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

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ABSTRACT

The production of sewage sludge from waste water treatment plant is increasing all over the world. Disposal of sewage sludge is becoming a serious environmental problem. Another alarming issue is attributed to the high usage of concrete in the construction industry where concrete is one of its main material. 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 by sewage sludge ash is essential to reduce both the emissions of carbon dioxide and the disposal problem of sewage sludge ash. An attempt has been made to investigate the use of sewage sludge ash as partial cement replacement in concrete. The sewage sludge is incinerated at the temperature of 600 ℃ and a duration of 3 hours. The incinerated sewage sludge ash is sieved through size of 150 μm. Four different percentages of 5%, 10%, 15% and 20% of sewage sludge ash (SSA) is used to replace the cement in the concrete. XRD and XRF tests were carried out to determine the similarity component present in the SSA. Water absorption test and slump test has also been carried out to check the capacity of water absorption, durability and workability of the SSA concrete. The compressive strength of SSA concrete is also determined through rebound hammer and compression test. Results show that SSA has the potential to replace cement as the major chemical component of SSA is similar to that of cement.5% of SSA concrete shows a lower absorption value than the control sample which shows that5% SSA would have a better durability. However, an increase in the percentage of SSA decreases the workability and compressive strength and yet, the5% SSA concrete possesses compressive strength higher than 25 N/mm^2 which can be applied in structural applications. The findings suggested that the suitability of sewage sludge ash concrete in different cement replacement ratio is applicable for different usage. The application of sewage sludge ash in concrete will directly reduce the quantity of the cement used which also decreases the emissions of carbon dioxide and solving the disposal problem of sewage sludge.

ABSTRAK

Pengeluaran enapcemar kumbahan dari loji rawatan air sisa semakin meningkat di seluruh dunia. Pelupusan enapcemar kumbahan telah menyebabkan masalah alam sekitar yang serius. Pada masa kini, konkrit banyak menyumbang kepada kerja-kerja pembinaan kerana konkrit adalah salah satu elemen utama bangunan. Oleh itu, ini akan menyebabkan permintaan terhadap cemen juga meningkat dan secara tidak langsung akan meningkatkan pengeluaran karbon dioksida kerana industry cemen merupakan pemancar utama karbon dioksida. Oleh itu, penyelidikan bagi penggantian simen dengan abu enapcemar kumbahan adalah penting untuk mengurangkan pelepasan karbon dioksida dan masalah pelupusan abu enapcemar kumbahan. Satu kajian telah dijalankan dalam penggunaan abu enapcemar kumbahan sebagai sebahagian penggantian simen di dalam konkrit. Enapcemar kumbahan telah dibakar pada suhu 600 ℃ dan tempoh selama 3 jam. Abu enapcemar kumbahan yang telah dibakar disaring melalui saiz 150 µm. Empat peratusan yang berbeza, iaitu5%, 10%, 15% dan 20% abu enapcemar kumbahan digunakan untuk mengganti simen di dalam konkrit. Ujian XRD dan XRF telah dijalankan untuk menentukan persamaan komponen yang terdapat di dalam SSA. Selain itu, ujian penyerapan air dan ujian kemerosotan telah dijalankan untuk memeriksa kapasiti penyerapan air, ketahanan dan kebolehkerjaan konkrit SSA. Kekuatan mampatan konkrit SSA juga diuji melalui rebound hammer dan ujian mampatan. Kajian menunjukkan bahawa SSA mempunyai kompenen utama seperti simen dan berpotensi untuk menggantikan simen. Selain itu,5% SSA konkrit menunjukkan nilai penyerapan yang lebih rendah berbanding dengan sampel kawalan, ini bermaksud5% SSA akan mempunyai ketahanan yang lebih baik. Walau bagaimanapun, peningkatan dalam peratusan SSA mengurangkan kebolehkerjaan dan kekuatan mampatan dan5% SSA konkrit mempunyai kekuatan mampatan yang lebih tinggi dari 25 N/mm^2 menunjukkan 5% SSA boleh digunakan dalam aplikasi struktur. Hasil kajian mencadangkan bahawa kesesuaian enapcemar kumbahan abu konkrit dalam nisbah penggantian simen yang berbeza digunakan dalam bidang yang berbeza. Penggunaan abu enapcemar kumbahan dalam konkrit secara langsung akan mengurangkan kuantiti simen yang digunakan dan juga mengurangkan pelepasan karbon dioksida dan dapat menyelesaikan masalah pelupusan enapcemar kumbahan.

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LIST OF SYMBOLS

℃	Degree Celsius
%	Percentage
mm	Millimeter
±	Plus-Minus
m^3	Cubic meter
kg	Kilogram
N	Newton
kg/m^3	Kilogram per cubic meter
g	Gram
kV	Kilovolt
mA	Milliampere
$	Dollar
µm	Micrometer

LIST OF ABBREVIATIONS

Al_2O_3	Aluminium Oxide
ASTM	American Society for Testing and Materials
BS	British Standard
CaO	Calcium Oxide
CO_2	Carbon Dioxide
DOE	Department of Environment
FA	Fine Aggregate
Fe_2O_3	Iron Oxide
K_2O	Potassium Oxide
L	Lime
MgO	Magnesium Oxide
Na_2O	Sodium Oxide
OPC	Ordinary Portland Cement
P_2O_5	Phosphorus Oxide
Q	Quartz
SiO_2	Silicon Oxide
SS	Sewage Sludge
SSA	Sewage Sludge Ash
UPV	Ultrasonic Pulse Velocity
US	United States
XRD	X-Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

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.

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 & Tay, 1990).

Incineration became one of the alternative solutions for the disposal of sewage sludge. One of the researches at the Nanyang Technological Institute shows that 550 ℃ is a favorable condition for sludge incineration. The sewage sludge was dewatered during the filter process from various sewage treatment plants in Singapore and was auto-thermal during combustion at 550 ℃. The purpose of incinerating sewage sludge at the temperature above 550 ℃ is to remove any organic matter which is not suitable in concrete production (Tay, 1987).

The principal component of sewage sludge after going through the high temperature incineration such as SiO_2, CaO, Al_2O_3, are the components of ordinary cements (Tenza-abril et al., 2011). The incineration process reduces the amount of sewage sludge to approximately 10-15% of its original amount. The residue is practically inert and odourless.

1.2 PROBLEM STATEMENT

The increase in population indicates that more sewage sludge will be generated. Thus, disposal of domestic sewage sludge becomes a significant issue time by time and it is increasing the financial burden of wastewater treatment companies. Disposal of domestic sewage sludge would cause numerous environmental and health risk related issues. Thus, the disposal of sewage sludge must be mitigated to avoid causing serious problems in the country. In the year of 2020, it is predicted that 7 million metric tons of sewage sludge will be generated annually from current 3 million metric tons (Siti Noorain, 2013). Siti Noorain (2013) stated that the cost of managing the sewage sludge is about US$ 0.33 billion per year. Information from Indah Water Konsortium stated that Malaysia produces more than 4.5 million cubic meters of domestic sludge annually since 2005 and the volumes of sludge produced increases from year to year.

Sewage sludge is one of the largest contributors of waste material in Malaysia, and it indirectly elevates local environmental problems. The general sludge treatment is processed before the sludge cake is transported to approval site for disposal. The waste products produced by domestic waste water sludge end up in sanitary landfills as practiced in Malaysia. One of the major challenges in the processing of domestic waste water sludge is highly connected to the management of high moisture content and its unstable organic substances in which decomposes to produce bad odours.

Due to the problems and limitations of sewage sludge disposal options, the use of sewage sludge as a non-conventional construction material has been studied and carried out by various researchers. The unprocessed sewage sludge is used as a filler and blended cement material for concrete and indirectly used as raw material to produce products such as bricks, lightweight aggregate, tiles and paving blocks, and cementitious material (Tay & Show, 1994). By the year of 2050, the demand for Portland cement will rise to 200% from 2010 levels, and the usefulness of reusing SSA in concrete to reduce the amount of cement used in concrete mix is noted. 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 CO_2 emissions are caused by cement plants, 900 kg of CO_2 is emitted to the atmosphere for producing one ton of cement (Benhelal et al., 2013)

Other research shows positive and negative results of using sewage sludge ash (SSA) as a cement component. The use of sewage sludge ash (SSA) faces problems in concrete mixtures since it has the effect of slightly retarding the setting time of concrete and increasing water demand. SSA shows evidence of being pozzolanic. However, it has been inferred that SSA concrete shows positive result frequently led to comparable or higher compressive strength than conventional concrete, although only at ages beyond 28 days, and the proportion of SSA replacement is more often at a level of less than 20% by the mass of the cement fraction (Dyer et al., 2011).

1.3 OBJECTIVE

The aim of this study is to experiment the possibility of using SSA as partial replacement of cement in concrete to determine its compressive strength.

1. To determine the chemical composition of sewage sludge ash.
2. To determine the compressive strength of SSA concrete.
3. To determine the workability of SSA concrete.

1.4 SCOPE OF STUDY

1. Only Ordinary Portland Cement is used (OPC).
2. The sewage sludge is obtained from the same treatment plant throughout the research and the sludge is only collected after 7 consecutive non-raining days.
3. The SSA is sieve through sieve size of 150 μm.
4. Sewage sludge is oven dried at temperature of 100℃ for 24 hours at the thickness of approximately 20 mm in the mould before incineration process.
5. Sewage sludge is incinerated at temperature of 600℃ for 3 hours.
6. Specimen of 100 mm x 100 mm x 100 mm will be used for compression test.
7. The samples are tested on the 1st, 7th, and 28th day.

1.5 RESEARCH SIGNIFICANT

Significant growth of sewage sludge and problems of disposing sewage sludge becomes an attention of many parties. By the successful use of sewage sludge ash in concrete, it can reduce the amount of cement production in the factory which would bring the benefits of :

1. Reduction in the use of cement in concrete mix design.
2. Reduction in waste disposal cost.
3. Provision of excellent sustainable practice of conversion of sewage sludge into useful product (Cenni et al., 2005).
4. Reducing the amount of CO_2, NO_x and other air pollutants emitted from the manufacturer of cement clinker (Valls & Va, 2001).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Literature review is a section which involves reading the materials which is related to the topic. It grants a theoretical basis which would aid in the determination of the nature of the research. In this section, the composition of concrete and sewage sludge ash as well as its usage in the construction site is discussed. The benefit and impact of using SSA to the environment are also included in this chapter. Finally, a concluding remark is made to this topic.

2.2 CONCRETE

Concrete and cement being used as the main material in the construction field dates back over a century. Concrete can be mixed depending on the requirement of the building; it is up to the user to exploit and utilize the unique properties of each of the components to develop an independent, high quality, durable construction material of high impermeability to suit the strength and characteristic of the building. Concrete is considered to be the most important building material with the huge production figure of 10 billion tons of concrete being produced annually.

The demand for concrete is expected to increase to approximately 18 billion tons a year by 2050. This is due to the prediction of the increase in the world's population from the present day of 6 to 9 billion by the year 2050 to 11 billion by the end of the century. Consequently, natural resources are important alternatives in the concrete industry to produce cement and concrete (Shafigh et al., 2014).

Concrete is heavily utilized in almost every type of construction including housing, bridges, roadways, tunnelways and airports. In order to ensure future competitiveness of concrete as the main resource in construction, it is of dire importance to improve concrete structure's sustainability. In the meantime, the impact to the environment and resource consumption reduction-potentials are considered. Use of waste products in construction can reduce the use of natural resources and reduces the waste products.

The building material is known as a factor of the largest materials consumers, responsible for 24% of global material extraction. Despite the depletion, the extraction caused problems such as damage to the landscape and disruption of ecosystems, contamination of soil, air, and water from materials during use phase. The production, processing of concrete and cement, the activities during construction such as maintenance and demolition of the building also led to damage to health by contamination of the indoor and outdoor environment (Blankendaal et al., 2014).

2.3 Cement

There are various types of cement with different mixed composition in production in the industry. Ordinary Portland Cement or OPC, is one of the most common types of cement in general usage everywhere in construction field. OPC, a hydraulic binder obtained from limestone and clay, is traditionally used for building and civil engineering construction. Though widespread, OPC production emits around 5% of the worldwide carbon dioxide (CO_2) man-made emissions (Juenger et al., 2011).

Generally, Portland cement clinker is manufactured by sintering the mixtures of limestone, iron ore, quartz sand, bauxite or clay. Industrial waste can be used to generate the raw material used to produce cement clinker. This would help to conserve natural resources and enable the sintering temperature to be lower and widening sintering range during the clinker-making process. There are researches which are investigating the use of sewage sludge ash as the main ingredient in the production of cements, and making use and involve sewage sludge ash in some of the construction structure, such as mortars, precast concrete blocks, and even in the mix design of concrete as a replacement for the fines in the mix (Tenza-abril et al., 2011). Industrial waste with high Calcium Oxide (CaO), Silicon Dioxide (SiO_2), and Iron Oxide (Fe_2O_3) content can be used as calcium, silicate and iron sources respectively in cement clinker production (Zhang et al., 2013).

2.4 Aggregate

Aggregate generally occupy 70-80% of volume in concrete and is mainly used as an underlying material for foundations and pavements and as ingredients in Portland cement and asphalt concretes. In the dictionary of civil engineering, aggregate means a mass of crushed stone, gravel, sand, etc., predominantly composed of individual particles, but in some cases, including clay and silts. According to Mamlouk & Zaniewski (2006), in Portland cement, 60% to 75% of the volume and 79% to 85% of weight is made up of the aggregate. The function of aggregate is to reduce the amount of cement paste needed in the mix. Maximizing the amount of aggregate in concrete would improve the quality and economy of the mix as aggregate have greater volume stability if compared to cement paste (Mamlouk & Zaniewski, 2006).

2.4.1 Coarse aggregate

According to Mohamed Abdel et al. (2007), coarse aggregate need to be the size of minimum 4.75 mm and it is consists of gravel, crushed stone or geosynthetic aggregate.

2.4.2 Fine aggregate

According to Mohamed Abdel et al. (2007), fine aggregate consists of natural or manufactured particles ranging in size from 150 mm to 4.75 mm. In concrete construction, the size of fine aggregate is acceptable and ranged between 4.75 mm to 75 µm.

2.5 CHARACTERIZATION AND POSSIBLE USE OF SSA

Research had been carried out to determine and explore more towards the characterization and possible use of sewage sludge ash. Laboratory-scale tests were carried out which focused on the properties of sewage sludge ash as replacement materials in their potential to be used as a hydraulic cement and in the fabrication of ceramic product after thermal treatment. Sewage sludge ash is not adequate in its usage as landfill material. It is also not suitable to act as aggregate, granular sub-base or ditches. This is due to the fact that their liquid limit is too high and small particle size Result on the use of SSA in concrete shows lower compressive strength; Addition of sewage sludge to concrete slows the curing process and reduces the mechanical strength of the concrete, particularly in the short term (Albareda et al., 2005). Therefore the suitability and the possibility of using SSA in cement manufacturing or as filler in concrete are still called into question (Merino et al., 2005).

2.6 ADMIXTURE OF INDUSTRIAL WASTE

Research has been carried out by Baeza et al., (2014) for the admixture of industrial waste which includes marble dust, fly ash, and rice husk ash with sewage sludge ash. Binary and ternary combination of SSA with marble dust, fly ash, and rice husk ash is used as replacement in Portland cement pastes. Individual, binary and ternary combinations have been tested. Mixture of SSA and rice hulk ash possess the best mechanical results. In cement/FA/SSA ternary systems for binder’s manufacturing, the SSA provides an important pozzolanic activity, increasing the mechanical strength of mortars between 7 and 28 days. Likewise, SSA reduces the fluidity of mortars while the FA improve it (Baeza et al., 2014).

2.7 LIGHTWEIGHT AGGREGATES

The main chemical composition of sewage sludge ash is SiO_2 (57.43–63.31%), Al_2O_3 (15.29–15.38%) and Flux (Fe_2O_3, CaO, MgO, Na_2O, and K_2O, 11.66–12.18%). This composition fulfill the composition of expansive clay (SiO2: 48–70%, Al2O3: 8–25% and Flux: 4.5–31%) which also shows that the composition of sewage sludge and sewage sludge ash were similar to those of expansive clay (such as Chung-li clay). Thus, sewage sludge could be sintered individually or together with sewage sludge ash in the production of lightweight aggregate (Chiou et al., 2006).

2.8 CONCLUDING REMARK

Based on the literature review discussed, the use of sewage sludge ash and waste materials as raw material in production of cement and concrete mixtures is becoming more and more general. There are many researches being carried out for the character and chemical composition of sewage sludge ash and heavy metal is found in the disposal of sewage sludge. The gradual increase in production of sewage sludge and the method of proper disposal of sewage sludge ash is becoming a serious issue. It is necessary to investigate and examine the possibility and the suitability of sewage sludge ash as partial replacement of cement in a concrete mixture to mitigate the use of cement and reduces the sewage sludge.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter, experiments and tests were carried out in order to examine the achievement of sewage sludge ash as a filler in concrete. The procedure of preparing the sewage sludge, the materials used for the experiment and the type of testing such as XRD test, yield analysis, compressive test, flexural are being discussed. The methodology and setup of the experiments for the concrete were conducted according to British Standard and American Standard.

3.2 PREPARATION OF MATERIAL

The concrete mix design is calculated by using a trial mix design method. The trial mix design method is used to acquire a perspective on the constituents of the concrete based on specific requirement. The proportion of the cement, water, coarse aggregate and fine aggregate was calculated based on the British DOE method. The concrete strength is specified to be 30 N/mm^2, standard deviation of 5 N/mm^2, percentage deflection of 10% (k=1. 28) due to freshness and lack of experience in casting concrete and the slump is specified to be in the allowable range of 75 ± 25 mm for the concrete mix.

3.2.1 Ordinary Portland Cement

YTL Ordinary Portland Cement (Figure 3.1) is selected as a binder for the concrete in this research. It is commonly used in the construction field in Malaysia and easily obtained in Malaysia. For the purpose of quality control, the cement is sieved to make sure it passes through 150 µm and the cement are under the same batch of delivery. After the cement is sieved, the cement is placed in a dry storage to prevent the cement from contact with water.

Figure 3.1: Ordinary Portland Cement, ORANG KUAT brand

3.2.2 Coarse aggregrate

According to Mamlouk & Zaniewski (2006), the size where all the aggregate passes through the smallest sieve size is known as the maximum size. From the result obtained through the sieve analysis, the maximum selected size of coarse aggregate is 20 mm. Crushed stone is one of the most accessible natural resources and is a high volume, low value commodity. Crushed stone possesses the good interlocking effect and create a much better bonding than gravel. The coarse aggregate is roughly cubical in shape and flaky pieces are removed. The batch of crushed stone is washed and dried as shown in Figure 3.2 to make sure the stone is free from impurities and stored in a container for good quality control.

Figure 3.2: Crushed coarse aggregate

3.2.3 Fine aggregate

River sand is selected as the fine aggregate as river sand can be easily obtained in Malaysia. Before the sieving process, the sand is washed and dried in the oven for 24 hours to make sure the sand is dry and free of impurities. The sand is sieved to obtain the exact proportion for the zone of grading of fine aggregate (BS 882) in designing the proportion of concrete mix design. Fineness modulus of fine aggregate ranges from 2.00 to 4.00 which the smaller value indicates a finer aggregate. As shown in Figure 3.3, the sand is stored in a container to make sure that the sand is always in the dry condition.

Figure 3.3: Dried sand

3.2.4 Water

The water used is the tap water supplied at the concrete laboratory. The water used is clean and under normal room temperature as higher temperature will affect the result of the experiment. Water is added according to the calculated water-cement ratio.

3.2.5 Sewage sludge

Throughout the research, 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 as shown in Figure 3.4 to prevent the sewage sludge from contact with other impurities.