PROPERTIES AND PERFORMANCE OF CLAY BRICK CONTAINING WATER TREATMENT SLUDGE (WTS)

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Thesis submitted to Universiti Pertahanan Nasional Malaysia, in fulfilment/partial fulfilment of the requirements for the Degree of Master of Science (Civil Engineering)

JUNE 2018

ABSTRACT

Every year, a large quantity of water treatment sludge (WTS) is produced from water treatment plant in Malaysia. Sanitary landfill disposal of sludge at authorized site is the common practice in Malaysia. However, searching the suitable site for landfill is the major problem as the sludge produced keeps on increasing. Reuse of the sludge could be an alternative to disposal. This study investigated the reusability of WTS as brick making material. The performance of clay-WTS bricks produced by mixing clay with different percentages of WTS with an increment of 20% from 0% up to 100% by weight was investigated. Each molded brick with optimum moisture content was pressed under constant pressure, oven-dried at 100˚C for 24 hours and heated up to 1050˚C for 5 hours. Scanning electron microscopy (SEM), X-ray diffraction (XRD) and energy dispersive X-ray (EDX) analysis were used to characterize clay, WTS and clay-WTS bricks. The performance of the bricks were evaluated with firing shrinkage, loss on ignition (LOI), water absorption, bulk density, and compressive strength tests. Increasing the sludge content results in an increase of brick shrinkage and water absorption. The results revealed that the brick with 100% by weight of sludge could generate the highest compressive strength of 15.6 N/mm^2. The optimum amount of sludge that could be mixed with clay to produce good bonding of clay–WTS bricks was found to be 40% by weight and comply with the British Standard 3921:1985, which can fulfil the requirement for general usage of clay bricks.

ABSTRAK

Setiap tahun, kuantiti enapcemar yang besar dihasilkan daripada loji rawatan air di Malaysia. Kaedah pelupusan di tapak pelupusan sanitari enapcemar di tapak yang ditetapkan adalah amalan biasa di Malaysia. Walau bagaimanapun, mencari tapak yang sesuai untuk pelupusan adalah masalah utama kerana jumlah enapcemar yang dihasilkan terus meningkat dari tahun ke tahun. Penyelidikan ini mengkaji potensi enapcemar untuk menjadi bahan dalam pembuatan batu bata. Prestasi batu-bata daripada campuran tanah liat dan enapcemar, dengan mencampurkan tanah liat dengan peratusan enapcemar yang berbeza, iaitu kenaikan 20% daripada 0% sehingga 100% berat enapcemar telah dikaji. Setiap bata dibentuk dengan kandungan lembapan yang optimum ditekan di bawah tekanan yang sama, dikeringkan di dalam ketuhar pada suhu 100˚C selama 24 jam diikuti dengan pemanasan sehingga 1050˚C selama 5 jam. Analisis Mikroskop imbasan elektron (SEM), sinar-X pembelauan (XRD) dan tenaga serakan X-ray (EDX) telah digunakan untuk mengkaji pencirian tanah liat, enapcemar dan batu bata. Bagi mengkaji prestasi batu bata, ujian pengecutan, kehilangan akibat pemanasan, penyerapan air, ketumpatan pukal, dan ujian kekuatan mampatan dijalankan. Hasil kajian menunjukkan, semakin banyak kandungan enapcemar, semakin meningkat nilai pengecutan akibat pembakaran dan penyerapan air. Hasil kajian juga menunjukkan bata dengan 100% mengikut berat enapcemar mampu menjana kekuatan mampatan yang tertinggi iaitu 15.6 N/mm^2. Jumlah enapcemar yang optimum bagi menghasilkan batu bata dengan komposisi tanah liat-enapcemar yang baik ialah 40% dan

mematuhi piawaian British Standard 3921:1985, iaitu boleh memenuhi keperluan untuk penggunaan umum bata tanah liat.

ACKNOWLEDGEMENT

Bismillahirahmanirrahim,

Alhamdulillah, finally I am able to finish my Master Thesis research. Foremost, I want to offer this endeavor to our almighty Allah for the wisdom He bestowed upon me, the strength, peace of my mind and good health in order to finish this research.

I would like to express my gratitude to my supervisor, Prof. Madya Mohd Asri bin Md Nor and my co-supervisors Prof. Dr. Ong Keat Khim and Prof. Faisal bin Ali who are willing to spend so much time to guide, motivate and support until I complete this study. Without their patience, flexibility, genuine caring, concern and faith in me during the research process, I would never be able to get through until this level.

I also would like to thank my husband Mohd Ashraf Harizan, for his endless support, patience and unwavering love. I appreciate my parents, my family and my family in law, which I owe a big debt of gratitude to them for their endless love, blessing and supporting me in all my pursuit. Not to forget my lovely kids, Ahmad Uwais Elhadiff and Aisya Umaira Elhana which was born during my studies, thank you for always making me stronger.

This acknowledgement also goes to my lecturers, my laboratory assistants, my fellow friends, and juniors for all the cooperation and support during the beginning until the end of this project. I am also indebted to my university, Universiti Pertahanan Nasional Malaysia (UPNM) for all the references given for this project.

Last but not least, I would like to extend my sincere thanks to all individuals who are involved directly and indirectly giving me kind support and help throughout my master journey. Thank you.

APPROVAL

I certify that an Examination Committee has met on 8^{th} February 2018 to conduct the final examination of Alia Syafiqah Binti Abdul Hamed on her master thesis entitled Properties and Performance of Clay Brick containing Water Treatment Sludge (WTS). The committee recommends that the student be awarded the Master of Science (Civil Engineering).

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WTS	Water Treatment Sludge
LOI	Loss on Ignition
SEM	Scanning Electron Microscopy
XRD	X-ray diffractometer
EDX	Electron Dispersive X-Ray
OMC	Optimum Moisture Content
BS	British Standard
WTP	Water Treatment Plant
AASTHO	The American Association of State Highway and Transportation Officials
TCLP	Toxicity Characteristics Leaching Procedure

CHAPTER 1

INTRODUCTION

1.1 Background

Environmentally-sound sludge management is the cornerstone of Malaysia's new approach to sewerage services. Effective and efficient sludge management will significantly contribute to provide a cleaner and safer Malaysia for future generations. There are more than 450 water treatment plants (WTPs) in Malaysia, which produce more than 400,000 million litres per day (MLD) of treated water, and this production of clean water has generated a large amount of sludge (Malaysian Water Association, 2013). It was estimated that 491,902.87 metric tons of water treatment sludge (WTS) were produced and managed under special management approval as stipulated under Environmental Quality (Scheduled Wastes) Regulations, 2005. (Department of Environment, 2013)

WTS is classified as SW204 under the same regulations, which refers to sludge containing one or several metals including chromium, copper, nickel, zinc, lead, cadmium, aluminium, tin, vanadium and beryllium. (Department of

Environment, 2013). Untreated or treated sludge is disposed to surface water, deep well injection, spray irrigation disposal in drain field or borehole, discharge to sanitary sewer collection and land application. However, these approaches may cause environmental hazards in long term application. An alternative to disposal is the utilization of the sludge, which will reduce cost, an amount of sludge to be disposed and also reduce environmental hazards.

Various waste materials such as petroleum effluent treatment plant sludge (Segupta *et al.,* 2002), sewage sludge (Liew *et al.,* 2004), water treatment residual (WTR) and excavation waste soil (Huang *et al.,*2005), textile effluent treatment plant sludge (Balasubramanian *et al.,* 2006), cigarette butts (Kadir *et al.,*2008a) , water treatment sludge and rice husk (Chiang *et al.,* 2009) , paper sludge and palm oil fuel ash (Ismail *et al.,* 2010) , silica fume and rice husk ash (Hegazy *et al.* 2012) , shipyard repair and maintenance hazardous waste (Salleh *et al.,* 2014) have been incorporated in brick production. According to Ramadan (2008), mineralogical composition of the WTS is particularly similar to that of clay and shale, which promotes the application of water treatment sludge in brick manufacture.

This study explores the possibility of utilizing local WTS instead of clay replacement in bricks production based on British Standard BS 3921:1985. The clay bricks were characterized using SEM/EDX and XRD, whereas the performance of the clay bricks was evaluated using criteria such as firing shrinkage, loss on ignition (LOI), water absorption and bulk density. Leaching of these toxic metals from produced brick may pose a hazard to the human and surrounding environment. Thus, leaching test was also conducted in this study.

1.2 Problem Statement

The demand for clean water increases and thus there is an increased in water treatment sludge (WTS) as the population develops. Currently, WTS needs special management approval from Department of Environment, 2013 for disposal. The decrease in land availability and stricter regulations for disposal will increase the cost of WTS management. An alternative to the sludge disposal is utilization of the sludge which will reduce cost and also reduce environmental risks. Environmentally friendly waste recycling has been one of the most important research fields for many decades. Nonetheless, one of the concerns to utilize WTS in the brick making is based on the leaching of toxic metals from the produced brick. Laboratory leach study is a useful approach to assess the potential effects from leaching materials.

A number of studies have revealed that sludge can be used as construction material after being evaluated in terms of mechanical properties and environmental effects. However, there is a lack of study focusing on the complete replacement of WTS in clay brick production. Most of the studies focused on incorporating the WTS proportion up to 50% only and it was concluded that the optimum sludge proportion to produce sludge-clay brick is only up to 50% (Mahbub et al., 2013; Sulthana et al., 2013 ; Victoria, 2013 ; Hegazy et al., 2012 ; Chiang et al., 2009 ; Ramadan et al., 2008). Therefore, sludge replacement of up to 100% of the clay in brick was proposed for this research.

1.3 Research Objectives

The main objective of this research is to explore the possibility of utilizing WTS as clay replacement in brick making. In order to ensure the target is achieved, the objectives of the research are:-

i. To characterise water treatment sludge (WTS) and clay.
ii. To determine the mechanical properties; firing shrinkage, loss on ignition (LOI), water absorption, bulk density, and compressive strength tests of WTS in fired clay brick production.
iii. To study the effect of WTS in fired clay brick production towards leachability properties.
iv. To investigate the optimum percentage of WTS in fired clay brick production.

1.4 Scope of research

This study investigated the characteristics and performance of water treatment sludge as brick making material. The performance of bricks produced by mixing clay and different percentages of WTS with an increment of 20% from 0% up to 100% was investigated. In this scope of research, moulds of size 50 x 50 x 50 mm were used in forming the mixed brick. Each WTS-clay brick with optimum moisture content was pressed under constant pressure of 15 kN.

Preliminary laboratory work, such as soil classification test including particle size distribution test, optimum moisture content (OMC) test, and Atterberg limit test were conducted at the Geotechnical Laboratory. In order to characterize clay, WTS and clay-WTS bricks, scanning electron microscopy-energy dispersive X-ray (SEM-EDX) and X-ray diffraction (XRD) analysis were conducted at the Department of Chemical and Environmental Engineering, Universiti Putra Malaysia (UPM) and Centre for Research and Instrumentation Management (CRIM), Universiti Kebangsaan Malaysia (UKM) respectively.

The mechanical properties of the brick were evaluated with firing shrinkage, loss on ignition (LOI), water absorption, bulk density, and compressive strength tests. In addition, leaching test using Toxicity Characteristics Leaching Procedure (TCLP) was also conducted at the Wastewater Laboratory, Faculty of Engineering, Universiti Malaya. Heavy metal content of the samples were analysed using Atomic Absorption spectrophotometer (AAS) or Inductively Coupled Plasma – Optical Emission Spectrometry(ICP-OES) and conducted at the Environmental Laboratory, Faculty of Engineering, UPNM.

1.5 Significance of Research

Numerous studies have been conducted on the potential usage of wastewater treatment sludge as part of construction material. The sludge is used directly or after processing. In the studies, the sludge is used as part of raw material for cement, brick and ceramic production. Only limited studies have focused on utilizing water treatment sludge (WTS) as construction material. This study will contribute some knowledge on the technical aspects of potentially utilizing water treatment sludge as partial or full clay replacement in brick making. Laboratory leach study is a useful approach to assess the potential effects from leached materials.

1.6 Thesis Overview

This thesis dissertation is divided into five main chapters as follows;

Chapter 1 introduces the main concept of the thesis together with the objectives, the research problem statement, scope of research, and also significance of the research.

Chapter 2 highlights the literature review on works done in the past focusing on the brick background, brick composition and brick making process. Besides, this chapter also presents the literature studies on research method and experimental procedures for clay brick studies by previous researchers.

Chapter 3 generally outlines the methodology and experimental procedures used throughout the research. Research methodology in this study was divided into five main phases.

Chapter 4 provides the test results and discussion of research findings. An analysis of the data collected is also provided in this chapter.

Chapter 5 summarizes the content of the thesis, together with the limitation of the research and some recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses on the overview of brick background, a process of brick production and brick standard and requirement. A general literature review of research was conducted on the characterization of material, mechanical properties and leaching studies affecting the masonry structures are also presented in this chapter.

2.2 Brick Background

Brick is one of the most demanding masonry units and have been a major construction and building material for decades. It has the widest range of products with its unlimited assortment of patterns, textures and colours. The dried-clay bricks were used for the first time in 8000 BC and the fired-clay bricks were used as early as 4500 BC. Presently, the worldwide annual production of bricks is about 1391 billion units and the demand for bricks is expected to increase continuously (Zhang, 2013).

In recent decades, the utilization of waste materials to produce bricks has been interesting research subjects due to sustainable development and environmental protection. It was also stated that there is a shortage of clay in many parts of the world. To protect the clay resource and the environment, some countries such as China have started to limit the use of bricks made from clay (Zhang, 2013). Numerous studies have investigated waste materials such as kraft pulp residue, wood sawdust, limestone powder, recycle paper mill waste, coal combustion residues, sugarcane bagasse ash waste, wastewater treatment sludge and cigarette butts as clay replacement in bricks production by other researchers (Kadir et. al, 2011).

In term of brick classification, brick is a diverse product, therefore it is difficult to standardize for classification. It may be categorized by the terms used in BS 3921 – that is, compressive strength (N/mm^2) and percentage by mass for water absorption. Alternatively, the manufacturer's name or catalogue descriptions may be used, strength acceptable to the Building Regulations in 5 N/mm^2 over the gross sectional area (2.8 N/mm^2 for blocks). In addition, brick classifications are categorized by its varieties, qualities and types. Some common terminologies used in varieties of brick are:

a) Common brick; suitable for general building work but having no special claim to give an attractive appearance.

b) Facing brick; specially made or selected to have an attractive appearance when used without rendering or plaster.

c) Engineering brick; having a dense and strong semi-vitreous body conforming to defined limits for absorption and strength.

For qualities of bricks, common terminologies used are:

a) Internal brick; Suitable for internal use only, may need protection on site during bad weather or during the winter,

b) Ordinary brick; less durable than special quality but normally durable in the external face of the building. Some types are unsuitable for exposed situations.

c) Special brick; for use in the condition of extreme exposure where the structure may become saturated and frozen such as retaining walls and paving.

Furthermore, other terminologies used for the types of brick are;

a) Solid brick; those in which small holes pass through or nearly through the brick do not exceed 25% of its volume or in which frogs (indentation) do not exceed 20% of its volume. A small hole is defined as a hole less than 20 mm wide or less than 500 mm^2 in an area.

b) Perforated brick; those in which holes passing through the brick exceed 25% of its volume and the holes are small as defined above.

c) Hollow brick; those in which the holes passing through the brick exceed 25% of its volume and the holes are larger than those defined as small holes.

d) Those in which the holes are closed at one end and exceed 20% of the volume of the brick.

Bricks may also be classified by one or more of the following:

a) Raw material, for example, concrete.
b) Place of origin, for example, China.
c) Surface texture, for example, sand faces.
d) Use, for example, wall.
e) Manufacturer, for example, soft mud process.
f) Colour, for example, orange.

2.3 Brick Composition

Clay brick is made primarily from clay, brick earth or shale, which are mined in open pits located near brick manufacturing facilities. Once the clay is mined, it is ground to suitable particle size and then mixed with water. This mixture is then formed into the brick. Most plants use material from the same pit extracted through multiple soil layers for a minimum of 50 years, thus minimizing their impact to the surface area (El-adaway et al., 2011).

2.3.1 Clay

Clay's application for brick production varies broadly in their proportion and is dependent on the locality from which the soil originates. Different compositions of clays are composed mainly of silica, alumina, lime, iron, manganese, sulphur and phosphate. Brick made out of clays are durable, fire resistant