the mixed of sewage sludge ash and other materials such as cement, hydrated lime, nano-silicon dioxide and nano-aluminium oxide to stabilize the soft soil. Chen and Lin use the mix of sewage sludge ash and cement to treat the soft subgrade soil. The results of unconfined compressive strength test shows that the soil sample mix with sewage sludge ash and cement has 3-7 times higher strength compared to untreated soil. In some samples, the additive (mix of sludge ash and cement) has improve the CBR values by up to 30 times to that of untreated soil [37].

Lin *et al.* investigated the properties of soft subgrade soil using sewage sludge ash/cement mixture and nano-silicon dioxide. From their study, they found that the ratio of sludge ash/cement (3:1) produce the best improvement and the most efficient treatment to increase the soil strength with additional 2 percent of nano-silicon dioxide [21]. Luo *et al.* examined the ability of using incinerated sewage sludge ash/cement mixture with nano-aluminium oxide to improve the strength of soft cohesive soil. From the study, they conclude that 15 percent of SSA/cement replacement could effectively stabilize A-6 clay soil, and 1 percent of nano-aluminium oxide additive may be the optimum amount to add to the soil [38]. In another study conducted by Lin *et al.*, they use the mix of sewage sludge ash with hydrated lime to improve the geotechnical properties of soft soil. The test result indicate that SSA/hydrated lime could improve 95% of CBR values, triaxial shear strength, unconfined compression strength, and shear strength parameter. Moreover, test results also suggest that the optimum amount of SSA/hydrated lime additive to be added to soft soil is 8% [39].

2.5 Sewage Sludge and Sewage Sludge Ash in Agriculture Application

Even though sewage sludge contain a trace of heavy metal elements that can harm the environment, it is undeniable that sewage sludge also contain other type of elements such as carbon, nitrogen, phosphorus and potassium which are really needed for crops to grow up. Therefore, besides using sewage sludge in construction industry, it also suitable to be used as fertilizer in agriculture industry. Hossain *et al.* conducted a study to evaluate the effects of industrial and residential sludge on seed germination and growth performance of Swietenia Mahagoni seedlings. From the results, it shows that the seed germination percentage and the seedling growth parameters varied significantly in the soil added with sludge compare to the soil without the sludge. However, due to heavy metal elements, they recommend that the application of sludge in agriculture industry is only use for non-food crops. It is also necessary to find out the accurate rates of sludge application in order to avoid over or under fertilization to reduce the risk of extensive heavy metal additions [40].

Sohaili *et al.* investigated the feasibility of using municipal sewage sludge as fertilizer by comparing the nutrient content in sludge and chemical fertilizer that available in the market. Using Abelmoschus Esculentus plant as a specimen, they found that sewage sludge obtained from Municipal Sewage Treatment Plant (MSTP) potentially contains nutrients which can be used as fertiliser in order to enhance the plant growth. However, the contents of nutrients (nitrogen, phosphorus, potassium and sulphur) in the sludge were much lower compare to the concentrations of nutrients in fertilizer sold in the market [41].

Franz in his study extracted phosphorus from sewage sludge ash to produce phosphate fertilizer. By measuring the weight of plants after 6 weeks of growth, phosphate fertilizer made from SSA was proven to be equal in its plant uptake efficiency compared with conventional phosphate fertilizer. From the positive findings in his study, he change the people perspective on SSA from a useless waste material to become an effective phosphate fertilizer which will benefiting the agriculture industry [14].

Lazdina *et al.* studied the effect of sewage sludge fertilization on productivity of Salix energy crop and forest plantations. From the result, it shows that fertilization with sewage sludge has a positive effect on Salix growth, however it causes problems with weed control. Due to heavy metal contains in sewage sludge, the concentration of heavy metals in the top soil layer with sewage sludge fertilization also increased, but it did not exceed the regulations issued by the Cabinet of Ministers of Latvia about the soil quality [42].

Hughes *et al*. examined the efficacy of sewage sludge in ameliorating subsoil acidity and providing the nutrient requirements of wheat grown under glasshouse. In their study, various rates of air-dried washed sludge (0, 20, 40, 80 and 160 Mg ha^{-1}) were mixed into the top 120 mm of topsoil overlying subsoil in packed soil columns. Soil mixed specimen were then analyzed for exchangeable cations, pH and phosphorus. At lower rates of sludge application, pH actually decreased in the topsoil and pH were only observed to significantly increased at the highest level of sludge application (160 Mg ha^{-1}), where pH increased from 4.4 to 5.0. Moreover, sludge additions resulted in slight increases in the amounts of NH_4^+ and Na^+ in the leachates [43].

3.0 DISCUSSION

The application of sewage sludge and its ash in various industry has been proven by various researchers in various ways. In construction industry, most of the study use sewage sludge and sewage sludge ash as partial replacement of the fine aggregate in concrete mix or mortar, as raw material in cement clinker production, as partial cement replacement for bricks and precast concrete and so on. It is undeniable that some studies show negative effect on the usage of sewage sludge and its ash. However, majority of the researcher agree that sewage sludge and sewage sludge ash has good potential in replacing cement in construction industry. It is recommended that the amount of sewage sludge ash to be used in concrete structural application can goes up to 25 percent and even higher for non-structural application.

Similar to cement mixture, fine particles size that belongs to sewage sludge ash is an advantage to be used as filler replacement for hot asphalt mixture. Even though the amount of sewage sludge ash used in asphalt mixture is intangible, but it brings diversity of sewage sludge ash application in various industry. Other study revealed that the usage of sewage sludge in asphalt mix could harm and reduce the stability of the mixture. Therefore, the application of sewage sludge in hot asphalt mixture must be well studied before it can be applied at site.

In soil application, sewage sludge ash was used as chemical stabilizer to improve the physical and engineering properties of weak soil. It is recommended that for soft clayey soil, the amount of sewage sludge ash to be added is around 7 to 8 percent and for fine-grained soil, the amount of ash to be added could be higher and sometimes can goes up to 50 percent. Some researchers use the combination of sewage sludge ash and cement to stabilize the soft soil due to its chemical properties that almost similar to cement properties. This combination sometimes can improve the soil strength up to 30 times compare to untreated soil.

From agricultural point of view, the usage of sewage sludge and sewage sludge ash as fertilizer is attractive due to the presence of nutrients such as nitrogen and phosphorus and other organic matter, which can increase fertility of the soil. However, due to the accumulations of heavy metal element, it is recommended that sewage sludge and its ash could only use for non-food crops. For sludge that contain high amount of Cadmium (Cd) and Zink (Zn), extra care should be given since these two elements are easily absorbed by the plants and exert an adverse effect on crops yield.

4.0 CONCLUSION

Reuse of sewage sludge waste material as ash contribute multiple benefits apart enhancing the sustainable development practice. The main chemical composition of sewage sludge and sewage sludge ash consists of iron oxide (Fe_2O_3), silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), phosphorus pentoxide (P_2O_5), calcium oxide (CaO) and sulphur trioxide (SO_3). In construction industry, this ash chemical composition offers the benefits such as resistance to chloride attack in concrete application and hinders quick setting in cement as well as quality control in concrete. It can also substitute natural aggregate for structural application up to 25 percent of the natural aggregate while for non-structural, it may be further increased accordingly with the quality of the concrete as the priority consideration. Moreover, this ash can be added up to approximate 8 percent in soil stabilization as researches concluded that it can effectively improve the strength of soft cohesive subgrade soil and it can be further enhanced if it is used with nano-silicon dioxide or hydrated lime. In agriculture, despite the metal elements in the ash and problems when being used with weed control, it can be utilized as fertilizer in non-food crops to enhance the growth. However, further researches are recommended to be conducted on eliminating the problem such as when being used with weed control and the accurate approximate rate that this ash can be used as fertilizer considering the risk of the extensive heavy metal elements.

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