PHYSICAL AND MECHANICAL STUDIES OF KAOLIN-BASED GEOPOLYMER MASONRY BRICK

by

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
Si	-	Silica
Al	-	Alumina
O	-	Oxygen
XRD	-	X-Ray Diffraction
SEM	-	Scanning Electron Microscopy
BS	-	British Standard
FBS	-	Face Brick Standard
FBX	-	Face Brick Extra
FBA	-	Face Brick Aesthetic
Fe	-	Iron
Ti	-	Titanium
P	-	Phosphorus
S	-	Sulfur
Mg	-	Magnesium
K	-	Potassium
Ca	-	Calcium
Zn	-	Zinc
Sr	-	Strontium
XRF	-	X-Ray Fluorescence
CaO	-	Calcium Oxide
NaOH	-	Sodium Hydroxide
Na_2SiO_3	-	Sodium Silicate

MPa	-	Mega Pascal
EPA	-	Environmental Protection Agency
TCLP	-	Toxicity Characteristic Leaching Procedure
CO_2	-	Carbon Dioxide
SiO_4	-	Silicate
AlO_4	-	Aluminates
OPC	-	Ordinary Portland Cement
CEGeoGTech	-	Center of Excellence Geopolymer and Green Technology
SPCI	-	South Pacific Chemicals Industries
M	-	Molar ratio
mm	-	Millimeter

Kajian Fisikal Dan Mekanikal Terhadap Bata Masonry Geopolimer Berasaskan Kaolin

ABSTRAK

Bata kebiasaannya digunakan sebagai bahan binaan dalam pembinaan dinding. Bata pembinaan konvensional kebiasaannya diperbuat daripada simen Portland, tanah liat dan pasir, yang mana dicampur dan dibentuk dengan pelbagai kaedah dan perlu dikeringkan dan dibakar pada suhu antara 900 hingga 1200 darjah selsius. Proses pengeringan dan pembakaran mengambil masa 2 hingga 4 hari untuk dilakukan. Selain daripada itu, proses penghasilan simen Portland menggunakan tenaga yang tinggi dan turut mengeluarkan 1 hingga 1.2 tan gas karbon dioksida (CO_2) untuk setiap 1 tan simen Portland yang dihasilkan. Pada masa kini, bahan binaan yang baru iaitu simen geopolimer telah menyaksikan perkembangan yang hebat di serata dunia. Ini berpunca daripada isu alam sekitar yang menekan pihak industri untuk menyediakan produk dan bahan binaan yang lebih mesra alam. Matlamat penyelidikan ini adalah untuk menghasilkan produk yang akan memberikan alternatif kepada bata konvensional dengan ciri-ciri yang baik melibatkan penggunaan bahan geopolimer iaitu kaolin, mengurangkan pencemaran alam sekitar dengan menggantikan penggunaan simen Portland dalam industri membuat bata, dan menghasilkan produk guna pakai efektif yang boleh digunakan oleh meningkatkan sifat-sifat produk yang sedia ada. Kajian ini telah dijalankan untuk menghasilkan bata geopolimer berasaskan kaolin dengan menggunakan kaedah pembentukan menggunakan tekanan tanpa proses pembakaran dan pengggunaan tenaga yang rendah. Kajian dijalankan pada bata kaolin berasaskan geopolimer dengan mempelbagaikan nisbah pasir terhadap kaolin (4:1 – 8:1, berdasarkan nisbah jisim), nisbah Na_2SiO_3 terhadap NaOH (0.2:1 - 0.4:1, berdasarkan nisbah jisim) dan nisbah kaolin terhadap alkali pengaktif (0.5:1 - 1.5:1, berdasarkan nisbah jisim) dengan nilai molariti NaOH, suhu pengawetan dan masa pengawetan yang malar iaitu 8 molar, 80 darjah selsius selama 24 jam. Kekuatan mampatan, ujian penyerapan air, ujian dimensi, dan analisis ketumpatan telah ditetapkan sebagai ciri – ciri mekanikal yang akan diuji pada bata geopolimer berasaskan kaolin. Kekuatan mampatan mencecah 5.87 MPa telah diperolehi dengan nisbah sodium silikat terhadap sodium hidroksida, kaolin terhadap alkali pengaktif, dan pasir terhadap kaolin 0.3:1, 1:1 dan 8:1. Julat ketumpatan bata geopolimer kaolin adalah antara 1636 kg/m^3 hingga 2175 kg/m^3. Sifat mikrostruktur bata Geopolimer berasaskan kaolin-telah dikaji dengan menggunakan analisis XRD yang mana menunjukkan komponen mineral yang utama dalam bata geopolimer berasaskan kaolin adalah kaolinite dan quartz.

Physical and Mechanical Studies of Kaolin-Based Geopolymer Masonry Brick

ABSTRACT

A brick is mainly applied as a building material in construction of walls. Conventional construction bricks are usually made from Portland cement, clay and sand, which are mixed and molded in various method and need to be dried and burned with the temperature range between 900 to 1200 degree centigrade. The drying and firing process takes 2 to 4 days to be done. Other than that, the production of Portland cement consume high energy and can emit 1 to 1.2 ton of carbon dioxide (CO_2) for every 1 ton of Portland cement product. Nowadays, a novel family of building materials which is geopolymer cement has seen a great development around the world. It is caused by the environmental issues that pressured the industries to manufacture a products and materials that are more environmental friendly. The aim of this research was to produce a product that would provide an alternative to the conventional bricks with a good properties by utilizing a geopolymer material which is kaolin, reduce the pollution of environment by replacing the usage of Portland cement in brick making industry, and produce effectively usable product by enhance the properties of ordinary product. This study has been conducted to produce kaolin-based geopolymer bricks by means of pressure forming without firing procedure and low energy consumptions. The experiments were conducted on kaolin-based geopolymer bricks by varying the ratio of sand-to-kaolin (4:1 - 8:1, by mass of ratio), Na_2SiO_3-to-NaOH (0.2:1–0.4:1, by mass of ratio) and kaolin-to-activator (0.5:1– 1.5:1, by mass of ratio) with constant molarity of NaOH, curing temperature and time which is 8 molar, 80 degree celcius for 24 hours. Compressive test, water absorption, dimensional test and density analysis were performed on the kaolin -based geopolymer bricks. Compressive strength up to 5.87 MPa was obtained with ratio of sodium silicate-to-sodium hydroxide, kaolin-to-alkaline activator, and sand-to-kaolin 0.3:1, 1:1 and 8:1 by mass. The density of geopolymer bricks were ranged between 1636 kg/m^3 to 2175 kg/m^3. The microstructural properties of kaolin-based geopolymer bricks were investigated by using XRD analysis which shows that the major mineral components of kaolin- based geopolymer brick were kaolinite and quartz.

CHAPTER 1

INTRODUCTION

1.1 Background

Based on previous archaeological studies, the technology of brick is believed began in about the third millennium before century around Middle East (Woods, 2006). In the past, the bricks were made from the remains of mud left after flood that came from the river. The bricks were shaped into brick shape by hand and dry under normal condition (Das, 2010). Modern bricks were made from concrete, sand and lime compared to traditional structures that were built by layering the bricks using mud. Brick is still being used until today in building construction industries because of its characteristic which is high resistant, durable and long lasting when properly maintain.

The brick is mainly applied as a building material in construction of walls. A blend of fine-grain sand, a cementations material such as ordinary Portland cement (OPC) and water were used in production of cement brick which is one of brick types which also called masonry brick. When the mixing of brick cement is still in wet condition, it can be controlled and manipulated like a thick paste. However, when the mixture dried, it hardens and sets, turning into a strong solid bricks. Brick cement can be used in new construction, and also in repainting, in which old cement is carefully removed and replaced to enact repairs. Proper process of producing cement brick can lead to a better quality of brick.

However, with increased activities in construction, deficiency of building materials and construction waste improvements have encouraged the development of new building materials. Conventional construction bricks are usually made from cement, clay and sand, which are mixed and molded in various method and need to be dried and burned with the temperature range between 900 to 1200 degree centigrade and the drying and firing process takes 2 to 4 days to be done. This process consume alot of energy and take a long time before the brick can be used. Other than that, the production of conventional construction brick that used OPC as its main ingredient is a highly energy intense product that generate CO_2 (Habert, d'Espinose de Lacaillerie, & Roussel, 2011).

Due to this problem, many research had been conducted in order to find an alternative to the ordinary construction material which uses alternative raw materials such as kaolin, fly ash, boiler ash and others to be implement as a building and construction materials including brick (Wan Mastura W. I., Kamarudin, Khairul Nizar, Mustafa Al bakri, & Binhussain, 2013; Ferone, Colangelo, Cioffi, Montagnaro, & Santoro, 2011), mortar (Swanepoel & Strydom, 2002; Hardjito, Cheak, & Lee, 2008; Temuujin, VanRiessen, & Mackenzie, 2010), and concrete (Sumajouw, Hardjito, Wallah, & Rangan, 2007; Abdullah, et al., 2011) that lead to the introduction of geopolymer technology in brick production.

The production process of geopolymer bricks consume less energy due to low curing temperature besides low production cost in term of production and less time consuming compared to conventional bricks. The development of geopolymer brick is

an important step towards producing a brick with better performance and environmental friendly material.

The aim of producing this brick is to create the solution with the low cost involved by utilizing a low cost material, reduce the pollution of environment by replacing the usage of Portland cement in brick making industry, and produce effectively usable product by enhance the properties of ordinary product.

1.2 Problem Statement

Conventional bricks need to be dried and burned with the temperature range between 900 – 1200 degree centigrade. The drying and firing process takes 2 to 4 days to be done. This process use alot of energy and take a long time before the brick can be used. Besides that, in Malaysia construction industries, people are too dependent on cement as their construction materials. The production of ordinary Portland cement, which is widely being used in construction such as masonry brick incredibly energy intensive to make and can emit 1 to 1.2 ton of carbon dioxide (CO_2) for every 1 ton of Portland cement product(Swamy, 2000). This will have a significant impact on the environment. Due to this problem, other alternative has been discovered which the replacement of clay brick to cement brick.

Early 2007, Dr. Henry Liu has come out with a brilliant solution which is producing the fly-ash bricks. Innovative use of fly ash to manufacture high quality building materials will potentially decrease some of the negative environmental impact of coal fired power generation while meeting increasing demands for greener building

materials (NSF Press Release 07-058,100% Fly Ash Brick is the nation's "Greenest Brick", May2007). This fly ash brick can reduce the cost of bricks and also can reduce the amount of fly ash that emitted into landfill can save the energy and reduce the pollution.

Geopolymer, which is also known as mineral polymers or inorganic polymer glasses which the chemical compositions of the geopolymer materials resemble to natural zeolitic materials with amorphous microstructure, is a promising new form of inorganic polymer material that could be another good alternative to the ordinary Portland cement in production of cement masonry brick industries. In earlier study, researchers have focused on kaolin as the aluminosilicate source in geopolymer (J., 1999). Later, the utilization of fly ash as aluminosilicate source in producing construction materials became major study areas (Hardjito, Cheak, & Lee, 2008; Sumajouw, Hardjito, Wallah, & Rangan, 2007; Temuujin, VanRiessen, & Mackenzie, 2010; Abdullah, et al., 2011). However the use of kaolin in geopolymer brick production has not been studied in details.

The aim of this research is to produce a product that will create an alternative to the cement masonry brick with a good properties involved by utilizing kaolin as aluminosilicate source, reduce the pollution of environment by replacing the usage of Portland cement in brick making industry, and produce effectively usable product by enhance the properties of ordinary product.

In addition, the use of kaolin is not common in the Malaysia’s brick manufacturing sector. This study will be able to enhance the understanding on the

production of kaolin - based geopolymer brick production and suitability of kaolin - based geopolymer brick as a substitute to the conventional masonry brick in the construction industries as a construction material.

1.3 Objectives of Study

The main purpose of the research was to study the development of kaolin based geopolymer mortar brick with geopolymerization process. The main objectives of this study were:

1. To produce kaolin based geopolymer brick by using geopolymer brick making machine.
2. To obtain the optimum ratios and identify the effect of different sand/kaolin, activators (Na_2SiO_3/NaOH) and kaolin/activator ratio on the mechanical properties such as compressive strength, density and water absorption of kaolin based geopolymer brick.
3. To identify the correlation between compressive strength, water absorption and density of kaolin based geopolymer brick.

1.4 Scope of Research

This study focuses on the production and properties of geopolymer brick made with kaolin as its geopolymer raw material. The geopolymer raw material that was used in this study which is kaolin was locally supplied by Kaolin Industries Sdn. Bhd. The kaolin based geopolymer brick was produced by mixing sand, kaolin and alkaline

solution consist of sodium silicate and sodium hydroxide with various ratiosby using geopolymer brick making machine. Then the geopolymer samples had been tested in the laboratory to determine its compressive strength, density and water absorption properties in order to identify the optimum ratios of all the parameters. The whole testing was done accordance to the standard. The morphology of the original kaolin and kaolin based geopolymer brick with different ratios sand to kaolin, kaolin to activator and Na_2SiO_3 to NaOH was studied by using XRD analysis. The correlation between compressive strength, water absorption and density of kaolin based geopolymer brick were also studied.

1.5 Organization of the Thesis

Chapter 1 presents the background of the research work, the problem statement that lead to the research work, the objectives of the current study and also the scope of the research work.

Chapter 2 review the literatures of the potential application of kaolin to be used in production of geopolymer brick by using geopolymerization process. This chapter also brief literatures about different types of brick, its classification, size of brick that is commonly produced, and also the application and advantages of the brick. This chapter also discusses about geopolymer technology and its suitability in brick production with much focussing on the material used in producing kaolin-based geopolymer brick, the production and also properties of the brick.

Chapter 3 describes the experimental methods to prepare kaolin-based geopolymer brick, the production process and the experimental testing and analysis method conducted to evaluate the engineering properties of the kaolin-based geopolymer brick accordance to standard.

Chapter 4 presents the result and discussion of the analysis. The result and discussion include the characterization of raw materials, microstructure study of kaolin-based geopolymer brick and the effect of each parameters which is different Sand/Kaolin, activators (Na_2SiO_3/NaOH) and Kaolin/Activator ratios to the properties of the kaolin-based geopolymer brick. The correlation between kaolin-based geopolymer properties were also discussed in this chapter.

Chapter 5 summarize and conclude the result of this study and the suggestions and recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a short review of bricks available in the market, their specifications and classifications. This will be followed by the review on the background of geopolymer technology, application of geopolymer in brick production and also the reaction in geopolymer process. This chapter will also discussing the materials in kaolin - based geopolymer brick production, the curing process of geopolymer brick, the application and advantages of the brick, and also the engineering properties of bricks in terms of compressive strength, water absorption, dimension tolerances and density of the bricks.

2.2 Definition of Brick

Brick is a solid or hollow manufactures masonry unit, usually formed into a small rectangular prism. Brick selection is made according to the specific application in which the brick will be used. Standards for brick cover specific uses of brick and classify the brick by performance characteristics. The performance criteria include strength, durability and aesthetic requirements. Selection of the proper specification and classification within that specification, along with proper design and construction, should result in expected performance.

2.3 Types of Brick

In the market, there are numerous types of bricks that can be found and being used in the construction industry. The types of bricks were classified according to the material and method used for making those different types of bricks. There are four commonly used bricks types which are clay bricks, calcium silicate bricks, concrete bricks and cement brick. These types of bricks had been standardized for its usage.

2.3.1 Clay Brick

Clay brick is the most extensively used type of masonry units throughout the world. Its widespread use is mainly due to the availability of clay and shale in most countries (Obam, 2015). Clay bricks are made by shaping suitable clays to units of standard size, which are then fired to a temperature in a range of 900°C to 1200°C (Abdul Kadir, 2012). In Malaysia, clay brick is commonly used in construction based on the British Standard BS 3921: 1985, standard for specification of clay bricks. By referring to BS 3921: 1985, the work size of clay brick is 215 mm x 102.5 mm x 65 mm while the coordination size of clay brick had been set to 225 mm x 112.5 mm x 75 mm.

The coordinating dimensions are a measure of the physical space taken up by a brick together with the mortar required on one bed, one header face and one stretcher face. The working dimensions are the sizes to which manufacturers will try to make the bricks. The difference between the working and coordinating dimensions of a brick is 10mm and this difference is taken up with the layer of mortar into which the bricks are pressed when laying. The difference between working and coordinating size can be