DURABILITY PERFORMANCE OF TERNARY BLEND ALKALI ACTIVATED MORTARS FOR CONCRETE SURFACE DAMAGE REPAIR

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My mother, whose sacrifice;
My father, whose dream;
My **Brothers and sisters**, whose support and encouragement;
And
My wife, whose patience;
Lead to achieve my doctoral degree

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ABSTRACT

The progressive deterioration of concrete surface structures being the major concern in construction engineering requires special protection and precise repairing. The adverse physical, chemical, thermal and biological processes that cause such rapid decay need to be overcome. The durability of concrete structure is found to be strongly influenced by inappropriate use of materials as well as their physical and chemical condition of the surroundings. The immediate consequence is the anticipated need of maintenance and execution of repairs. Lately, many alkalis activated mortars are synthesized by selectively combining some waste materials containing alumina and silica compounds which are further activated via strong alkaline solution. Despite the emergence of various alkalis activated as prospective material toward emergency repairs and coating, a functional alkali activated with efficient repairing attributes and endurance is far from being achieved. Generally, the alkaline solution prepared by mixing concentrated sodium silicate and sodium hydroxide restrict the broad array of repairing applications of alkalis activated mortar. Furthermore, they are not only expensive and hazardous to the workers but negatively impact the environment. The research attempted to produce environmental friendly alkali activated by blending different ratios of sodium hydroxide and sodium silicate at low concentration. Durability and mechanical strength of the synthesized ternary blend alkalis activated mortars were evaluated to inspect their repairing effectiveness towards concrete surface damage. Tests were performed for determining the porosity, shrinkage, compressive strength and slant bond shear strength. Microstructures and thermal properties were evaluated using XRD, SEM, TGA, DTG and FTIR measurements. The prepared ternary blend contained the ground blast furnace slag, fly ash and palm oil fuel ash or ceramic waste powder. The prepared fresh, hardened and durable mortars were activated with affable alkaline solution (at low concentration) of sodium hydroxide and sodium silicate. The ground blast furnace slag that acted as the main resource of Ca^{++} was used to replace the low amount of Na^{+} in the geopolymerization process. The amount of slag in the blend varied in the range of 20 - 70%. The addition of slag to the blend had improved the strength and durability properties as well the microstructure characteristics. This improvement is majorly attributed to the participation of calcium silicate hydrate and calcium aluminosilicate hydrate beside sodium aluminosilicate hydrate bonds in reaction products. The results revealed that all the prepared mixes developed appreciable strength under mild alkaline solution. Furthermore, the alkali activated specimens prepared with high slag content displayed good durability including abrasion, thawing-freezing and shrinkage. The research has established that the ternary blend alkalis activated mortars with friendly alkaline solution contributes towards the development of high strength and durable repairing materials for concrete structures.

ABSTRAK

Kerosakan progresif struktur permukaan konkrit limpah merupakan masalah utama dalam bidang kejuruteraan pembinaan dan masalah ini memerlukan perlindungan khas dan pembaikan pulih. Kesan negatif fizikal, kimia, perubahan suhu dan biologi menyebabkan kerosakan yang cepat dan perlu diatasi dengan segera. Jangka panjang ketahanan struktur konkrit didapati dipengaruhi oleh penggunaan bahan serta keadaan fizikal dan kimia persekitaran. Sejak kebelakangan ini, banyak mortar berakali teraktif telah disintesis dengan menggabungkan beberapa bahan buangan yang mengandungi sebatian alumina dan silika yang seterusnya diaktifkan melalui larutan alkali yang kuat. Meskipun terdapat pelbagai alkali teraktif sebagai bahan untuk pembaikan pulih lapisan konkrit, namun, alkali teraktif yang mempunyai sifat-sifat pembaikan pulih yang cekap dan berketahanan tinggi masih belum dapat dihasilkan. Umumnya, larutan alkali yang disediakan dengan mencampurkan sebatian pekat silikat natrium dan sodium hidroksida mampu membaiki aplikasi mortar berakali teraktif dengan meluas. Di samping itu, sebatian ini bukan sahaja mahal dan berbahaya kepada pekerja tetapi memberi kesan negatif kepada alam sekitar. Kajian ini mengambil usaha untuk menghasilkan alkali teraktif yang mesra alam dengan menggabungkan nisbah natrium hidroksida dan natrium silikat yang berbeza pada kepekatan yang rendah. Ketahanan dan kekuatan mekanikal mortar berakali teraktif yang telah disentisis melalui pelbagai gabungan sebatian tersebut telah diuji untuk menilai keberkesanan pembaikan pulih kerosakan permukaan konkrit. Ujian dilaksanakan bagi menentukan keliangan, pengecutan, mampatan dan kekuatan ricihan condong. Mikrostruktur dan sifat haba pula dinilai dengan menggunakan ukuran XRD, SEM, TGA, DTG dan FTIR. Sebatian ternar yang disediakan mengandungi galian sanga relau bagas, abu terbang dan abu bahan bakar kelapa sawit atau serbuk sisa seramik. Mortar yang baharu, terkeras dan tahan lasak kemudiannya diaktifkan dengan larutan alkali (pada kepekatan rendah) natrium hidroksida dan natrium silikat. Galian sanga relau bagas sebagai sumber utama Ca^{++} telah digunakan untuk menggantikan Na^{+} dalam proses geopolimerisasi. Jumlah sanga dalam campuran dikekalkan dalam lingkungan 20% hingga 70%. Penambahan sanga keatas campuran telah meningkatkan ciri-ciri kekuatan dan ketahanan serta sifat mikrostruktur. Kesan peningkatan ini disebabkan oleh hasil tindak balas campuran sebatian kalsium silikat hidrat dan kalsium aluminosilikat hidrat dan natrium aluminosilikat. Hasil kajian menunjukkan bahawa semua campuran meningkatkan kekuatan ketara di bawah larutan alkali yang sederhana. Tambahan pula, spesimen alkali teraktif yang disediakan dengan kandungan sanga tinggi memaparkan ketahanan tinggi termasuk lelasan, pencairan-pembekuan dan pengecutan. Kajian ini membuktikan bahawa pelbagai campuran mortar berakali teraktif sebatian tenar yang dihasilkan dengan larutan alkali yang sederhana boleh menyumbang ke arah pembangunan bahan-bahan pembaikan pulih struktur konkrit yang mempunyai kekuatan yang tinggi dan tahan lama.

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LIST OF ABBREVIATIONS

ASTM - American Society for Testing and Materials
BET - Brunauer Emmett Teller
BS - British Standard
CWP - Waste Ceramic Materials
DTA - Differential Thermal Analysis
Eq - Equation
FA - Fly Ash
FTIR - Fourier Transformed Intrared
GBFS - Ground Granulated Blast Furnace Slag
GP - Geopolymer
IS - Indian Standards
LOI - Loss on Ignition
MK - Metakaolin
MOE - Modulus of Elasticity
Ms - Silica Modulus
NC - Concrete Substrate
NH - Sodium Hydroxide Solution
NHNS - Sodium Hydroxide and Sodium Silicate Solution
NS - Sodium Silicate
OPC - Ordinary Portland Cement
POFA - Palm Oil Fuel Ash
RHS - Rice Husk Ash
SEM - Scanning Electron Micrograph
TGA - Thermogravimetry Analysis
UPV - Ultrasonic Pulse Velocity
XRD - X-Ray Diffraction
XRF - X-Ray Fluorescenc

LIST OF SYMBOLS

A - Cross section area of specimen

Al - Alumina

Al_2O_3 - Aluminium oxide

B - Binder

B:A - Binder to aggregate ratio

Ca - Calcium

$Ca(OH)_2$ - Calcium hydroxide

CaO - Calcium oxide

$CaO:SiO_2$ - Calcium to silicate ratio

C-A-S-H - Calcium aluminium silicate hydrate

C-A-S-H - Calcium aluminium silicate hydrate

CO_2 - Carbon dioxide

C-S-H - Calcium silicate hydrate

fb - Bond strength

fc - Compressive strength

Fe - Iron

Fs - Flexural strength

Ft - Tensile strength

H_2SO_4 - Sulphuric acid

Hrs - Hours

KOH - Potassium hydroxide

$MgSO_4$ - Magnesium sulphate

MPa - Mega pascal

NaOH - Sodium hydroxide

Na_2O - Sodium oxide

Na_2SO_3 - Sodium silicate

NH:NS	-	Sodium hydroxide to sodium silicate ratio
P	-	Porosity
PSA	-	Particles size analysis
S:B	-	Solution to binder ratio
Si	-	Silicon
SiO_2	-	Silicate oxide
$SiO_2:Al_2O_3$	-	Silicate to aluminium ratio
Θ	-	Theta

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Over the years, Ordinary Portland Cement (OPC) has been widely employed as concrete binder and various building substances worldwide. It is known that, large scale manufacturing of OPC causes serious pollution in the environment in terms of considerable amount of greenhouse gases emission (Duxson *et al.*, 2007c; Rashad *et al.*, 2013). The OPC production alone is accountable for nearly 6 to 7% of total CO_2 emissions as estimated by International Energy Agency (IEA) (Palomo *et al.*, 2011). In fact, among all the greenhouse gases approximately 65% of the global warming is ascribed to the CO_2 emission. It was predicted that the mean temperature of globe could raise by approximately 1.4–5.8 °C over the next 100 years (Rehan and Nehdi, 2005). Globally, in the present backdrop of CO_2 emissions mediated climate change, the sea level is expected to rise and the frequent occurrence of natural disasters will cause huge economic loss (Stern, 2007). On top, the emitted greenhouse gases such as CO_2, SO_3 and NO_X from the cement manufacturing industries can cause acid rain and damage the soil fertility (Zhang *et al.*, 2011). Generally, the industrial consumption of raw materials is around 1.5 tonnes per each tonne of OPC production (Rashad, 2013b). To surmount such problems, both scientists, engineers and industrial personnel have been continuously dedicating many efforts to develop novel construction materials to achieve alternate binders (Rashad, 2013a).

The term ‘‘geopolymers’’ was coined by Joseph Davidovits in 1972 (Komnitsas and Zaharaki, 2007) to describe the zeolite like polymers. Geopolymers that are being commonly synthesized by activating slag, fly ash (FA), calcined clay and other aluminosilicate materials using alkali have been realized as promising alternative binders. Geopolymers are the alumino-silicate polymers which consist of three dimensional amorphous structures formed due to the geopolymerization of alumino-silicate monomers in alkaline solution (Rowles and O'connor, 2003). In the past, intensive studies have been carried out on calcined clays (metakaolin) or industrial wastes such as FA, palm oil fuel ash and slag (Chang, 2003; Kong *et al.*, 2007; Temuujin *et al.*, 2010b). Yet, the complex process so called geopolymerization is not fully understood (Yao *et al.*, 2009). Davidovits proposed a reaction pathway involving the polycondensation of orthosialiate ions (hypothetical monomer) (Provis *et al.*, 2005). The mechanism of geopolymerization process (Dimas *et al.*, 2009) is based on three steps: (i) dissolution in alkaline solution, (ii) reorganization and diffusion of dissolved ions with the formation of small coagulated structures and (iii) polycondensation of soluble species to form hydrated products. In recent years the name of alkali-activated has been used to replace the geopolymer name for a matrix using calcium in geopolymerization process.

Compared to OPC, alkali activated mortars are well-known for their excellent properties such as high compressive strength (Burciaga-Díaz *et al.*, 2013; Zhang *et al.*, 2010a), low shrinkage (Chi *et al.*, 2012; Zhang *et al.*, 2010a), acid resistance (Palomo *et al.*, 1999), fire resistance, devoid of toxic fumes emission (Duxson *et al.*, 2007c), low thermal conductivity (Zhang *et al.*, 2010a), excellent heavy metal immobilization, high temperature stability (Yao *et al.*, 2009), low manufacturing energy consumption for construction purposes and several engineering applications (Zhang *et al.*, 2010a). Owing to these distinctive features, Geopolymers are potentially being used in construction engineering, fire proof, biomaterials and waste treatment (Davidovits, 2002; Yao *et al.*, 2009). New applications including the use of Geopolymer as concrete repair material is under in-depth exploration.

In recent times, use of the alkali activated mortar as surface concrete repair materials has generated renewed research interests (Balaguru, 1998; Zhang *et al.*, 2012; Zhang *et al.*, 2010b). In the exploitation of the alkali activated mortar as repair material, the bond strength between the substrate concrete and the repair material (Geissert *et al.*, 1999b; Momayez *et al.*, 2005) plays a decisive role. Alkali activated mortar is compatible with Portland cement concrete because of the close match of various properties such as the modulus of elasticity, Poisson's ratio, and the tensile strength (Hardjito *et al.*, 2005). Furthermore, alkali activated mortar can also cure at ambient temperature as conventional concrete (Nath and Sarker, 2015). All these merits make alkali activated mortar an excellent candidate for surface concrete repair. Despite much research, the durability of these applications has not been evaluated comprehensively.

Commercial repair materials due to their good mechanical properties and bonding strengths are generally used for the repair work in concrete (Mirza *et al.*, 2014). However, they are rather expensive. Thus, less expensive alternative repair materials with comparable properties are needed. Constant research efforts are made (Hu *et al.*, 2008; Pacheco-Torgal *et al.*, 2008a; Suksiripattanapong *et al.*, 2015) to utilize alkali activated mortar as repair material, where tests are performed to determine their slant shear, pull-out, direct shear and bond strength between mortar substrate and alkali activated mortars. Interestingly, alkali activated mortar exhibits higher bonding strength than that of Portland cement mixture. Pacheco-Torgal et al. (2008a) determined the bond strength between concrete substrate and alkali activated mortar produced from tungsten mine waste containing calcium hydroxide. They found that Alkali activated binders have very high bond strength even at an early age as compared to commercial repair products. Suksiripattanapong et al. (2015) tested the bond strength between rebar and concrete substrate using geopolymer paste as the bonding agent. They reported that the bond strengths of rice husk ash and silica fume geopolymer paste are approximately 1.5 times higher than epoxies. Consequently, the occurrence of sufficiently high bond strength of geopolymer materials made them suitable alternative bonding material for repairing.

1.2 Study Background

The surfaces of concrete structures such as sidewalks, pavements, parking decks, bridges, runways, canals, dykes, dams, spillways. to cite a few deteriorate progressively due to varieties of physical, chemical, thermal and biological processes. Actually, the durability of concrete structure is strongly influenced by the inappropriate use of materials, physical and chemical conditioning of the surroundings. The immediate consequence is the anticipated need of maintenance and execution of repairs (Alanazi *et al.*, 2016). For the repair and maintenance, several expensive surface repair mortars are easily available commercially. They are constantly being used without prior laboratory testing. Earlier, many materials including cement mortars, polymer-modified cement-based mortars containing styrene butadiene rubber (SBR) and acrylics, sand epoxy mortars and emulsified epoxy mortars, have been developed to repair the damaged concrete surfaces. These repair materials are often sold in the market with the promise of achieving wonderful results (Pacheco-Torgal *et al.*, 2014).

Information on most of these commercially available products has always been inadequate and thus the manufacturers are unable to supply specific data on these mortars' resistance to the harsh conditions exist in many parts of the globe. Even though some data on the performance of these repair materials are provided by the suppliers and the manufacturers, the values are generally given based on the laboratory ambient temperature of 21±1 ^{o}C. Insufficient evaluation work on the important laboratory or field has ever been made public to determine the effectiveness of these repair materials, especially at severe hot and cold climatic conditions. Further, the practising engineers find difficulties to select the right product for the particular repairing purpose. Certainly, there is a need to select appropriate materials for repairing the deteriorated concrete surfaces of various structures.

It is worth noting that millions of tons of natural, industrial and agriculture wastes such as FA, coal and oil-burning by-products, bottom ash, palm-oil fuel ash (POFA), rice-husk ash, bagasse ash, used tires, cement dust, stone crushers dust, marble dust, waste ceramic materials (CWP), silica fume, are wasted every year in Malaysia. These waste materials cause severe environmental problems like air pollution and leaching of toxic chemicals. Several studies revealed that many of these wastes can be used successfully in all kinds of new concrete structures by replacing cement (sometimes up to 70%) (Lim *et al.*, 2015). Moreover, these newly developed concrete can provide environmentally safe, stable, more durable and low cost green construction materials. Yet, development of different Alkali activated mortars containing these wastes which can be used as repair materials, especially for deteriorated concrete surfaces are rarely explored.

As aforementioned, geopolymerization is a complex and important process in the alkali activated industry, where high pH alkaline solution that is used to dissolute the aluminosilicates is still to be clarified. The term “alkali activator solution” is used for a combination of a silica-rich solutions (e.g. sodium or potassium silicate) and highly concentrated alkali solutions (e.g. sodium or potassium hydroxide) with certain weight ratios. Such combination is used to dissolve the alumina-silicate from pozzolanic waste materials for building the amorphous structure of Alkali activated. An increase in the ratio of silica-rich solution to alkali solution enhances the possibility of geopolymerization because of high amount of SiO_2. For various aluminosilicate sources, it has been authenticated that availability of SiO_2 is a key factor to determine mechanism of geopolymerization (De Vargas *et al.*, 2011).

Even though the knowledge regarding the mechanisms that control the alkali activation process is considerably advanced but many things need further investigations. The study of alkali activation of aluminosilicates is a relatively a new research domain as compared to traditional Portland cement-based systems. Alkali-activated aluminosilicates are differentiated from hydrated Portland cements by their higher initial alkalinity and the absence of lime. This is quite different hydration products from the diverse systems. Thus, the predictions on the properties of alkali-activated aluminosilicates that are made based on Portland cement chemistry remain inappropriate. Whereas the main binding phase of hydrated Portland cement is an aluminate substituted calcium silicate hydrate (C-(A)-S-H) gel and the main product in alkali activated systems is sodium aluminosilicate hydrate gel designated (N-A-S-H). Thus, it is significant to determine the detail mechanism of (N-A-S-H) formation.

Recent research indicated that the amount of calcium content in the FA have significant impact on the resultant hardened geopolymer. Most of the earlier studies revealed promising results (Phoo-ngernkham *et al.*, 2015b). Calcium oxide is believed to form calcium silicate hydrate (C-S-H) together with the aluminosilicate geopolymer gel. Main challenge for wide application of aluminosilicate materials based geopolymer is the requirement of curing at elevated temperature. Earlier, researchers have attempted to enhance the reactivity of these materials by adding some calcium containing substances (Al-Majidi *et al.*, 2016). The addition of calcium oxide (CaO) allowed forming the hydrated products such as C-S-H together with the alumino-silicate geopolymer network. The amount of CaO content of the precursor materials is found to have considerable influence on the resultant hardened geopolymer. Meanwhile, an increase in the strength and a decrease in the setting time are observed with increasing CaO content.

The compatibility of the two cementitious gels so called C-(A)-S-H and N-A-S-H has important implications for hybrid Portland cement as well alkali activated aluminosilicate systems, where both products might be expected (Yip *et al.*, 2005). Previous studies used the synthetic gels to determine the effects of the constituents of each gel on the other such as the high pH conditions. The presence of aqueous aluminate is found to strongly influence C-S-H composition and structure (Garcia-Lodeiro *et al.*, 2011). Besides, the aqueous Ca modified the N-A-S-H gels and led to a partial replacement of sodium with calcium to form C-A-S-H and N-A-S-H gels (Garcia-Lodeiro *et al.*, 2011) as explained using the following reactions. Despite these observations, the conditions required for such modifications have not been fully defined. Furthermore, to explore the possibility of constructional cements having both gels co-existing, a systematic study of N-A-S-H and C-A-S-H compatibility seems essential. The process of producing the C-S-H, C-A-S-H and N-A-S-H gels has been explained in equation (1.1 to 1.6).

$$SiO_2 + Al_2O_3 + OH^- \rightarrow SiO_2(OH)_2^{-2} \text{ or } SiO_2(OH)_2^{-1} + Al(OH)_4^{-1} \quad (1.1)$$

$$CaO + H_2O \rightarrow Ca^{+2} + OH^- \quad (1.2)$$

$$Ca^{+2} + SiO_2(OH)_2^{-2} \text{ or } SiO_2(OH)_2^{-1} + Al(OH)_4^{-1} \rightarrow \text{C-A-S-H}_{gel} \quad (1.3)$$

$Ca^{+2} + 2(OH^-) + SiO_2 \rightarrow C\text{-}S\text{-}H_{gel}$ (1.4)

$Ca^{+2} + 2(OH^-) + Al_2O_3 \rightarrow C\text{-}A\text{-}H_{gel}$ (1.5)

$Na^{+1} + SiO_2(OH)_2^{-2}$ or $SiO_2(OH)_2^{-1} + Al(OH)_4^{-1} \rightarrow N\text{-}A\text{-}S\text{-}H_{gel}$ (1.6)

1.3 Problem Statements

Most of the commercial repair materials owing to their low durability and sustainability perform poorly under severe hot and cold climatic conditions. Although few epoxy repair materials display good performance but they are somewhat costly. Geopolymer prepared from the waste materials with high content of aluminium-silicate and alkaline activator solution has emerged as a leading repair material. Geopolymeric binders are preferred because they generate 70-80% lesser CO_2 with remarkably reduced greenhouse gas emissions than Portland cement. However, new binders are prerequisite for enhanced durability performance, better sustainability, reduced cost and environmental affability.

Currently, intensive researches on the alkali activated mortar as emerging construction material have been undertaken, where most studies revealed that an elevated concentration of sodium hydroxide and high ratio of sodium silicate to sodium hydroxide ≥ 2.5 are preferred for the production of high performance alkali activated mortars. Sodium silicate is known to impact negatively on the environment. Besides additional cost, high concentration of sodium hydroxide has negative effect on the environment and remains hazardous to the workers. High molarity of sodium hydroxide and enriched sodium silicate in alkaline solution content are the major problems for the usage of alkali activated mortar as new construction materials, especially for repairing. This is a serious concern for the environmental safety because it is a mineral based material with relatively high demand for sodium silicate during synthesis. These deficiencies caused by alkaline solution limits the diversified use of geopolymer in the construction industry.

Several studies are carried out on the materials containing calcium compounds especially ground granulated blast furnace slag (GBFS). However, most of these studies used high volumes and concentrations of corrosive sodium silicate and/or sodium hydroxide to achieve geopolymer products, which posed health and safety issues of workers during handling. Davidovits et al. (Davidovits, 2013) proposed a user friendly method for geopolymer production to improve the strength, reduce the costs by avoiding thermal activation and promote an easier handling mechanism. So far, no studies are made on the mechanical performance of ‘user friendly’ alkali activated, only the mineralogical and microstructure analyses of the geopolymer cement paste have been conducted.

Pacheco-Torgal et al. (2008b) established two models of alkali-activated binding systems. First one is related to the alkali activation of Si + Ca systems including GBFS with mild alkaline media to form C-A-S-H gel as main product. Second model deals with the alkaline activation of Si + Al system such as FA and metakaolin that requires a medium with strong alkaline to form N-A-S-H gel as the main product. Therefore, potential production procedure of alkali activated mortar need to be developed where low alkaline solution concentration (low sodium hydroxide molarity and low amount of sodium silicate) must be used by combining the effect of slag, high alumium and silicate content materials including FA, POFA and CWP with varying ratios of $SiO_2:Al_2O_3$, $CaO:SiO_2$ and $CaO:Al_2O_3$. Consequently, the present study intends to develop an environmental friendly and low cost alkali activated mortar with broad arrays of applications in the construction industry.

1.4 Aim and Objectives of the Research

The aim of this study is to investigate the impact of GBFS on fresh, mechanical and durable properties of ternary blended alkali activated mortars containing FA and POFA or CWP activated with low concentration of sodium hydroxide and sodium silicate. Based on the aim of the study and the above mentioned problem statement the following objectives are set:

1. To characterize the microstructures, physical and chemical properties of FA, POFA, GBFS and CWP constituents to develop a mixture proportion of ternary blended alkali activated mortars with enhanced durability.
2. To determine the fresh and hardened properties of synthesized ternary blend alkali activated mortars.
3. To evaluate the durability performance of ternary-blend alkali activated mortars.
4. To compare the bonding properties of ternary blend alkali activated mortars with normal OPC mortar substrate.

1.5 Scopes of the Research

This research (experimental) focuses on the feasibility of achieving a new alkali activated mortars with improved mechanical properties and enhanced durability. This new ternary blend alkali activated mortars can be achieved by combining FA, GBFS and POFA or CWP with appropriate proportions. The effects of various concentration ratios of blends, molarities, on the durability and mechanical properties of synthesized alkali activated mortars are examined. Different tests are performed to characterize the prepared alkali activated mortars. Materials characterizations are performed in terms of physical properties, chemical properties and mineralogical compositions. To obtain the optimum ternary blend, tests on the properties of various ternary blended mixes are carried out with varying replacement levels, the minimum content of slag (kept up to 20% by weight) and constant alkaline solution binder ratio of 0.40. Molarity of sodium hydroxide and the ratio of sodium silicate to sodium hydroxide are kept constant of 4 M and 0.75, respectively. The properties considered are mortar flow as well as compressive strength, flexural strength and porosity after ambient-cured for up to 365 days. The achieved optimum multi blend is further used for detail investigations on fresh and hardened properties, microstructures and durability. In addition, different proportions of SiO_2:Al_2O_3, CaO:SiO_2 and CaO:Al_2O_3 are used for the production of optimum mortar.

In the fresh state, the setting times, standard consistency and flowablity of the optimized ternary blend are determined. Conversely, in the hardened state the compressive strength, splitting tensile, flexural, dry shrinkage, bond strength, microstructures and durability properties for up to 6 months are evaluated. The durability is assessed in terms of resistance of magnesium sulphate, sulphuric acid attack, freezing-thawing, abrasion-erosion resistance. Microstructure of alkali activated mortar is characterized using the Thermal Gravimetric Analysis (TGA), X-ray Diffraction (XRD), Fourier Transform Infrared (FTIR) and Scanning Electron Microscopy (SEM) measurements. The series of tests are conducted based on the procedures of British Standards (BS) and American Society for Teststing and Materials (ASTM). International Union of Laboratories and Experts in Construction Materials, Systems and Structures is adopted in reviewing the literature. As these methods are being well established has enabled a comparison with related studies with information on their precision known.

In addition to compressive strength and porosity, the amount of CaO is varied for assessing the microstructure of the optimized alkali activated mortars specimens in the hardened state. Meanwhile, residual compressive strength, residual mass and expansion are used as parameters for measuring the resistance of specimens to sulphuric acid, magnesium and sulphate attacks. All the results are analysed and presented in the form of graphs and output plots from the XRD, TGA, DTG, and FTIR tests. The findings are validated and compared with similar relevant existing studies whenever available in the literature.

1.6 Significance of the Research

As abovementioned, this research intends to generate new information on the use of ternay blend alkali activated mortars by means of systematic methods of sample preparation from waste materials economically, appropriate and careful materials characterizations, and subsequent data analyses useful for the development of standard specifications for ternary blend alkali activated mortars system for diversified practical applications. This generated knowledge is expected to contribute to the development of environmental friendly and inexpensive geopolymer material for wide range of applications in the construction industry. This would be greatly beneficial for sustainable development of Malaysia, where wastes disposal problems towards the land filling can be avoided and minimized. The outcome of the study is believed to provide the basis for further researches and better understanding of the behaviour of a ternary blend alkali activated mortar obtainable from the waste material in a cheap and environmental affable manner.

1.7 Thesis Organisation

Chapter 1 : renders a general background as well as concrete rationale for conducting this study. In addition, a brief explanation of the problem background by emphasizing the need of better repair materials and development of new alkali activated mortars, aims and objectives, scope and limitations, and importance of this study are depicted.

Chapter 2 comprehensively reviews the existing relevant literature and describes the properties of alkali activated mortar as well as pozzolanic materials. It also outlines the review of previous studies on used geopolymer mortars as repair material for fixing damaged concretes. Although, there few or no literature available on friendly alkali activated mortar using low molarity of sodium hydroxide and low content of sodium silicate as alkaline solution.

Chapter 3 emphasizes a comprehensive description of the materials and sample synthesis methods together with the test used for characterizing the samples. Basic principle of various tests is underscored useful for the evaluation of alkali activated mortars performance.

Chapter 4 highlights the physical and chemical characteristics of FA class F, POFA, GBFS and CWP. The outcomes on the optimization of ternary blend alkali activated mortar and the in-depth discussions are underlined.

Chapter 5 presents the significant experimental outcomes and discussions on the fresh and hardened properties of alkali activated mortar, where the microstructure properties of the optimized ternary blend alkali activated mortars are analysed and discussed. The results on the properties of alkali activated mortars studied in its fresh state are the workability/flow, and setting time. At the hardened state, the results on characteristics of alkali activated mortars presented are the compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity. A relationship between (SiO_2:Al_2O_3) and compressive strength of alkali activated mortar is established. Furthermore, SEM images and XRD spectra of the ternary blended alkali activated mortars revealing the microstructure is analyzed and the mechanisms of the formation is understood.

Chapter 6 depicts the results on porosity, chemical attack, freezing-thawing and abrasion-erosion resistance tests of the ternary blended alkali activated mortars.

Chapter 7 emphasizes the basic insight on the bond strength between conventional mortar and ternary blend alkali activated mortars. An evaluation of the durability of synthesized alkali activated mortars is presented. The applications of the achieved alkali activated mortars as repair material are assessed.

Chapter 8 concludes the thesis and makes some recommendations for further researches in ternary blend alkali activated mortars using waste materials.

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