THE EFFECT OF SEWAGE SLUDGE ASH AS CEMENT REPLACEMENT MATERIAL ON THE MECHANICAL AND CHEMICAL PROPERTIES OF MORTAR, CONCRETE AND TERRAZZO TILES

by

MOHAMAD NAZLI BIN MD JAMIL

Thesis submitted in fulfilment of the requirements
for the degree of
Master of Science

April 2017

KESAN TERHADAP ABU ENAP CEMAR SEBAGAI BAHAN PENGGANTIAN SIMEN KE ATAS SIFAT MEKANIKAL DAN SIFAT KIMIA BAGI CAMPURAN MORTAR, KONKRIT DAN JUBIN TERAZO

oleh

MOHAMAD NAZLI BIN MD JAMIL

Tesis yang diserahkan untuk
Memenuhi keperluan bagi
Ijazah Sarjana Sains

April 2017

ACKNOWLEDGEMENT

In the name of Allah S.W.T, the Most Gracious and the Most Merciful

Alhamdulillah. First of all, I would like to thank Allah S.W.T. for His blessing and kindness for giving me the health and opportunity to complete my journey in the degree of Master of Science.

I would like to extend my most gratitude to my supervisor, Associate Prof. Dr. Norazura Muhamad Bunnori who guided, inspired and supported me; technically, morally and spiritually throughout my study.

I would like to express my appreciation to the lab technician, Mr. Shahril Izham Md Noor, Mr. Mohd Fauzi Zulkifle, Mr Abdullah Md Nayan and Mr. Mad Fadzil Ali who assisted me in Concrete Laboratory. I also would like to thanks Mrs. Samsiah Mohamed Ali, Mr. Mohammed Nizam Mohd Kamal, Mr. Muhammad Zaini Mohd Zuki and Mr. Mohad Shukri Zambri who helped me in Environmental Laboratory.

I am also grateful to take this opportunity to extend my sincere gratitude to Universiti Sains Malaysia especially School of Civil Engineering for allowing me to use their facilities and infrastructure in accomplishing this research.

Last but not least, I would like to express my highest gratitude to my family especially my parents Mr. Md Jamil Ahmad and Mrs. Narishah Saad, for their love, understanding, continuous support and encouragement. Thank you also to those has helped and supported me in any respect but not has been mentioned above by name.

TABLE OF CONTENT

CHAPTER THREE - MATERIAL AND EXPERIMENT DETAIL

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society Of Testing And Material
BS	British Standard
BS EN	British European Standard Specification
CS0	Concrete specimen with 0% of SSA900 replacement
CS5	Concrete specimen with 5% of SSA900 replacement
CS10	Concrete specimen with 10% of SSA900 replacement
CS15	Concrete specimen with 15% of SSA900 replacement
CS20	Concrete specimen with 20% of SSA900 replacement
DTA	Differential Thermal Analysis
ICP	Inductive Couple Plasma
ISAT	Initial Surface Absorption Test
JSTP	Jelutong Sewage Treatment Plant
LOI	Loss On Ignition
MS	Malaysian Standard
M0	Mortar specimen with 5% partially cement replacement of dried sewage sludge
M500	Mortar specimen with 5% partially cement replacement of incinerated sewage sludge at 500^{o}C
M600	Mortar specimen with 5% partially cement replacement of incinerated sewage sludge at 600^{o}C
M700	Mortar specimen with 5% partially cement replacement of incinerated sewage sludge at 700^{o}C
M800	Mortar specimen with 5% partially cement replacement of incinerated sewage sludge at 800^{o}C

M900	Mortar specimen with 5% partially cement replacement of incinerated sewage sludge at 900^{o}C
M1000	Mortar specimen with 5% partially cement replacement of incinerated sewage sludge at 1000^{o}C
PTV	Pendulum Test Value
RCPT	Rapid Chloride Permeability Test
SSA	Sewage Sludge Ash
SSA500	Sewage Sludge Ash with incinerated temperature of 500^{o}C
SSA600	Sewage Sludge Ash with incinerated temperature of 600^{o}C
SSA700	Sewage Sludge Ash with incinerated temperature of 700^{o}C
SSA800	Sewage Sludge Ash with incinerated temperature of 800^{o}C
SSA900	Sewage Sludge Ash with incinerated temperature of 900^{o}C
SSA1000	Sewage Sludge Ash with incinerated temperature of 1000^{o}C
TS0	Terrazzo Tile specimen with 0% of SSA900 replacement
TS5	Terrazzo Tile specimen with 5% of SSA900 replacement
TS10	Terrazzo Tile specimen with 10% of SSA900 replacement
TS15	Terrazzo Tile specimen with 15% of SSA900 replacement
TS20	Terrazzo Tile specimen with 25% of SSA900 replacement
TGA	Thermal Gravimetric Analysis
TLCP	Toxicity Leaching Characteristic Procedure
UKSRG	United Kingdom Slip Resistance Group
USEPA	United State Environmental Protection Agency
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

LIST OF SYMBOL

^{o}C	Degree Celsius
%	Percent
mm	Milimeter
µm	Micrometer
m/s	Meter per second
ml	Mililitre
rpm	Revolution per minute
N/s	Newton per second

KESAN TERHADAP ABU ENAP CEMAR SEBAGAI BAHAN PENGGANTIAN SIMEN KE ATAS SIFAT MEKANIKAL DAN SIFAT KIMIA BAGI CAMPURAN MORTAR, KONKRIT DAN JUBIN TERAZO

ABSTRAK

Kumbahan enapcemar adalah hasil pembuangan dari loji rawatan air sisa. Pada masa kini, penghasilan kumbahan enapcemar dalam kuantiti besar diterajui oleh pembangunan pesat loji rawatan kumbahan. Jumlah enapcemar yang besar ini dihasilkan secara berterusan dan menyebabkan pengehadan dalam kawasan pelupusan. Oleh itu, langkah alternatif perlu dilakukan untuk mengguna semula kumbahan enapcemar sebagai pembangunan lestari. Objektif utama dalam kajian penyelidikan ini adalah untuk menggunakan kumbahan enapcemar sebagai bahan tambah semulajadi dalam jubin terazo. Abu kumbahan enapcemar (SSA) dihasilkan daripada proses pengeringan dan pengisaran. Suhu pembakaran optimum SSA ditentukan daripada pembakaran SSA dengan suhu yang berbeza iaitu dari 500 - 1000^{o}C dengan selaan 100^{o}C setiap satu dan dibancuh sebagai mortar. Ciri-ciri fizikal dan kimia setiap mortar telah diuji. Dengan mempertimbangkan keputusan daripada ujian-ujian tersebut, SSA dengan suhu pembakaran 900^{o}C (SSA900) dipilih sebagai suhu pembakaran optima. Kemudian, campuran konkrit dibancuh dengan berbeza peratus penggantian SSA900 untuk menentukan jumlah peratusan yang ideal. Sifat-sifat kejuruteraan dan kepekatan logam berat juga diuji. Hasil daripada ujian yang dijalankan, konkrit dengan peratusan penggantian SSA900 sebanyak 15% dipilih sebagai peratusan penggantian ideal kerana ia menunjukkan hasil yang positif. Prestasi jubin terazo SSA telah diperiksa dengan menguji mereka dengan kekuatan pecah, penyerapan air dan rintangan gelinciran bagi penggantian 0, 5, 10, 15 dan

20%. Menurut MS 738: 1981, kekuatan minimum bagi jubin terrazzo adalah 3.0 MPa, kadar penyerapan kapilari dan penyerapan total haruslah tidak melebihi 0.4 g/cm2 dan 8% masing-masing. Kadar gelinciran jubin terrazzo ini juga telah diklasifikasikan sebagai amat rendah oleh United Kingdom Slip Resistance Group (UKSRG, 2011).

THE EFFECT OF SEWAGE SLUDGE ASH AS CEMENT REPLACEMENT MATERIAL ON THE MECHANICAL AND CHEMICAL PROPERTIES OF MORTAR, CONCRETE AND TERRAZZO TILES

ABSTRACT

Sewage sludge is a residual from wastewater treatment plant. Nowadays, the large production in sewage sludge quantity is led by the rapid development of sewage treatment plant. This large amount of sewage sludge is generated continuously and has caused in limitation of the disposal area. Hence, an alternative way must be sought out to reuse the sewage sludge for sustainable development. The main objective of this study is to utilize the sewage sludge as a natural admixture in terrazzo tile application. The sewage sludge ash (SSA) was produced by drying and ball-milling process. The optimum incineration temperature of SSA was determined by incinerating the SSA at varying temperature ranging from 500 – 1000^{o}C an with interval of 100^{o}C respectively and mixed as mortar. The physical and chemical properties of each mortar were tested. From the results of the tests, the incinerated temperature of SSA at 900^{o}C (SSA900) was chosen as optimum incineration temperature. Then, concrete mixture with the replacement of SSA900 was casted to determine the ideal percentage amount. The engineering properties and heavy metal concentration were tested. As a result, the concrete with 15% of SSA900 replacement was chosen as an ideal percentage of replacement because it showed the positive outcome for the most of the tests. The performance of SSA terrazzo tiles were examined by testing on breaking strength, water absorption and skid resistance for replacement of 0, 5, 10, 15 and 20%. According to MS 738:1981, the minimum breaking strength is 3.0 MPa, the capillary and total absorption must not exceed of

0.4 g/cm^2 and 8% respectively. The terrazzo tile specimens passed the standard requirement. Plus, the tiles were also classified as extremely low in slip potential as compared to United Kingdom Slip Resistance Group (USRG, 2011).

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Portland cement is the most in command building material and binder that have been widely used worldwide in construction industries. Varies of application of Portland cement can be made such as mortar and concrete mixture. Sometimes, several admixtures are added to the mixtures to enhance the needed behaviour. There are two types of admixtures that are typically used which are chemical and natural admixtures. The application of natural admixture must be pozzolan which contains reactive siliceous or siliceous aluminous material. There are many natural admixtures that are typically used such as fly ash, metakaolin and silica fume. Recently, many studies were conducted on the application of waste material as part of cement replacement such as sewage sludge.

The sewage sludge can be collected at the wastewater treatment plant. There are five components in sewage treatment process which include pretreatment, primary treatment, secondary treatment, tertiary treatment and sludge disposal (Cooper, 2014). After completion of all stages of treatment, the sludge at the bottom of the tank will be treated and disposed at the same time. The sludge undergoes the processes of conditioning, thickening, dewatering and stabilization during treatment. The dewatering process was proposed to remove as much water as possible to produce concentrated sludge (Battersby and Bassett, 2004).

Sewage sludge ash (SSA) is a pozzolanic material or pozzolan (Monzo et al., 1996). ASTM C618 (1999) describes a pozzolan as a siliceous or siliceous and aluminous material which possesses little or no cementitious value but will, in finely divide form and in the presence of moisture, chemically react with lime in hydration process at ordinary temperatures to form compounds possessing cementitious properties. According to the ASTM C618-99 (ASTM, 1999), there are some chemical requirements for natural admixture that must be followed as noted below:

a) Total composition of SiO_2 + Al_2O_3 + Fe_2O_3 must be at least 70%.
b) Total composition of alkalis must be less than 1.5%.
c) Amount of SO_3 must be less than 4.0%.
d) Amount of loss of ignition (LOI) must be less than 10.0%.

The highest amount of oxides compound in SSA is SiO_2 which is about 38% - 48%. The second highest is either Al_2O_3 or Fe_2O_3 approximately 15 – 21% and 6 – 17% respectively. The total amount of SiO_2, Al_2O_3 and Fe_2O_3 in typical SSA is around 68 – 74%. It also contains 0.24 – 4.04 % of SO_3, 2.11 % of LOI and 1.0 – 3.2% of alkalis (Wang et al., 2005; Yen et al., 2012; Morais et al., 2009; Tantawy et al.,2012). From these properties, the SSA has the potential to be used as a natural admixture since most of the values are within requirement range.

1.2 Problem Statement

Sewage sludge is a by-product of wastewater treatment plant. The production of sewage sludge is unavoidable. The population growth will increase the sewage sludge production. Sewage sludge will generate in an ever-increasing amount due to the urbanization and higher effluent criteria implemented in recent years. Without proper disposal, it will cause a secondary pollution problem to the environment.

Space limitation on the existing landfills and increasing environmental concerns such as groundwater pollution from landfill leachate, odour emission and soil contamination have prompted the investigation of alternative disposal routes.

According to the Report of Census 2010 by The Department of Statistics, Malaysia has a population of 28.3 million and the estimated volume of wastewater generated by the municipal and industrial sector is 2.97 billion cubic meter per year (Tuan Mat et al., 2013). As reported by Abdul Jalil (2010), the domestic waste generated per capita was approximately 0.8 to 1.3 kg per day in Kuala Lumpur only. The production of sewage sludge also gives impact to the global generation around the world. The annual sludge production of are shown in the table below.

Table 1.1: Global Generation of Sludge Production

Country/region	**Amount/year**	**Source**
Malaysia	7.4×10^6 m^3	Chiang et al. (2009)
Japan	0.5×10^6 tonnes	Murakami et al. (2009)
North America	1.2×10^6 tonnes	Cyr et al. (2007)
Taiwan	1.2×10^8 m^3	Chiou et al. (2006)
United states	7.0×10^6 tonnes	Anderson (2002)
EU	10.0×10^6 tonnes	Anderson (2002)

These statistics show that the large volume of dry sludge production will lead to trouble on the acquisition of the disposal area. Thus, new alternative ways must be conducted to reduce and reuse usage of sewage sludge which leads to a sustainable environment. The application of sewage sludge in building materials is an option to alleviate the significant quantity. Plus, the usage of SSA in several types of building construction will reduce the cost and increase the economic efficiency. Mattenberger et al. (2008) reported the sludge produced accumulates toxic organic and inorganic substances due to manifold contamination sources polluting its precursor which is wastewater. So, the precaution method must be taken to prevent this serious issue effect the environment.

The terrazzo tile for external use is a new building material which can be produced by replacing some amount of SSA in the tile mixture. Further study on optimum incinerated temperature and ideal cement replacement must be conducted to produce an efficient building for a safe environment.

1.3 Research Aim and Objectives

This research was carried out to investigate three main objectives including:

a) To investigate the optimum incineration temperature of sewage sludge ash by examining their behaviour on mechanical and chemical properties of mortar specimens.
b) To determine the suitable percentage of replacement of sewage sludge ash as admixture in concrete mixture by studying the physical, chemical and durability characteristics.
c) To study the performance of terrazzo tiles with the replacement of sewage sludge ash on the engineering properties.

1.4 Overview of Methodology

The aim of this research study is to produce a sustainable terrazzo tile by replacing some cement compound with sewage sludge ash which is suitable to the environment and comply to the engineering properties. The scope of study covers several important elements such as preparation and characterization of materials and determination of physical, chemical and durability of the specimens which includes mortar, concrete and terrazzo tiles.

The scope of work in this research includes:

a) Preparation of SSA from raw sludge by oven-drying for 48 hours, ball milling and sieved passing 300µm. Thermal Gravimetric Analysis was conducted to determine the optimum starting temperature of SSA. The SSA went through the incinerated process from temperature 500 – 1000^{o}C by interval of 100^{o}C respectively.
b) Characterizations on the raw and incinerated SSA are determined by measuring the particle size, surface area and fineness. The mineralogy of SSA was also verified by X-Ray Diffraction (XRD) and X-Ray Fluorescence.
c) Determination of the optimum temperature of SSA which is suitable to be used as a replacement in concrete mixture by testing it to mortar specimens. The suitable optimum temperature was determined by compressive strength, water absorption and heavy metal concentration results.
d) Determination of preferable quantity of SSA replacement in concrete and terrazzo tile by conducting the physical, chemical and durability tests on 7, 14, and 28 days of curing age.

1.5 Layout of Thesis

This thesis consists of five chapters including:

Chapter 1 (Introduction) discusses on the background of the study with short overview of the present research and the problem statement. The research objectives and scope of work are provided in this chapter.

Chapter 2 (Literature Review) consists of a brief explanation on Portland cement and the manufacturing process. The production of sewage sludge and some reviews from previous researchers on the usage of sewage sludge in concrete and the effect in pozzolanic activities of SSA are also provided.

Chapter 3 (Methodology) presents an overview of the research program and describes the preparation in making sewage sludge ash. The experimental procedures on physical, chemical and durability tests for mortar, concrete and tiles are also provided.

Chapter 4 (Results and discussion) shows the results and data for all the conducted experiments including physical, chemical and durability tests. The mineralogy and characterization of sewage sludge ash are presented in this chapter.

Chapter 5 (Conclusion) provides the summary of results and conclusion for the research study. The recommendations of future study are included in this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

There are two commonly used structural materials which are steel and concrete. Those building materials complement each other sometimes, yet compete with one another at times. Thus, many structures of similar type and function can be built in either of these materials. Concrete is made from combination of cement, aggregates and water. Sometimes, certain types of admixture are added to the concrete mix to improve its behaviour. There are two types of admixture that have been used i.e. chemical admixtures such as super plasticizer and accelerator, and natural admixtures such as fly ash, metakaolin and silica fume. Other than enhancing the concrete behaviour, some natural admixture has been used from industrial by-product and they are sustainable. Many researchers have studied by-product of natural admixture such as rice husk ash (Behak and Perez, 2008; Seco et al., 2011), ceramic waste (Baronio and Binda, 1997), Phoshogypsum (Shen et al., 2007; Degirmenci et al., 2007) and sewage sludge (Weng et al., 2003; Lin et al., 2005; Chen and Li, 2009). These types of materials have the potential in replacing certain amount of concrete since they have pozzolanic properties that are essential in concrete behaviour. This chapter discuss and present some literature review about the usage of sewage sludge as natural admixture incorporated in concrete mixture.