

DURABILITY OF GEOPOLYMER MORTARS USING AGRO-INDUSTRIAL
WASTE

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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 28°C for 28 days and heat cured at 90°C 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 28°C selama 28 hari, dan pada suhu 90°C 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 90°C 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.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	AUTHOR DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xii
	LIST OF FIGURES	xiv
	LIST OF SYMBOLS	xix
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Problem Statement	3
	1.3 Objectives of the Research	4
	1.4 Scope of the Study	4
	1.5 Limitations of study	5
2	LITERATURE REVIEW	8
	2.1 Introduction	8
	2.2 Geopolymer Concrete	9
	2.2.1 The Polymerization Process	10
	2.3 Alkaline Solution	13

2.4	Curing Process	13
2.5	Palm Oil Fuel Ash (POFA)	14
2.6	Pulverized Fuel Ash (PFA)	15
2.7	Concrete Durability	17
2.7.1	Sulphate Attack	17
2.7.2	Acid Attack	19
2.7.3	Chloride Attack	21
2.7.4	Drying Shrinkage	22
2.7.5	Permeability And Water Absorption	22
2.8	Advantage of Geopolymer Mortars/Concrete	24
2.8.1	Sustainability Issues	24
2.8.2	Waste Consumption	25
2.8.3	Greenhouse Gases	25
2.8.4	Environmental Advantage	26
2.9	A Practical New Way To Reduce Global Warming	27
2.10	Application of Geopolymer Concrete	28
2.11	Summary	29
3	RESEARCH METHODOLOGY	30
3.1	Introduction	30
3.2	Materials	32
3.2.1	Palm Oil Fuel Ash (POFA)	32
3.2.2	Pulverize Fly Ash (PFA)	35
3.2.3	Super Plasticizer	37
3.2.4	Fine Aggregates	38
3.2.5	Alkaline Solutions	38
3.2.6	Ordinary Portland Cement (OPC)	40
3.3	Mix Proportions	41
3.4	Preparation of Specimens	44
3.5	Curing Conditions	47
3.6	Tests	48

3.6.1	Compressive Strength Test	48
3.6.1.1	Residual Compressive Strength	49
3.6.2	Water Absorption Test	50
3.6.3	Permeability Test	51
3.6.4	Drying Shrinkage Test	52
3.6.4.1	Coefficient of Thermal Expansion Test	56
3.6.4.2	Linear Shrinkage Calculation	57
3.6.4.3	Linear Coefficient of Thermal Expansion	57
3.6.5	Sulphate Resistance Test	58
3.6.6	Acid Resistance Test	59
3.6.7	Chloride Ion Penetration Test	61
3.6.8	Dry-Wet Cyclic Resistance Test	62
3.6.8.1	Ultrasonic Pulse Velocity (Upv) Test	63
3.6.9	Elevated Temperature Test.	65
4	TEST RESULTS AND DISCUSSION	67
4.1	Introduction	67
4.2	Selection of Optimum Mix Proportion	67
4.3	Water Absorption	70
4.4	Water Permeability	72
4.4.1	Relationship between Water Absorption, Water Permeability Coefficient and Compressive Strength	73
4.5	Drying Shrinkage	75
4.5.1	Mass change (%) of Drying Shrinkage Specimens	78
4.5.2	Coefficient of Thermal Expansion	79
4.6	Sulphate Resistance	82
4.6.1	Visual Appearance of Specimens after Immersion.	82

4.6.2	Mass Change (%) of Specimens in Sodium Sulphate Solution	83
4.6.3	Residual Compressive Strength	85
4.6.4	Relationship between Compressive Strength and Immersion Period	87
4.7	Acid Resistance	88
4.7.1	Visual Appearance of Specimens after Immersion.	89
4.7.2	Mass Change (%) of Specimens in Acid Solutions	90
4.7.2.1	Sulphuric Acid	90
4.7.2.2	Hydrochloric Acid	93
4.7.3	Residual Compressive Strength	94
4.7.4	Relationship between Compressive Strength and Immersion Period	98
4.8	Chloride Ion Penetration Resistance	100
4.8.1	Visual Appearance of Specimens after Immersion.	100
4.8.2	Mass Change (%) of Specimens in Sodium Chloride	101
4.9	Dry-Wet Cyclic Test	104
4.9.1	Ultrasonic Pulse Velocity (UPV) Test	104
4.9.2	Mass Change (%) of Dry-Wet Cycle Specimens	106
4.9.3	Residual Compressive Strength	107
4.10	Effect of Elevated Temperature on Compressive Strength	109
4.10.1	Mass Change (%) of Elevated Temperature Specimens	111
4.10.2	Relationships between Compressive Strength and Elevated Temperature	113

4.11	Summary	114
5	CONCLUSIONS AND RECOMMENDATIONS	115
5.1	Conclusions	115
5.2	Recommendations	117
5.2	Acknowledgment	117
6	REFERENCES	118

LIST OF TABLE

TABLE NO.	TITLE	PAGE
1.1	Limitations of studies	6
2.1	Application of geopolymer materials based on silica-to-alumina atomic ratio	29
3.1	Chemical composition of POFA	34
3.2	Chemical composition of PFA	36
3.3	Chemical composition of Ordinary Portland Cement.	40
3.4	Mix proportions of geopolymer mortar with different PFA: POFA ratio	42
3.5	Optimum mix proportions of geopolymer mortars.	43
3.6	Mix proportion for ordinary Portland cement (OPC) mortar	43
3.7	Assessment criteria for absorption	51
3.8	Dry-wet cycles	63
4.1	Compressive strength of geopolymer mortar.	68

4.2	Mass change (%) of geopolymer and OPC mortars in 5% sodium sulphate solution.	83
4.3	Residual compressive strength (%) of mortars after immersed in 5% sodium sulphate solution	85
4.4	Mass change (%) of mortars after immersed in 2% sulphuric acid solution	91
4.5	Mass change (%) of mortars after immersed in 2% hydrochloric acid solution	93
4.6	Residual compressive strength (%) of mortars after immersed in 2% sulphuric acid solution	95
4.7	Residual compressive strength (%) of mortars after immersed in 2% hydrochloric acid solution	96
4.8	Mass change (%) of mortars after immersed in 2.5% sodium chloride solution	101
4.9	UPV travel time reading of Dry-wet cyclic specimens	105
4.10	Residual compressive strength (%) of mortar after dry-wet cyclic test	108
4.11	Compressive strength (MPa) of mortars after elevated temperature test	109
4.12	Mass change (%) of geopolymer mortars and OPC mortar after expose to elevated temperature	111

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Schematic formation of geopolymer (Davidovits, 1994; Van Jaarsveld <i>et al</i> , 1997)	12
3.1	A flowchart of Research Methodology	31
3.2	Production of POFA	33
3.3	Palm Oil Fuel Ash (POFA) after grinding	34
3.4	Pulverized fuel ash (PFA)	36
3.5	Rheobuild 1100 super plasticizer in powder form	37
3.6	Fine aggregate use to make a geopolymer mortars	38
3.7	Alkaline solutions (a) sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) (b) Mixing of Na_2SiO_3 and NaOH at least one day before casting process	39
3.8	Hobart mixer used to cast geopolymer mortars and OPC mortar	45
3.9	Fresh geopolymer mortar	45

3.10	Compaction of geopolymer mortar casted in 70 x 70 x 70 mm mould	46
3.11	Final product of geopolymer mortar	46
3.12	Heat cured at 90°C	47
3.13	The apparatus and equipment for permeability test	52
3.14	Mortar bar mould 25x25x250 mm	53
3.15	Cube size mortar for compression strength test	53
3.16	Specimen had been marked with pen	54
3.17	The strut was pasted with Araldite before pasted on specimen	55
3.18	Placing strut on marked position	55
3.19	Measurement of drying shrinkage strain using mechanical extensometer	55
3.20	Specimen length was measured using vernier caliper	56
3.21	5% sodium sulphate solution used for sulphate test	59
3.22	Acid solutions used for acid test	60
3.23	2.5% sodium chloride solution used for chloride ion penetration test	61
3.24	Cross section for chloride test (Shaikh <i>et al</i> , 1999)	62
3.25	Ultrasonic Pulse Velocity Equipment	64
3.26	Different conditions that may be encountered when testing an element	64

3.27	Blast furnace	65
3.28	Elevated temperature exposure period	66
4.1	Compressive strength vs. percentage of PFA to POFA	69
4.2	Water absorption test of geopolymer mortars and OPC mortar	71
4.3	Permeability coefficient of geopolymer mortars and OPC mortar	72
4.4	Relationships between water absorption and water permeability coefficient	74
4.5	Relationships between compressive strength and water permeability coefficient	74
4.6	Drying shrinkage of geopolymer and OPC mortars vs. Period	75
4.7	Shrinkage behaviour between geopolymer obtained from this study and previous study (Prof. Rangan)	77
4.8	Percentage of mass change between heat cured and room temperature cured geopolymer mortars and OPC mortars	78
4.9	Geopolymer mortar after conducting thermal expansion test (a) heat cured geopolymer (b) room temperature cured geopolymer	79
4.10	The coefficient of thermal expansion of heat cured and room temperature cured geopolymer mortars and OPC mortars	80
4.11	Coefficient of thermal expansion of heat cured and room temperature cured geopolymer mortar at various heating/cooling cycle	81

4.12	Condition of specimens after immersed in 5% sodium sulphate solution	82
4.13	Mass change vs. Immersion period in 5% sodium sulphate solution	84
4.14	Residual compressive strength vs. immersion period for specimens immersed in 5% sodium sulphate	86
4.15	Relationships between compressive strength and immersion period in 5% sodium sulphate	88
4.16	Specimens after 365 days immersed in 2% of sulphuric acid solution (a) geopolymer mortar and OPC (b) OPC mortar	89
4.17	Specimens after 365 days immersed in 2% hydrochloric acid solution (a) geopolymer mortar and OPC (b) OPC mortar	89
4.18	Mass change vs. immersion period for specimens immersed in 2% sulphuric acid solution	91
4.19	Mass change vs. immersion period for specimens immersed in 2% hydrochloric	93
4.20	Residual compressive strength vs. immersion period for specimens immersed in 2% sulphuric acid	95
4.21	Residual compressive strength vs. immersion period for specimens immersed in 2% hydrochloric acid	96
4.22	Relationships between compressive strength and immersion period for specimens immersed in 2% sulphuric acid	98
4.23	Relationships between compressive strength and immersion period for specimens immersed in 2% hydrochloric acid	99

4.24	Specimens immersed in 2.5% sodium chloride solution	100
4.25	Mass change vs. immersion period of mortars immersed in 2.5% sodium chloride	102
4.26	Test result of geopolymer mortars and OPC mortars sprayed with 0.1N silver nitrate solution	103
4.27	UPV travel time vs. Cyclic	106
4.28	Mass change of dry-wet cycle geopolymer mortar and OPC mortar	107
4.29	Residual compressive strength vs. cyclic	108
4.30	(a) Specimen before put in blast furnace (b) Specimens after taken out from blast furnace	109
4.31	Compressive strength vs. Temperature at elevated temperature	110
4.32	Mass change of geopolymer mortars and OPC mortar	112
4.33	Relationship between compressive strength and elevated temperature	113

LIST OF SYMBOLS

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 buildings 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 billion tons in 1995 to 2.2 billion in 2010 (Maholtra 1999). According to Lafarge (2012), a global cement production in 2012 is approaching to 4 billion tons which can be considered as a bigger amount.

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 (CO₂) gas is released while producing it. In fact, CO₂ 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 CO₂ cementitious material. It does not rely on the calcination of limestone that generates CO₂. This technology can save up to 80% of CO₂ emissions caused by the cement and aggregate industries. The emission of CO₂ 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 90°C and room temperature cured (28°C).

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 90°C and room temperature cure (28°C). 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 90°C + 6 days at room temperature (28°C) ii) Room temperature (28°C) 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 <i>et al</i> , 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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