DURABILITY OF GEOPOLYMER MORTARS USING AGRO-INDUSTRIAL WASTE

NUR FARHAYU BINTI ARIFFIN

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UNIVERSITI TEKNOLOGI MALAYSIA

DEDICATION

Praise be to Allah s.w.t, the Lord of the Worlds

Who says (interpretation of the meaning):

"Give thanks to Me and to your parents. Unto Me is the final destination"

[Quraan, Luqmaan 31:14]

All glory and honor to Him

Then I dedicate this work

to my beloved mom, dad and siblings.

And also to all who supported me by Doa and work. Thanks for everything. May Allah bless you. Amin

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ABSTRACT

Geopolymer is a binding material produced from the reaction of silica and alumina (in a source material of geological origin or in by-product material), with alkaline solutions. The use of geopolymer as cement replacement material in concrete might be able to reduce the pollution due to the emission of carbon dioxide to the atmosphere generated from the production of Ordinary Portland Cement (OPC). This thesis presents the results of laboratory investigation on geopolymer mortar cubes in which the durability of specimens was studied. The cement replacement materials used were Palm Oil Fuel Ash (POFA) and Pulverized Fuel Ash (PFA), with a mass ratio of sand to blended ash of 3:1, while the alkaline solution was made of sodium silicate and sodium hydroxide with the mass ratio of 2.5:1 and has concentration of 14 Molar. In order to determine the optimum mix proportion at a specified compressive strength of normal mix using OPC, mortar cubes containing various ratios of POFA to PFA were tested with the target of using as much POFA as possible in the mixture. With the optimum mix proportion, that is 30:70, geopolymer mortar in the forms of 70x70x70 mm cubes were cured at room temperature of 28ºC for 28 days and heat cured at 90ºC for 24 hours, were tested for durability. The performances were measured in terms of water absorption, water permeability coefficient, drying shrinkage, sulphate resistance, acid resistance, chloride ion penetration resistance, dry-wet cyclic resistance and elevated temperature resistance. The evaluations were done through visual observation, measurement of mass change and residual compressive strength. The test result shows that the heat cured geopolymer mortars possess higher degree of durability compared to those using OPC. This suggests that geopolymer with correct proportion may be used as cement replacement material in the production of a more environment-friendly concrete.

ABSTRAK

Geopolymer adalah bahan pengikat yang dihasilkan dari tindak balas silika dan alumina (dalam bahan sumber asal geologi atau bahan produk), dan diaktifkan oleh larutan alkali. Penggunaan geopolymer sebagai bahan gantian dapat mengurangkan pencemaran yang disebabkan oleh pelepasan karbon dioksida ke atmosfera yang dijana daripada pengeluaran Simen Portland Biasa (OPC). Tesis ini membincangkan hasil kajian ketahanan ke atas kiub mortar geopolymer. Bahan gantian simen yang digunakan adalah dari campuran bahan api abu kelapa sawit (POFA) dan abu bahan api terhancur (PFA), dengan nisbah jisim pasir kepada abu campuran 3:1, manakala larutan alkali diperbuat daripada campuran sodium silikat dan sodium hidroksida dengan nisbah jisim 2.5:1 mempunyai kepekatan 14 Molar. Dalam penentuan perkadaran campuran optimum pada kekuatan tertentu mampatan campuran biasa menggunakan OPC, kiub mortar yang mengandungi campuran POFA dan PFA telah diuji dengan sasaran menggunakan POFA seberapa banyak yang mungkin di dalam campuran geopolymer. Menggunakan nisbah optimum yang diperolehi iaitu 30:70, spesimen mortar geopolymer dibancuh di dalam 70x70x70 kiub mm dan dibiarkan pada suhu bilik 28ºC selama 28 hari, dan pada suhu 90ºC selama 24 jam. Penilaian diukur dari segi penyerapan air, kebolehtelapan, pengecutan pengeringan, rintangan sulfat, rintangan asid, rintangan penembusan ion klorida, rintangan kitaran kering basah dan rintangan suhu. Penilaian telah dilakukan melalui pemerhatian visual, pengukuran perubahan jisim dan kekuatan mampatan sisa. Keputusan ujian menunjukkan bahawa geopolymer mortar yang dibiarkan pada suhu 90ºC mempunyai tahap rintangan yang lebih tinggi berbanding menggunakan OPC. Ini menunjukkan bahawa geopolymer dengan kadar yang betul boleh digunakan sebagai bahan gantian simen dalam menghasilkan konkrit yang lebih mesra alam.

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σ_c	Compressive strength
P	Pressure
A	Area
ε	shrinkage strain
t	time
L	length
k	linear coefficient of thermal expansion

CHAPTER 1

INTRODUCTION

1.1 Introduction

The demand for concrete used has been increasing in line with national developments. Development of a country brings an expansion of construction industry as more building are constructed nowadays. Concrete is the most prevalent building material and the world would be pretty flat without it. There can be no tall buildings and structures without concrete. It is estimated that the production of the cement will increase from 1.5 billions tons in 1995 to 2.2 billions in 2010 (Maholtra 1999). According to Lafarge (2012), a global cement production in 2012 is approaching to 4 billion tons which is can be consider as a bigger amount.

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The ordinary Portland cement (OPC) still continues to be the most commonly material used in infrastructure construction, because OPC is available and all the ready mixed cement companies using it as their product. Even though reports of earlier study with regard to its resistance to acid and sulphates indicated poor performance and hence render it as unsuitable in such adverse conditions, it always one of the main materials used in construction. Besides, the biggest disadvantage of OPC is that carbon dioxide (CO_2) gas is released while producing it. In fact, CO_2 gas can be harmful for human when exposed to it in bigger amount.

Nowadays, people are realizing the effect of OPC on the environment and for that reasons, they have started to find new solutions to overcome this problem. One of the solutions is by introducing geopolymer technology to reduce the use of OPC mortar. In the past few decades, geopolymer has emerged as one of the possible alternative to OPC as it gives higher early strength and excellent durability performance and for being environmental friendly.

Geopolymer is a new material that can be used for construction as a replacement of OPC. Davidovits (1994a) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product material such as fly ash and rice husk ash to produce binders. The chemical reaction that takes place in this case is known as polymerization process, thus the term 'Geopolymer' is used to represent these binders. The geopolymer technology have been used at most of the country for example, in Australia (June 2008) a path was constructed in the grounds of Curtin University using cast-insitu geopolymer concrete. Other than that, 'HySSIL', a technology company that develops and commercializes innovative building materials and products that based in Australia, has developed a range of cellular geopolymer precast panels and roof tiles which have almost similar durability and strength with conventional product.

As a new material, not much information is available on the durability of geopolymer concrete. The durability of concrete is an important requirement for the performance in aggressive environments throughout its design life period. This research studies the durability of geopolymer mortars made from the combination of blended ash and activated by alkaline solution. The test conducted for durability performance are water absorption test, permeability test, drying shrinkage test, sulphate resistance, acid resistance, chloride ion penetration, dry-wet cyclic, and the effect of elevated temperature on geopolymer mortars.

1.2 Problem Statement

The durability performance of concrete is important as it needs to have an ability to resist any weather attack and retain its original form, quality and serviceability when exposed to aggressive environment. It also needs to perform satisfactorily under anticipated exposure conditions during its service life span. No concrete structure material is inherently durable as a result of environmental interactions and the properties of materials change with time. A material is assumed to reach the end of service life when its properties are changed or deterioration after exposure to aggressive condition.

The OPC concrete always is a first material to choose when building is constructed. The problem regarding the resistance of OPC concrete toward aggressive environment had been widely discussed. Rangan (2008a) reported that OPC concrete have low durability resistance and has poor ability to resist any chemical attack. Geopolymer are a class of new binder generally manufactured by activating an aluminosilicate source material in a highly alkaline medium. Davidovits *et al* (1990) reported that geopolymer possesses high early strength, better durability and has no dangerous alkali-aggregate reaction.

The geopolymer binder is a low CO_2 cementious material. It does not rely on the calcination of limestone that generates CO_2. This technology can save up to 80% of CO_2 emissions caused by the cement and aggregate industries. The emission of CO_2 gases and the low durability performance of OPC are the main reasons why the geopolymer technology was introduced. So far, investigations in geopolymer mostly deal with the manufacturing processes and effects of synthesizing parameters on physical and mechanical properties. Very few studies have been carried out with regard to durability of geopolymer materials.

1.3 Objectives of the Research

The objectives of the research are:

i) To determine optimum mix proportions of geopolymer mortar using blended ash (PFA+POFA) along with an appropriate ratio of sodium hydroxide to sodium silicate as an activator.

ii) To investigate the durability of geopolymer mortars.

1.4 Scope of the Study

The research utilizes POFA as the base material for making geopolymer mortar. The POFA was obtained from only one source, because the main focus of this study was the durability of POFA geopolymer mortar. The same technology and equipment currently used to test the durability of OPC mortar will be used to check the durability performance of geopolymer mortar.

The study focuses on the durability performance based on the resistance of geopolymer mortar to water absorption test, permeability test, drying shrinkage, sulphate resistance, acid resistance, chloride ion penetration, dry-wet cyclic and elevated temperature test. The optimum mix proportion will be used to check the durability performance and be compared with OPC mortar. The size of specimens used was 70x70x70 mm and tested for 28 days and subjected to heat cured at 90ºC and room temperature cured (28ºC).

1.5 Limitations of Studies

The selection of mix proportion was first made in order to obtain the optimum mix proportions. The specimens were cast in 70x70x70mm cubic moulds for both geopolymer mortar and OPC mortar. Geopolymer mortar specimens were subjected to heat cure at 90ºC and room temperature cure (28ºC). OPC mortar specimens were cured in water for 28 days. After initial curing, all specimens were exposed to different durability tests up to one year. Limitations of this research works are summarized in Table 1.1.

Table 1.1: Limitation of Studies

Specimen size (mm)	**Curing condition**	**Test**	**Duration**	**Evaluation**
70x70x70	i) 24 hours heat cured at 90ºC + 6 days at room temperature (28ºC) ii)Room temperature (28ºC) cured for 28 days	Optimum Mix Proportion	1 day	Compressive strength
		Water Absorption (JIS A 6203)	48 hours	Mass change
		Water Permeability Coefficient (BS 1881-5:1970)	1 day	Flow of water into specimens
		Drying Shrinkage and Thermal Coefficient (ASTM C 531)	5 days	i) Linear shrinkage ii) Coefficient of thermal expansion
		Sulphate Resistance (ASTM C 267-01)	28, 56, 90, 120, 180 and 365 days	i) Visual observation ii) Mass change iii) Residual compressive strength
		Acid Resistance (ASTM C 267-01)	28, 56, 90, 120, 180 and 365 days	i) Visual observation ii) Mass change iii) Residual compressive strength
		Chloride Ion Penetration (ASTM C 1202)	28, 56, 90, 120, 180 and 365 days	i) Visual observation ii) Mass change
		Dry-Wet Cyclic (Kajio. S *et al*, 2004)	180 days	i) UPV time travel ii) Mass change iii) Residual compressive strength
		Elevated Temperature (GB/T 9978-1999)	3 hours	i) Mass change ii) compressive strength

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