UNIVERSITI PUTRA MALAYSIA

NEW GEO-POLYMERIZATION PROCESS FOR HIGH STRENGTH ALKALI-ACTIVATED BINDER WITH PALM OIL FUEL ASH AND GROUND GRANULATED BLAST FURNACE SLAG

MOSLIH AMER SALIH

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By

MOSLIH AMER SALIH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

March 2015

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DEDICATIONS

I dedicate this thesis to, my father, my mother, my brothers and my small family, my wife and children Mina, Ameen and Dima.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

NEW GEO-POLYMERIZATION PROCESS FOR HIGH STRENGTH ALKALI-ACTIVATED BINDER WITH PALM OIL FUEL ASH AND GROUND GRANULATED BLAST FURNACE SLAG

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MOSLIH AMER SALIH

March 2015

Chairman: Professor Dato' Ir Abang Abdullah Abang Ali,PhD

Faculty: Engineering

This study investigated a new geopolymerization process for the production of high strength alkali activated binder, using high volume palm oil fuel ash (POFA) mixed with ground granulated blast furnace slag (GGBS). The experimental work was designed for the geopolymer paste and mortar. In the paste, the optimum alkali activation parameters of POFA were identified. These parameters included Sodium Hydroxide concentration, Solid/Liquid ratio (S/L), and Sodium Silicate to Sodium Hydroxide ratio (SS/SH). The role of curing regime and its effect on the alkali activation of POFA was investigated at ambient and different temperatures. GGBS was introduced as a partial replacement of POFA in five percentages (10-50%) to study the role of Calcium ions and mechanisms to improve the load bearing capacity of the resulting gel to a high strength geopolymer binder.

The production of high strength geopolymerized mortar cured at ambient temperature was initially targeted by applying the activation parameters with the same replacement levels of GGBS as in the paste. The durability of the proposed alkali activated binder was investigated by exposing the mortar to extreme environments, namely elevated temperatures and sulfate attack. The compressive strength test, microstructural and chemical tests such as Scanning Electron Microscopy/Energy-Dispersive X-Ray Spectroscopy (SEM/EDX), X-Ray Diffraction (XRD), Thermogravimetric Analysis/Derivative Thermogravimetry (TGA/DTG), Differential Scanning Calorimetry (DSC) and Fourier Transform Infra-Red (FTIR), were conducted to study the underlying mechanisms of strength development.

The results showed that liquid Sodium Hydroxide at 12 Molarity, S/L ratio at 1.32, and SS/SH ratio at 2.5 were applicable to alkali activate 100% POFA and produce geopolymer paste with 32.84 MPa at the age of 28 days. One major finding was identifying the Calcium Silicate Hydrate gel (C-S-H) as the main binding phase; with no Calcium Hydroxide $Ca(OH)_2$ detected in the system. The test results showed that 100% POFA geopolymer paste can set and harden at ambient temperature with a comparable compressive strength to samples cured in the oven. Calcium ions dissolved from GGBS participated in increasing the binder strength by the formation of more C-

S-H gel. Aluminum ions provided by GGBS led to a higher degree of polymerization and significant degree of crosslinking between C-S-H chains and shifting it to C-(A)-S-H gel. The compressive strength for binary geopolymer paste was 78.12 MPa at the age of 28 days.

The alkali activated binder from the alkali activation of POFA as the only aluminosilicate material was able to produce geopolymer mortar with normal strength of 33.91 MPa at the age of 28 days. Inclusion of GGBS with POFA was effective to produce high strength geopolymer mortar with compressive strength of 70.25 MPa at the age of 28 days. Results from residual compressive test at elevated temperatures showed that samples maintained their dimensional stability at elevated temperatures due to the presence of evacuation routes (pore system) in the mortar which allowed water to be evaporated. Moreover, glass transition was detected between 600 ºC and 800 ºC which provided a relative increase in the strength of the geopolymer mortar. Test results showed that the proposed geopolymer mortar performed better than Portland cement mortar when exposed to sulfate attack. The results indicated that although Sodium sulfate and Magnesium sulfate had deterioration effect due to decomposing of Si and Ca ions from both C-S-H and C-A-S-H gels, the proposed geopolymer mortar experienced less strength depletion which can be related to the absence of calcium hydroxide in the matrix.

Keywords: POFA, Geopolymer binder, Geopolymer cement, GGBS, Alkali activation, Geopolymer mortar.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doctor Falsafah

PROSES GEO-POLIMERISASI BARU UNTUK PENGIKAT ALKALI TERAKTIF BERKEKUATAN TINGGI DENGAN ABU SISA BAHAN API KELAPA SAWIT DAN SANGA RELAU BAGAS BERBUTIR

Oleh

MOSLIH AMER SALIH

Mac 2015

Pengerusi: Professor Dato' Abang Abdullah Abang Ali, PhD

Fakulti: Kejuruteraan

Kajian ini telah menyiasat proses geo-polimerisasi untuk penghasilan pengikat alkali teraktif berkekuatan tinggi menggunakan abu sisa bahan api kelapa sawit (POFA) berisipadu tinggi diadunkan dengan sanga relau bagas berbutir (GGBS). Ujian-ujian telah dirancang untuk adunan dan mortar geopolimer. Dalam adunan, parameter-parameter alkali teraktif optimum telah dikenalpasti. Parameter-parameter ini termasuk kepekatan Sodium Hidroksida (kemolaran), nisbah pepejal kepada cecair (S/L) dan nisbah Sodium Silika kepada Sodium Hidroksida (SS/SH). Peranan rejim pengawetan dan kesannya terhadap alkali teraktif POFA telah dikaji dengan menggunakan suhu ambien and suhu yang berlainan. GGBS telah diperkenalkan sebagai gantian separa POFA sebanyak lima peratus (10-50%) untuk mengkaji peranan ion-ion kalsium dan mekanisma-mekanisma untuk memperbaiki kapasiti beban tahan galas gel yang terbentuk kepada pengikat geopolimer berkekuatan tinggi. Penghasilan mortar geopolimer berkekuatan tinggi pada yang terawet pada suhu ambien mulanya disasarkan dengan menggunakan parameter-parameter pengaktifan dengan aras-aras gantian GGBS yang sama seperti dalam adunan. Ketahanlasakan pengikat alkali teraktif yang dicadangkan telah dikaji selepas pendedahan mortar tersebut kepada sekitaran melampau seperti suhu ternaik dan serangan sulfat. Ujian kekuatan mampatan, ujian-ujian kimia dan mikrostruktur seperti XRD, SEM/EDX, TGA/DTG, DSC dan FTIR telah dijalankan untuk mengkaji mekanisma-mekanisma di sebalik perkembangan kekuatan. Hasil keputusan telah menunjukkan bahwa cecair Sodium Hidroksida pada kemolaran 12, nibah S/L pada 1.32 dan nisbah SS/SH pada 2.5 telah digunakan untuk aktif alkali 100% POFA dan menghasilkan 32.84 MPa kekuatan mampatan pada hari ke-28. Satu penemuan utama telah mengenalpasti struktur gel yang dominan – gel Kalsium Silika Terhidrat gel (C-S-H) – sebagai fasa pengikatan yang terhasil daripada 100% POFA alkali teraktif; lebih-lebih lagi tiada Kalsium Hidroksida $Ca(OH)_2$ telah dikesan di dalam sistem.

Keputusan ujian menunjukkan 100% POFA adunan geopolimer boleh set dan menhgeras pada suhu ambien dengan perbandingan kekuatan mampatan dengan sampel-sampel yang diawet di dalam ketuhar. Ion-ion kalsium terlarut daripada GGBS yang terlibat dalam peningkatan kekuatan pengikat dengan pembentukan lebih banyak gel C-S-H. Ion-ion Aluminium yang juga terhasil daripada GGBS membawa kepada tahap yang lebih tinggi polimerisasi dan tahap sambung-silang yang ketara di antara rantaian C-S-H beralih kepada gel C-(A)-S-H. Kekuatan mampatan pada adunan geopolimer binari adalah 78.12 MPa pada umur ke-28 hari.

Pengikat geopolimer yang terhasil daripada 100% POFA alkali teraktif sebagai bahan aluminosilikat sahaja dapat menghasilkan mortar geopolimer dengan kekuatan normal 33.91 MPa pada umur ke-28 hari. Kemasukan GGBS ke dalam POFA telah menunjukkan keberkesanan dalam penghasilan mortar geopolimer berkekuatan tinggi dengan kekuatan mampatan sebanyak 70.25 MPa telah tercapai pada umur ke-28 hari. Keputusan-keputusan daripada baki ujian mampatan pada suhu ternaik menunujukkan sampel-sampel mengekalkan kestabilan dimensi pada suhu-suhu ternaik disebabkan kehadiran laluan pemindahan yang sedia ada (sistem liang) dalam mortar di mana ia membenarkan air disejat. Tambahan pula, transisi kaca telah dikesan di antara 600 ºC dan 800 ºC yang menyediakan peningkatan relatif dalam kekuatan. Ujian-ujian menunjukkan bahawa mortar geopolimer yang dicadangkan lebih baik daripada mortar simen Portland apabila didedahkan kepada serangan sulfat. Keputusan menunjukkan walaupun Sodium Sulfat dan Magnesium Sulfat telah merosot kesan akibat penguraian ion-ion Si dan Ca daripada kedua-dua gel C-S-H dan C-A-S-H, geopolimer mortar dicadangkan mengalami susutan kekuatan di mana boleh dikaitkan dengan kehadiran Kalsium Hidroksida di dalam matriks.

Kata Kunci: POFA, pengikat Geopolimer, Simen Geopolimer, GGBS, Alkali teraktif, mortar geopolymer

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I certify that a Thesis Examination Committee has met on 30 March 2015 to conduct the final examination of Moslih Amer Salih on his thesis entitled "New Geo-Polymerization Process for High Strength Alkali-Activated Binder with Palm Oil Fuel Ash and Ground Granulated Blast Furnace Slag" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

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Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Dato Mohd Saleh bin Jaafar, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ratnasamy a/l Muniandy, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

John L. Provis, PhD
Professor
University of Sheffield
United Kingdom
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17 June 2015

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.

The members of the Supervisory Committee were as follows:

Abang Abdullah Abang Ali, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairperson)

Ramazan Demirboga, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Noor Azline Mohd. Nasir, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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Supervisory
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LIST OF ABBREVIATIONS AND ACRONYM

POFA	Palm oil fuel ash
GGBS	Ground granulated blast furnace slag
S/L	Solid to liquid ratio
SS/SH	Sodium silicate to sodium hydroxide ratio
SEM	Scanning Electron Microscope
EDX	Energy-dispersive X-Ray spectroscopy analysis
XRD	X-Ray Diffraction
TGA	Thermal Gravimetry Analyzer
DTG	Derivative Thermogravimetry
DSC	Differential Scanning Calorimetry
FTIR	Fourier Transform Infra-Red
C-S-H	Calcium Silicate Hydrate
C-A-S-H	Calcium Aluminate Silicate Hydrate

CHAPTER ONE

INTRODUCTION

1.1 Background

The development of alkali activated materials has been addressed by many researchers as a competitive friendly alternative to ordinary Portland cement (OPC) (Provis and Van Deventer, 2009; Provis and Van Deventer, 2014; Van Deventer et al., 2010; Li et al., 2010). Alkali activated binders are classified as the third generation cements in addition to lime and ordinary Portland cement (Shi et al., 2011; Li et al., 2010; Van Davidovits, 2011). The alkali activation process is gaining a great recognition and interest because of its low CO_2 emissions where carbon footprint is of concern (Provis, 2014a). Recently, scientific and technological development being made at a rapid pace due to their low energy consumption and qualities (Provis, 2014a; Villa et al., 2010; Provis et al., 2012; Chindaprasirt et al., 2007; Provis and Van Deventer, 2009). According to a recent rigorous and useful definition “Alkali activated materials are produced through the reaction of an aluminosilicate-normally supplied in powder form as an industrial by-product or other inexpensive martials-with an alkaline activator, which is usually a concentrated aqueous solution of alkali hydroxide, silicate, carbonate or sulfate” (Provis and Van Deventer, 2014; Provis, 2014a; Provis, 2009).

However, these materials, as new alternative binder to OPC in concrete technology, are still at the beginning stages of development and need more investigations related to the mechanisms of geopolymerization process (Pacheco-Torgal et al., 2012; Yip et al., 2008). The activation methods, the type and dosage of alkali activators, curing regime at the fresh state, and role of calcium in geopolymerization process are major factors and still subjects of discussions for the researchers in this field (Nath and Sarker, 2014; Nath and Kumar, 2013; Bernal et al., 2012; Bilim and Atiş, 2012; Yang et al., 2012a; Liew et al., 2012a; Somna et al., 2011; Hajimohammadi et al., 2011).

The alkali activation process for an aluminosilicate source involves different parameters. One of the governing factors on properties of the binding gel and its formation is the type and dosage of alkali activators (Juenger et al., 2011). It has been reported that different single activators were used in the activation process, such as sodium hydroxide and sodium silicate (Somna et al., 2011; Rashad and Zeedan, 2011). Combination of two different activators were also used in the alkali activation process by using different liquid solutions (Luo et al., 2012; Altan and Erdoğan, 2012).

So far, a mix of liquid sodium silicate which is known as water glass and liquid sodium hydroxide were the most used activating solutions in the geopolymers (Ryu et al., 2013). This combination of activators were reported to have better performance in the activation process comparing to single alkaline activators (Papa et al., 2014; Nath and Sarker, 2014). The alkali hydroxide is required for dissolution of aluminosilicate source while water glass solution acts as a binder, alkali activator and dispersant of plasticizer (Komnitsas and Zaharaki, 2007). So far, different approaches have been reported to measure the dosage of activators such as using sodium as a percentage of the source material, or adding the total activator as a percentage of the binder (Bernal et al., 2012; Bilim and Atiş, 2012; Yang et al., 2012a). Nevertheless, previous works have shown that solid to liquid (S/L) ratio and sodium silicate to sodium hydroxide (SS/SH) ratio have tremendous effect on mechanical properties (Palomo et al., 1999; Hardjito and Rangan, 2005a; Hardjito et al., 2004; Van Jaarsveld et al., 2002).

It has been reported that different factors affect the solid to liquid ratio and sodium silicate to sodium hydroxide ratio in the alkali activation process. Firstly the shape and particle size, and type of aluminosilicate precursor has an important effect on the required quantity of the activator by which results in advanced dissolution (Kong et al., 2007; Hardjito and Rangan, 2005a; Wang et al., 2005; Xu and Van Deventer, 2000b). The second factor affecting the geopolymerization process is the curing regime at the fresh state of activation. In most cases the curing for alkali activated materials is curried out at elevated temperatures ranging from 40 ºC to 90 ºC for a period of 4 to 48 hours which is a limiting factor in construction industry (Lemougna et al., 2013; Ryu et al., 2013; Rangan et al., 2005; Temuujin et al., 2009b). In order to overcome the liming factors in geopolymerization process such as low reactivity, low setting and slow strength development; calcium bearing materials or materials rich in calcium oxide like GGBS were used to alter the reactivity of aluminosilicate precursors (Oh et al., 2010; Guerrieri and Sanjayan, 2010; Yip et al., 2008; Nath and Sarker, 2014; Kumar et al., 2010).

So far, different types of aluminosilicate materials such as Metakaolin (Yunsheng et al., 2010; Liew et al., 2012b; Rashad, 2013; Pacheco-Torgal et al., 2011; Rovnaník, 2010), fly ash (Hardjito and Rangan, 2005b; Thomas et al., 2012; Provis et al., 2012) and slag (Němeček et al., 2011; Luo et al., 2012; Fu et al., 2011; Bernal et al., 2011; Bernal et al., 2010) were applied as alkali-activated cements.

Recently, researchers have incorporated palm oil fuel ash (POFA) as another potential aluminosilicate source that can be used as an alkali activated cement. POFA is an agro-waste produced in massive amounts from palm oil industry in South East Asia. POFA has been used with a low content in binary mixes with other aluminosilicate materials such as ground granulated blast furnace slag (GGBS), rice husk ash (RHA), and fly ash in order to produce geopolymer paste, mortar and concrete while curing at oven was the dominant regime in most of the studies.

This study intended to investigate the mechanisms by which calcium ions and aluminum ions participate in the system in order to produce a high strength binder at ambient temperature. It also studied the mechanism that governs the strength, chemical composition, and microstructural change in the matrix after exposure to elevated temperatures and sulfate attack.

1.2 Research Problem

The concept of alkali activated materials has been studied extensively as a promising alternative to ordinary Portland cement (Provis, 2014a). However, the alkali activated materials are still a complex class of binders (Provis and Van Deventer, 2009) and there is still an increasing interest to improve the properties and microstructure of the alkali activated binders. This is generated from the great need that is required to optimize the activation conditions in order to produce stronger, and more stable binder (Bernal et al., 2014).

Furthermore, results from recent studies on the activation methods that being used in alkali activation of different aluminosilicate sources have addressed the adverse effect of oven curing as the dominant regime by which the production will be limited in the real life situations comparing to Portland concrete.

There is also a consensus from some researchers regarding the use of Calcium bearing materials or Calcium rich materials in binders with low calcium intake which results in a better performance in terms of setting, hardening and also improving the load bearing capacity of the gel; however, the mechanism of Calcium ion coupled with Aluminum ion and their role in the system is still a complex subject.

Moreover, paucity has been noticed in the published studies and researches regarding the behavior and degradation mechanism of alkali activated materials when exposed to severe conditions such as heat exposure or sulfate attack. In this trend it is crucial to investigate the change in compressive strength mechanism after exposure to such environments.

Palm oil fuel ash (POFA) is one of the agricultural waste materials from the palm oil industry in South East Asia. Malaysia is considered as the leading and the largest producer of palm oil. It was estimated that only in Malaysia the wastes generated from palm oil industry is 24.99 million tons per year (Hosseini and Wahid, 2013). The huge amount of POFA is still a subject of wide criticisms and endless complaints because it poses health hazard leading to various health problems. POFA needs large area to be disposed which arising an environmental problem; in addition to the financial lost on transportation of the waste and allocating hectares of lands for disposal. So far, some studies have been conducted on low content POFA geopolymers although still a comprehensive study on activation parameters, curing regime, its underlying mechanism of geopolymerization, and its compatibility with other sources of aluminosilicate is indispensable.

Recently, palm oil fuel ash (POFA) has been recognized as an aluminosilicate material to be utilized in alkali activation technology. POFA was used as a supplementary material in mixes with other aluminosilicate materials to produce geopolymer cement paste, mortar and concrete. In all researches, a low content of POFA was kept to be mixed with slag, fly ash and rice husk ash or other aluminosilicate materials to alter POFA and increase its reactivity. Moreover, oven curing was associated to the production process. Still, no study investigated the activation mechanism and the microstructure of the resulted geopolymer binder from the activation of POFA as the only aluminosilicate material source. Moreover, no study investigated the potential of high volume of POFA to be activated with GGBS to produce high strength Geo-polymerized paste and mortar at ambient temperatures.

1.3 Hypothesis of the Research

The hypothesis that this study was built on is the role of calcium ions provided by GGBS in developing the chemical composition and the microstructure of the gel. The abundant quantity of calcium ions has the ability to develop the load bearing capacity of the formed binding phase of POFA. This will lead to enhance the compressive strength of the geopolymer binder to higher strength. Furthermore, Calcium ions will participate in changing the setting and the hardening of the developed binder to ambient temperature. In other words, calcium ions will develop the binding phase structure to be stronger and eliminate the need for higher temperature for curing and hardening.

1.4 Research Objectives

The main aim of this research was to study the ability of alkali activated materials to produce high strength binder at ambient temperature from high volume POFA blended with GGBS. This was assimilated by studying the mechanical and microstructural properties of alkali activated paste and mortar through the following four objectives:

1. To identify activation parameters, Sodium Hydroxide concentration (Molarity), Solid to Liquid ratio (S/L) and Sodium Silicate to Sodium Hydroxide ratio (SS/SH) in production of a geopolymer binder with POFA as a single aluminosilicate source.
2. To investigate the appropriate curing temperature in geopolymerization of 100% POFA.
3. To investigate the production of high strength geopolymer binder by using binary mixing of GGBS and POFA.
4. To assess the durability performance of the proposed geopolymer mortar when exposed to elevated temperatures and sulfate attack.

1.5 Research Questions

This study focused on the compressive strength, microstructural, chemical and thermal characteristics of POFA geopolymer paste and POFA geopolymer mortar produced from a binary mixture of POFA and GGBS in order to answer the following questions:

- How do the solid to liquid ratio and sodium silicate to sodium hydroxide ratio affect the geopolymerization process?
- What is the mechanism by which calcium ions available in the aluminosilicate material affect geopolymerization process and help the geopolymer binder to set at ambient temperature and produce high strength binder and high strength mortar?
- How do thermal and microstructural analysis differentiate between C-S-H and C-A-S-H as the main binding phases in alkali activated materials?
- How do elevated temperatures and sulfate attack deteriorate the C-S-H, and C-A-S-H in mortar?

1.6 Research Contribution

Palm oil fuel ash (POFA) is designated with a moderate content of silicate and a low content of aluminum which reportedly can produce a low strength geopolymer binder (less than 18 MPa) when POFA is the only alkali activated material. In the same time oven curing at 65 ºC to 75 ºC for 24 hours was associated as a curing regime in the production process of this binder.

The aim of this study is to produce a high strength geopolymer binder using high volume of palm oil fuel ash at ambient temperature. This study exploits the role of calcium ions coupled with aluminum ions provided by GGBS to investigate the mechanisms by which the strength of binding phase can be improved and allow to the binder to harden without oven curing. Investigating the degradation mechanisms governing the alkali activated mortar after exposure to elevated temperatures and sulfate attack is another major contribution of the present study.

1.7 Significance of the Study

The overarching purpose of this study is to activate POFA albeit its very low content of aluminum. The finding of this research will also explain the mechanism by which aluminosilicate with low aluminum content are involved in the geopolymerization process. Also, the results of this study may encourage and promote further research on the use of POFA in geopolymer technology in mortar and concrete as well as the use of other aluminosilicate materials with low aluminum content which will ultimately lead to development of more environmentally friendly products with low energy consumption and very low CO_2 emissions.

Furthermore, there is no comprehensive study on the effect of curing temperature on alkali activation of mixes with 100% POFA. So, the other purpose of this study is to investigate the microstructure and chemical composition of POFA geopolymer paste binder cured at ambient temperature (25-30) ºC and oven cured at 60 ºC, 70 ºC, and 80 ºC. This study proposes the applicability of ambient temperature as a curing regime in POFA geopolymer binders. Investigating the use of ambient temperature to produce a geopolymer binder from agro waste materials such as POFA will contribute to a development of mix design to be used in structural sector. It can lower the cost and energy consumption; meanwhile enhances construction pace.

Moreover, ground granulated blast furnace slag was used as a partial replacement of POFA in order to enhance the load bearing quality (capacity) of the binder. The purpose is to produce high strength binder as an alternative to ordinary Portland cement in high strength concrete using ambient temperature curing regime. The finding of this work may facilitate the development of high strength geopolymer concrete using higher calcium alkali activated materials at ambient temperature.

The last but not least, this study investigates the durability of alkali activated binder using the binary mix of POFA and GGBS after exposure to severe environment namely elevated temperatures and sulfate attack. The findings of this study assess the acceptability of the binder in terms of durability and also clarify on the deterioration mechanism.

1.8 Scope and limitations of the study

The main purpose of this study is to investigate new geopolymerization process to produce high strength alkali activated binder from high volume of POFA cured at ambient temperature. In order to achieve the established objectives, the scope and limitations of this study are summarized as follows:

In this study, activation parameters are limited to Sodium Hydroxide concentration (NaOH molarity), Solid to Liquid ratio (S/L), and Sodium Silicate to Sodium Hydroxide ratio (SS/SH). Furthermore, a combination of liquid Sodium Silicate (Na_2SiO_3) mixed with liquid Sodium Hydroxide (NaOH) was chosen as alkaline activators and represented by SS/SH ratio. As for the curing regime only for temperatures were assigned in the second objective which are namely; ambient temperature at (25-30) ºC, and oven curing at three different temperatures of 60 ºC, 70 ºC, and 80 ºC. In order to study the effect of Ca ions and to develop a high strength binder, GGBS was chosen and replaced with POFA at different levels of 10%, 20%, 30%, 40% and 50%.

The durability of geopolymer mortar produced from 100% POFA and POFA-GGBS geopolymerized mortar was limited to the performance of the geopolymerised mortar at elevated temperatures and in sulfate environments. The heat exposure was for one hour within the rates of 100 ºC, 200 ºC, 300 ºC, 400 ºC, 500 ºC, 600 ºC, 700 ºC, and 800 ºC. Furthermore; the durability of geopolymer mortar were investigated by exposing the mortars to Sodium sulfate and Magnesium sulfate. Geopolymer mortars were exposed for 6 months to three different concentrations 3%, 5%, and 8%.
All the tests were conducted on geopolymer paste and mortars and aggregate with size bigger than 4.75 mm were excluded from this study in order to eliminate the effect of the volume concentration factor in the matrix and to minimize the effect of the thermal conductivity and specific heat of the resulted matrix.

In this study, X-Ray fluorescence spectrometry scanning (XRF), setting time, flow table test, compressive strength, X-Ray diffraction (XRD), Scanning Electron Microscope (SEM) coupled with Energy-dispersive X-Ray spectroscopy analysis (EDX), Thermogravimetric Analysis/Derivative Thermogravimetric Analysis (TGA/DTG), Differential scanning calorimetry (DSC), and Fourier transform Infra-Red (FTIR) were the main tests conducted to trace properties of the materials before and after alkali activation in geopolymer paste and mortar.

1.9 Thesis Layout

In this study, an experimental work has been carried out to achieve the required objectives. The work presented in this thesis is spread across five chapters.

Chapter one includes a general introduction about the alkali activated materials and geopolymer technology as an alternative binder to ordinary Portland cement. The studied objectives were illustrated in general in this chapter. Chapter two initially illustrated the definition of alkali activated materials and the term geopolymer. History, geopolymerization mechanisms, activation methods, activators, aluminosilicate materials and tests that have been used in this technology were all illustrated. Chapter two is considered as a reference that can give all the required information and details about alkali activation technology and geopolymers. Figures and images were used to explain the way that the required tests were used in identifying the changes before and after alkali activation, and the changes in the paste and mortar with different parameters in the study. In chapter three, the methodology that used in the experimental work was illustrated. This chapter showed the applied method for alkali activation; moreover, the approach as a step by step method that being used to identify the required parameters in alkali activation of an aluminosilicate material. The designed methodology is considered as a reference for studying the alkali activation for any aluminosilicate precursor. Chapter four discussed the test results for the used method in alkali activation of POFA and POFA blended with GGBS. This chapter tended to introduce the most effective parameters in the activation process. The behavior of POFA geopolymer mortar and POFA blended with GGBS geopolymer mortar after exposure to elevated temperatures and sulfate attack was also discussed. Chapter five illustrated the conclusions of the study and recommendations for further research.

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