DECEMBER 2016 M.Sc. in Civil Engineering ESAMADDIN MULAPEER

HASAN KALYONCU UNIVERSITY
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

STRENGTH AND ABSORPTION CHARACTERISTICS OF FLY ASH BASED GEOPOLYMER COMPOSITE REINFORCED WITH GLASS FIBER

M. Sc. THESIS
IN
CIVIL ENGINEERING

BY
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DECEMBER 2016

Strength and Absorption Characteristics of Fly Ash Based Geopolymer Composite Reinforced with Glass Fiber

M.Sc. Thesis

In

Civil Engineering

Hasan Kalyoncu University

Supervisor

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By

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December 2016

REPUBLIC OF TURKEY
HASAN KALYONCU UNIVERSITY
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: Strength and Absorption Characteristics of Fly Ash based Geopolymer Composite Reinforced with Glass Fiber

Name of the student: Esamaddin M. Saeed Mulapeer

Exam date: 02.12.2016

Approval of the Graduate School of Natural and Applied Sciences

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Esamaddin M. Saeed Mulapeer

ABSTRACT

STRENGTH AND ABSORPTION CHARACTERISTICS OF FLY ASH BASED GEOPOLYMER COMPOSITE REINFORCED WITH GLASS FIBER

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M.Sc. in Civil Engineering
Supervisor: Assoc. Prof. Dr. Kasım MERMERDAŞ
December 2016, 48 pages

This thesis presents results of an experimental program to determine mechanical properties of glass fiber reinforced geopolymer mortar which is a mixture of fly ash, alkaline liquids, fine aggregates, and glass fibers. The effects of inclusion of glass fibers on density, compressive strength, splitting tensile strength, absorption and sorptivity of hardened geopolymer mortar composite (GPMC) was studied. Alkaline liquid to fly ash ratio was fixed as 0.33. NaOH and Na_2SiO_3 solutions were used as alkaline liquids for activation of fly ash. The alkaline liquid combination ratios of 2.5 to 1 were accounted for Na_2SiO_3 solution and NaOH solution, respectively. Glass fiber was added to the mixes in 0.2%, 0.4%, 0.6%, 0.8%, 1.0% and 1.2% by volume of mortar. Curing regime of 48 hours with 60 ^{o}C temperature was applied. The experimental results indicated that inclusion of the glass fibers resulted in decrease of the workability but improvement in compressive strength, splitting tensile strength, of the fly ash based GPM with increased fiber content. However, inclusion of glass fiber did not indicate a remarkable change in the water absorption and sorptivity of the geopolymer mortars.

Keywords: Geopolymer, mortar, fly ash, alkaline solution, glass fiber, strength, absorption.

ÖZET

CAM ELYAF İLE TAKVİYELİ UÇUCU KÜL ESASLI JEOPOLİMER KOMPOZİTİNİN DAYANIM VE GEÇİRİMLİLİK ÖZELLİKLERİ

MULAPEER, Esamaddin M. Saeed
İnşaat Mühendisliği Yüksek Lisans Tezi
Danışman: Doç. Dr. Kasım MERMERDAŞ
Aralık 2016, 48 sayfa

Bu tez, uçucu kül, alkali sıvılar, ince agregalar ve cam elyafların bir karışımı olan cam elyaf takviyeli geopolimer harcının mekanik özelliklerini belirlemek için gerçekleştirilmiş olan deneysel bir çalışmanın sonuçlarını sunmaktadır. Cam elyafların geopolimer harçlarının yoğunluk, basınç dayanımı, yarmada çekme dayanımı, absorpsiyon ve kılcal su emmesi üzerine etkileri araştırılmıştır. Alkali sıvıların toplam miktarının uçucu küle oranı 0.33 olarak alınmıştır. Uçucu külün aktivasyonu için alkali sıvılar olarak NaOH ve Na_2SiO_3 çözeltileri kullanılmıştır. Na_2SiO_3 ve NaOH çözelti oranları olarak sırasıyla 2.5 ila 1 olarak alınmıştır. Karışımlara cam elyaf hacimce %0,2, %0,4, %0,6, % 0,8, %1,0 ve %1,2 oranlarında ilave edilmiştir. 60 °C sıcaklıkta 48 saatlik kür rejimi uygulandı. Deneysel sonuçlar, cam elyaflarının eklenmesinin, uçucu kül esaslı geopolimer harçlarının işlenebilirliğini azaltırken basınç dayanımı, yarmada çekme dayanımı değerlerinde iyileşme sağladığını göstermiştir. Bununla birlikte, cam elyafın kullanılması, geopolimer harçlarının su emme ve kılcallık değerlerinde belirgin bir değişime sebep olmamıştır.

Anahtar Kelimeler: Geopolimer, Harç, Uçucu Kül, Alkali çözelti, Cam elyaf, Dayanım, Su emme.

ACKNOWLEDGEMENT

My heartfelt and sincere thanks to the Almighty God "ALLAH" who granted me all these graces to fulfill this task and supported me in all my life.

First of all, I thank Assoc. prof. Dr. Kasım MERMERDAŞ, who offered me two years of supervision and guided me through the whole research and thesis writing process.

Special thanks are reserved for Assist. Prof. Dr. Volkan KALPAKCI and Assist. Prof. Dr. Hasan Selçuk SELEK for serving on the committee and their contributions and suggestions to improve the quality of the thesis.

It is a pleasure to express my deepest gratitude to Assist. Prof. Dr. Dia Eddin NASSANİ for advising throughout the present study.

Thank my wife Aveen Rafiq, who always helps and supports me in my research and life and also thank all my family members.

My special thanks are served for Ph.D. candidates Safie Oleiwi and Mohamed Moafak ARBILI and all my friends. Finally, I would like to express my sincere gratitude to anyone who helped me throughout the preparation of the thesis.

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LIST OF SYMBOLS/ABBREVIATIONS

ACI	American Concrete Institute
Al_2O_3	Alumina (Aluminum oxide)
FA	Fly Ash
GPC	Geopolymer Concrete
GPM	Geopolymer Mortar
CaO	Calcium oxide
CO_2	Carbon Dioxide
F	Maximum load
f_c	Concrete compressive strength
Fe_2O_3	Iron oxide
f_t	Concrete flexural strength
K_2O	Potassium oxide
KOH	Potassium hydroxide
M	Molar
MgO	Magnesium oxide
Na_2SiO_3	Sodium silicate
NaOH	Sodium Hydroxide
OPC	Ordinary Portland cement
P_2O_5	Phosphorus oxide
SiO_2	Silica (silicon oxide)
ASTM	American Society for Testing and Materials
w/c	Water cement ratio

CHAPTER 1

INTRODUCTION

1.1 General

Generally, development of the country depends on the infrastructure and in most infrastructure concrete plays a critical role. Hence, we cannot imagine any developments without concrete. Using concrete in infrastructure need more cement production. As reported by Palomo (1999) worldwide annual consumption of concrete is estimated to be about 18 billion tons by the year 2050. Portland cement production processes release a large quantity of carbon dioxide (CO_2) which significantly affects the greenhouse emissions. Manufacturing of One ton of cement contributes to producing nearly one ton of CO_2 (Shinde, 2015). McCaffrey (2002) estimated that the OPC production is rising at the rate of about 3% annually. The role of CO_2 is cognizable for around 65% of global warming (McCaffrey 2002). Concrete is a widely utilized construction material, and traditionally it is created using ordinary Portland cement as a primary binder material. Hence due to increasing order and usage of concrete, production of ordinary Portland cement also increased. Furthermore, in the manufacturing of cement CO_2 is emitted.

Hence, in order to produce environmentally friendly concrete, many materials and methods have been studied to find suitable materials to be utilized as a partial or complete alternative to Portland cement. Davidovits (1988) suggested that the waste materials or by product materials such as husk ash, slag or fly ash that contain of aluminum (Al) and silicon (Si) can be used with an alkaline to interact as a source material of geological root to produce binder. He named these binders as geopolymers. Another pozzolan such as blast furnace slag can be used to produce binder when activated using alkaline liquids. Therefore, total replacement of ordinary Portland cement can be considered (Palomo, 1999). Hence, it can be said that geopolymer concrete is a concrete which can be produced without Portland cement.

Further consideration of geopolymer is that it is an environmentally friendly material, and other properties could better compare with ordinary Portland cement concrete. Rangan and Sumajouw (2006) through the study of reinforced geopolymer concrete based with low FA columns and beams concluded that the produced geopolymer concrete has excellent durable properties. Also they reported that creep was low, drying shrinkage was very low, with good resistance to acid and very high resistance to sulphate attack. Another benefit of GC is the recycling of industrial waste materials which have a disposal problem. For example, FA is a byproduct material from combustion coal particularly in power plants that are widely available throughout the world.

In order to increase concrete structural integrity, and improve mechanical properties, fibrous materials are added to the concrete. Through the history to improve construction materials, horsehair was added to mortar, and mud to make bricks stronger. Fibers have been used as strengthening since antiquity, and the idea is not new (Mehta and Monteiro, 2006).

The idea of fiber reinforced concrete and composite materials came into being in the 1950s and was one of the interesting topics. (Mehta and Monteiro, 2006), From 1960 many researchers have studied the influence of using various fibers type (synthetic, glass and steel fibers) as strengthening in OPC concrete to observe effective of fibers on durability properties. Another researcher such as Choi and Yuan, Ghugal and Deshmukh, and Mehta and Monteiro, has investigated the influence of adding glass fibers to OPC concrete on strength properties of conventional OPC concrete. In a recent research by Nematollahi et al. (2013) investigated the influence of glass fiber addition on properties of hardened and fresh FA based GPC. For production of geopolymer concrete (GPC) a solution of 8M Na_2SiO_3 (71.4%) + NaOH (28.6%) and ratio SiO_2/Na_2O utilized was 2. Moreover, they used glass fibers in varying percentages; 0.50%, 0.75%, 1.00% and 1.25% by volume of concrete, and concluded that with an addition of glass fiber results increase of flexural strengths, compressive strength, and density with decreasing the workability.

Ghugal and Deshmukh (2006) studied the modified properties of structural concrete by evaluating the results of experimental studies. They reported the influence of alkali-resistant glass fibers on workability, density, of different strengths grade concretes. Fiber content they used varied from 0.5 to 4.5% by weight of cement. Another study reported by Kumutha and Vishnuram (2012) on the characteristics of geopolymer concrete reinforced with glass fiber.

1.2 The Aim of the Study

Since 2000, there has been a tendency to produce new alternatives to ordinary Portland concrete. As a results of environmental impacts sustainable options of utilizing industrial wastes to produce useful construction materials, has attracted a great interest. This study deals with development of a FA based Geopolymer with enhanced properties. In order to improve the properties of Geopolymer mortar, glass fiber reinforcement was utilized.

The investigated properties of FA based glass fiber reinforced geopolymer are compressive and tensile strength together with absorption characteristics.

1.3 Organization of Thesis

The study consists of five chapters;

Chapter 1 includes a general introduction and aim of study.

Chapter 2 covers a brief literature review about OPC concrete, geopolymer concrete and the properties of materials used for production of geopolymer concrete.

Chapter 3 materials, mixtures, casting, curing conditions, and test methods are described.

Chapter 4 includes discussion of test results.

Chapters 5 summarize the main results of this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focused on the ecological effects from the industrialization of OPC process. Many studies on geopolymer concrete are summarized in this chapter. Moreover, glass fiber and its utilization in concrete technology was also discussed.

2.2 Concrete and Environment

Malhotra (1999, 2004) reported that the critical factor for the environment is the amount of emissions of carbon dioxide (CO_2). Some industrial activities like cement manufacturing process cause significant emissions of greenhouse gases. This greenhouse emission affects global warming significantly. The ‘tradable emissions’ indicates the economic mechanisms that are predicted to help countries around the world meted to reduce the emissions targets set by the Protocol of Kyoto1997. Estimate grew up to every 1 ton of emissions can get a value around $10.

McCaffrey (2002) Reported that cement production is growing about 3% annually (Producing of every 1 ton of cement release about 1 ton of CO_2 in the atmosphere, during combustion of fossil fuels and cement production processes as result of limestone de-carbonation of in the kiln (Roy 1999).

Malhotra (2002) reported the contribution of processes of cement production through worldwide to greenhouse gas emissions by about 7% of the total emissions of greenhouse gases into the earth's atmosphere, individually about 1.35 billion tons per year. Among of building materials after steel and aluminum, cement is the most energy-intensive

Szabo et al. (2003) estimated at the report the worldwide CO_2 emissions by the year 2030. Their estimation is shown in Figure 2.1

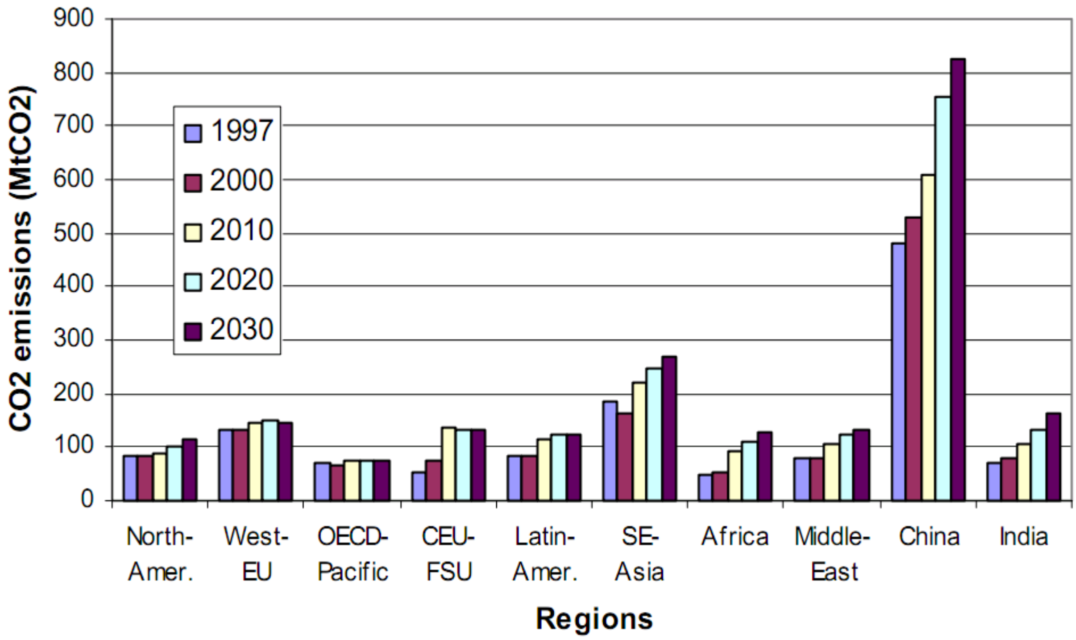

Figure 2.1 Worldwide CO_2 emissions estimation (Szabo et al. 2003)

Concrete deteriorated due to environmental effect, which has high effects on its serviceability, safety and durability. Three major factors scrawny extent and quality of cover, cracking, and the gross quality of the whole concrete structure that are accelerate aggressive agents due to transportation phenomena into the concrete like sulphate and chlorides.

2.3 Geopolymer

Geopolymer is a member of the family of inorganic polymers that composed of a polymeric Si–O–Al framework, such as zeolites style. Term “geopolymer” firstly coined by French scientist Joseph Davidovits (1978) in reference to aluminosilicate polymers formed in an alkaline environment, has an amorphous microstructure. Young et al. (1998) defined polymer is a category of materials made of large molecules that consist of a large number of repeated units (monomers). The unit molecular structure that forms the large molecules controls material properties. The amorphous state or non-crystalline is the state when regularity of atomic packing absent completely.

Due to chemical reaction of alkali polysilicates with Al_2SiO_5 an amorphous to semicrystalline in 3D structures produced of polymeric sialate bonds (Si-O-Al-O) (Davidovits 1991). Sialate tetrahedral arrangements, alkali silica-oxo-aluminate abbreviation, the figure 2.2 clarify calcium, sodium, lithium or potassium being the alkali (Davidovits 1978).

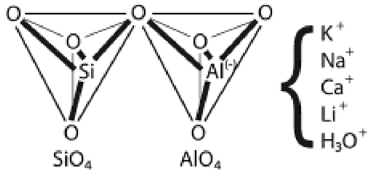

Figure 2.2 Sialate tetrahedral arrangements (Davidovits 1978)

From source material Al_2SiO_5 dissolves by the action of hydroxide ions (-OH). Foreboding ions then arrange into polycondense with monomers to form structures of polymeric (Hardjito and Rangan, 2005). The below chemical formula explain poly (sialate) (Davidovits 2011).

$$M_n[-(SiO_2)_z-Al_2]_n, wH_2O$$

During the curing and matrix formation of geopolymer amount of H_2O released and leaving behind intermittent nanopores that affect performance, comparing with the Portland cement hydration process, H_2O not require for chemical reaction. The role of H_2O is just to obtain adequate workability.

The Al_2SiO_5 natural sources include micas, clay, kaolinite, spinel and andalousite. Also by-product material can be considered as source materials such as FA, slag and silica fume. The geopolymerisation of source materials in general done through use of a watery alkaline colloidal polysilicates solution contains varied forms of silica based on sodium (Brykov, 2004; Leelathawornsuk, 2009).

Lee and Jang (2016) investigated the effect of FA properties on the development of FA based geopolymer strength, observed of delayed development of high strength geopolymer. Chemical and Physical properties of FA were observed by particle size analyzer, X-ray fluorescence test and X-ray diffraction test. They applied multi-technical descriptions using SEM & EDS, MIP and FT-IR to obtain a thorough understanding of the relationship between microstructure, reaction products, and strength growth according to the ripeness of geopolymer, concluded that the properties of FA significantly affect the characteristics of geopolymer.

2.4 Constituents of Geopolymer

2.4.1 Fly Ash

FA is a by-product of combustion a coal, mainly it's collected at energy power plants available through worldwide. The aluminous-siliceous material and due to FA ability to react chemically with calcium hydroxide $Ca(OH)_2$ is classified as a pozzolic to form cementitious compounds. FA can be classified according to the type of coal burned, FA produced from bituminous coals and anthracite is classified as Class F, and FA Class C produced from burning of lignite coals and sub-bituminous. Also from its contents are different; FA Class F contains greater amounts of Al_2O_3 and SiO_2 but less than 10% CaO. Instead of that, FA Class C contains CaO more than 10% and giving it individual self-hardening properties (ASTM C618, 2012).

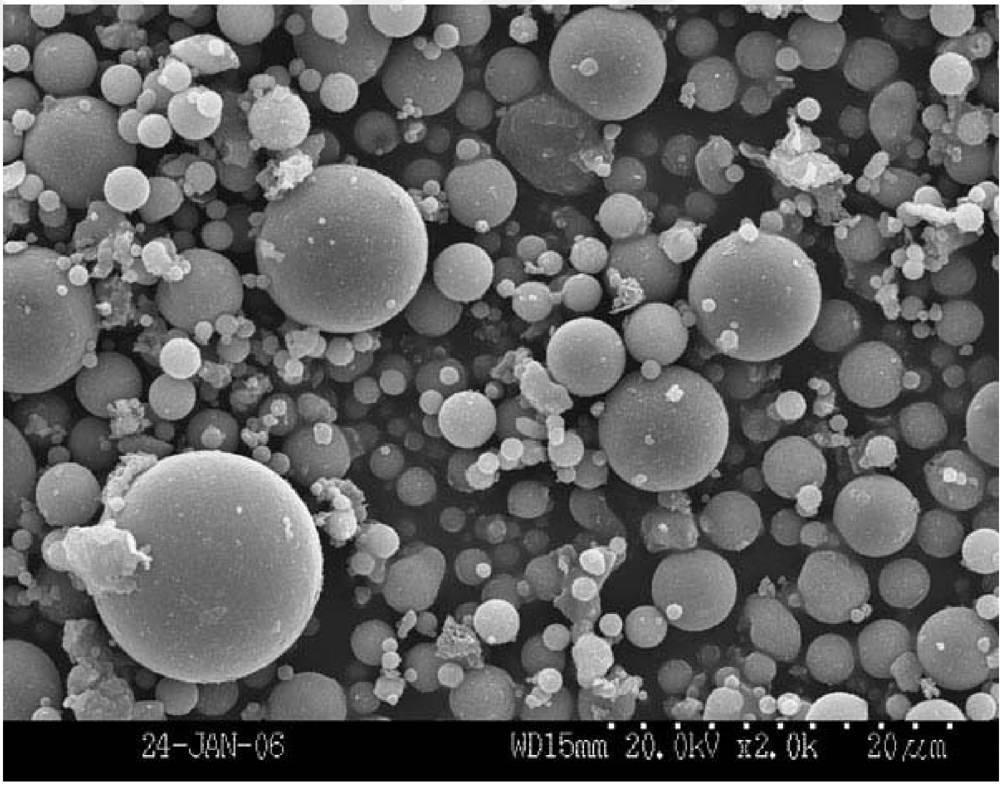

Figure 2.3 Microstructure of fly ash

The existence of Al_2SiO_5 in FA has stimulated it's to utilize it as a base material for the geopolymerisation as alternate of cement (Zeobond, 2007). Because of the appearance of high amounts of calcium oxide CaO uncleanness in FA Class C geopolymer precursors interact to produce C-A-H and C-S-H and has parallel formation to direction of Si-O-Al-O bonds. During compounds hydration the alkalinity of the mixture rise and encourages rapid poly condensation and dissolution. Because of the appearance of calcium oxide CaO the chemical reaction improved and increases the strength of the geopolymerisation (Diaz-Loya et al., 2011). FA reactivity dependents on the proportion of SiO_2 and its nature (Hemmings and Berry, 1988).

Zhuang et al. (2016) studied the FA-based geopolymer clean production, properties and applications, and concluded that the geopolymerisation includes the dissolution of silica, aluminosilicate and alumina in the FA feedstock by alkali.

2.4.2 Alkaline Activators

The most common alkali polysilicates solution is composed of sodium hydroxide NaOH and sodium silicate Na_2SiO_3 utilized for geopolymers production that based on FA. Also Van Deventer (2002) concluded that the mostly alkaline solution utilized to produce geopolymer is an integration of potassium hydroxide (KOH) or sodium hydroxide (NaOH) with potassium silicate (Ki_2SiO_3) or sodium silicate Na_2SiO_3).

The type of activator has the main role in the geopolymerisation product and when the alkaline activator contains soluble silicate, high rate of reactions happen and either potassium silicate (KOH) or sodium silicate (NaOH), compared with utilize of alkaline hydroxides only (Palomo et al. 1999).

Van Deventer and Xu (2000) approved that the solution made by adding sodium hydroxide (NaOH) solution to the sodium silicate (Na_2SiO_3) solution to made alkaline activator enhance the reaction between the solution and source material. Hence, by study of the geopolymerisation of (60) natural Si-Al minerals, they found in general the potassium hydroxide KOH solution caused a lower range of dissolution of minerals than the sodium hydroxide NaOH solution; therefore sodium hydroxide NaOH is better.

Indistinguishable and parallel stages to form the geopolymeric materials structure are proceeding. The first stage of the structure formation is dissolution of the Al_2SiO_5 in a strong alkaline solution from the source material as shown in the Figure (2.4).The second stage is the dissolution that followed by precursors formation of the geopolymer consisting of covalent bonds of Si-O-Al-O type. The third stage is through alternately connecting by oxygen ions, polycondense of the oligomers form a 3D framework of SiO_4 and AlO_4 in tetrahedral from; the mechanism involves the in same time removal of H_2O. Final stage, the solid particle bond and become hard and to produce the polymeric structure (Giannopoulou and Panias, 2007).

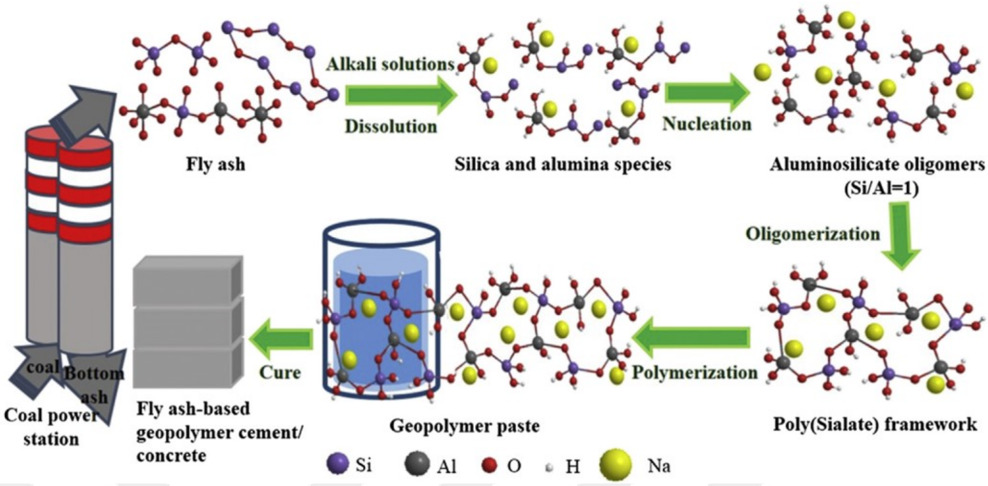

Figure 2.4 Geopolymerisation process (Zhuang at el. 2016)

2.4.3 Aggregates

Generally aggregates occupy about 70-77% of total concrete volume and it is obtained separately as fine and coarse aggregates. Otherwise artificially by manufacture industries or other ways such as recycled concrete, also aggregate can be made from slag or bottom ash and might be utilized as alternative to natural aggregate to produce concrete. Commonly aggregates are storage by different sizes: graded to utilize later to satisfy of the required grading. Mention the negative impact process it is possible to say the production of waste materials such as dust and water that neither of them is basically the damage to the environment. Meantime, the dust may be used in some other processes.

Conventional concrete consists of aggregate with shapes range and size of rocks or gravel. In other ways increase benefit in replacing alternate aggregate materials, also utilizing to use bottom ash and a new tendency recycled materials. Other materials like different solid wastes include glass fiber materials or slag, plastics, wood products and paper are used as aggregate replacement. This is important to identify that the differences between the aggregates and cement in the view of act that some materials have both behavior such as aggregate and cementitious material (such as Slag and FA). Since aggregate occupy most of volume of the concrete it significantly affects the cost of concrete. Also aggregate has significant effect on strength, durability, workability and volume stability.

The main mechanical properties of concrete durability, hardness and strength, are the three main aggregate properties that to be important for concrete structural. Generally the aggregate used in concrete production must be with no unwanted chemicals, clean as possible, no absorbed clay and other fine materials that cause the distortion of the hydration process and distorts concrete characteristics. Recycled aggregates should not be used in concrete in areas that has contact chloride ions and sulfate. In general concrete made by recycled aggregate has high absorption rates low specific gravities compared with conventional gravel aggregate concrete. The concrete which is produced with recycled aggregate possesses has bad workability with low compressive strength, because the compressive strength of concrete depends on the strength properties of the original aggregate and the W/C ratio of new one.

2.4.3.1 Classification of Aggregates

According to size, aggregates classified by BS 882 (1992) as:

a) Sand: aggregate pass through 5.0 mm BS 410 test sieve and that does not contain more coarse material which allows for various gradations in this specification.

b) Coarse aggregate: that aggregate retain on a 5.0 mm BS 410 test sieve and not contain material more accurately than is allowed for different sizes in this specification.

2.4.4 Superplasticizer

In general known as water reducer, Pirazzolli (2005) defined the superplasticizer as a linear polymer consisting groups of sulfuric acid attached to the polymer like backbone at regular intervals. The most commercial formulas available belong to one of these four families:

- Sulphonated melamine-formaldehyde condensates
- Modified lingo sulfonates
- Sulphonated naphthalene-formaldehyde condensates
- Polycarboxylate derivatives

Through the utilization of superplasticizer, it is possible to obtain concrete with good workability. Very high slump within 175-225 mm range can be obtained for structures which are heavily reinforced where appropriate consolidation cannot be achieved easily through vibration. Another benefit of utilizing superplasticizer materials in concrete is to produce concretes has high strength by using w/c ratio of (0.3-0.4). Superplasticizer materials that increase slump depend on its type, dose, and time adding plasticizers, w/c ratio, also the amount and of type cement. As the summery superplasticizer can increase the slump of concrete by improving the workability of concrete for all types of cement used and also affect other characteristics of concrete.

2.5 Mixtures Proportions

Van Deventer and Xu (2000) through a research concluded that the alkaline solution proportion to powder contain silicate-alumino by mass should be approximately 33% to provide geopolymerisation processes to occur satisfactorily. Thick gel formed immediately after mixing the with silicate-alumino powder alkaline solutions. The size of specimen used in their study 20x20x20 mm, and 72 hours of curing at 35^oC the maximum compressive strength obtained was 19 MPa with stilbite as the source material.

Van Jaarsveld et al. (1998) studied the use of ratio about 39% by mass of the solution to the powder in their work, 15% kaolin or calcined kaolin was mixed with 57% FA. The alkaline liquid comprised 4% NaOH or KOH, 3.5% Na_2SiO_3 and 20% H_2O. Size of specimen used in their study was 50x50x50 mm. Through the results the maximum compressive strength obtained was 75 MPa when FA used as the base material.

Barbosa et al. (2000) through a study prepared 7 mixes compositions of geopolymer paste and using varied range of molar oxide ratios: $3.3<SiO_2/Al_2O_3<4.5$, $10<H_2O/Na_2O<25$ and $0.2<Na_2O/SiO_2<0.48$. From the results of tests on the paste specimens, optimum composition occurred they found when the ratio of water to Na_2O was 10.0, and the ratio of SiO_2/Al_2O_3 was 3.3 and Na_2O/SiO_2 was 0.25. Mixes with high content H_2O, i.e. the ratio of H_2O to Na_2O=25, and obtained low compressive strengths results, that reflecting the role of H_2O content in the mixes.

2.6 Manufacturing and Curing Processes of Geopolymer

Skvara et al. (2007) researched the characteristics of FA based geopolymer concrete. Coarse and fine aggregate was used and mixed with FA first thin with alkaline activators. Different molar of alkaline activator was ranging from 1 to 1.6 were considered depend on ratio of SiO_2/ Na_2O was by manipulated the ratio of NaOH. The ratio of alkaline activator Na_2O to FA by mass was varied from 6% to 10%, and ratio of water to FA varied from 0.30 to 0.40 were used. Gypsum, limestone and slag were used in concrete. The influence of synthetic, glass fiber and steel fiber reinforcement also was studied.

Cheng and Chiu (2003) during mixing of the potassium hydroxide (KOH) with metakaolin and mixed firstly for 10 minutes, thin a mix of slag and Na_2SiO_3 were added, and continued mixing for another 5 minutes. Molds with dimension of 50x50x50 cm were used and mechanical vibration on vibrating table was used and vibrated for 5 minutes. Heat curing was used with constant temperature of 90 ^{o}C for 24 hrs. And the mechanical properties were studied.

Hardjito et al. (2004) reported that the rapid rate of geopolymerisation just stopped and started strength gaining when subjected to heat curing for short times, for example for 24 hrs.

2.7 Properties of Geopolymers

2.7.1 Geopolymer Density

Density of any material is the unit weight which is related to its element contents density, similar the density of concrete related to the density and quantity of the W/C ratio used; aggregate used and also amount of entrained air. Through the different researches by using different mix design the density of concrete fixed about 1750–2400 kg/m3 for normal concrete and lightweight (Dorf, 1996; Washington State Department of Transportation; Portland Cement Association; McGraw-Hill Encyclopedia of Science and Technology).

Vijai et al. (2010) researched the properties of FA based geopolymer concrete they found the densities were obtained ranged 2251 to 2400 kg/m^3 they used 2 type of curing, heat curing at 60 ^{o}C for 24 hrs. and ambient curing. Finally the densities were obtained in range of which equal to the conventional concrete density. Lloyd and

Rangan (2010) researched on GPC using varies aggregate grading and types, they obtained density at age of 28 days by using heat curing for 24 hours at 60^{o}C was 2355 ±65 kg/m^3.

2.7.2 Compressive Strength

Curing temperature play the main role on GPC compressive strength, also composition of source materials, type of alkaline activator and water content. Barbhuiya et al. (2009) studied the influence of using calcium hydroxide with silica fume to produce concretes and substituted by 30% FA of the OPC based content. The amount of silica fume used was 5% by mass of the OPC content. The amount of hydrated lime was about (0.05) to total mass of the binder cementious (FA+ OPC) materials. Room curing was used at first 24 hrs. at 20 ^{o}C. They see that with increasing the amount of hydrated lime the workability decreased a super plasticizer was added to improve this. Early compressive strength of the GPC mixes was found increased due to the addition of calcium hydroxide and silica fume. For age 72 hrs. Show that the strength of hydrated lime with silica fume mixes was greater by (30 MPa) than the standard concrete mix founded 24 MPa.

The compressive strengths differences were more clear at age of 28 days with a constant advancement from the OPC mix (49 MPa) FA inclusive of hydrated lime (53 MPa) and then the combined mix of silica fume was compressive strength 58 MPa at age of 28 day.

Hardjito (2004) obtained excellent results of compressive strength and with no aggregate segregation from mixes improved workability by using addition water or using superplastisizer which the mix has high slump result up to 240 mm.

Nguyen (2009) produced GPC by using same mixing to produce OPC. They obtained that there was important difference between OPC with geopolymer concrete in the binder.

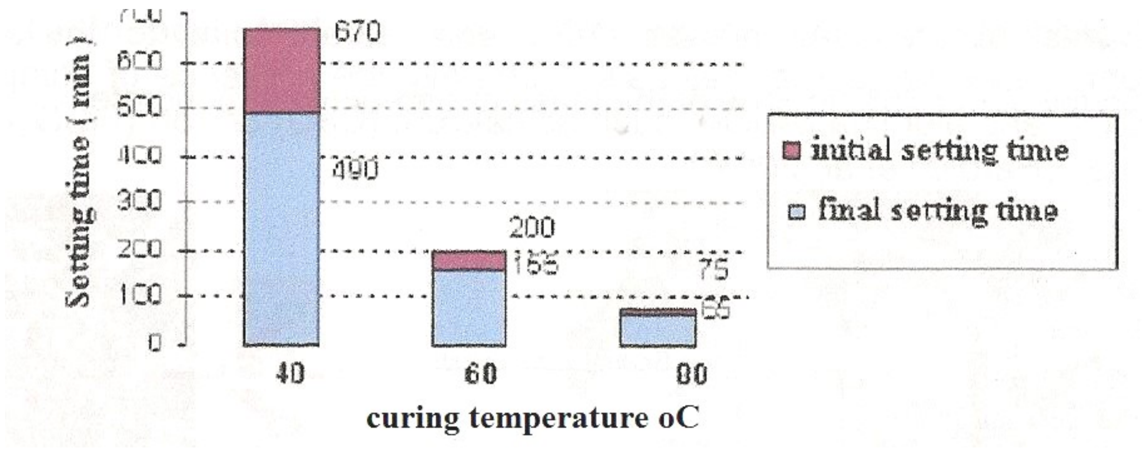

Figure 2.5 Effect of curing temperature on setting time of a geopolymer concrete (Nguyen, 2009)

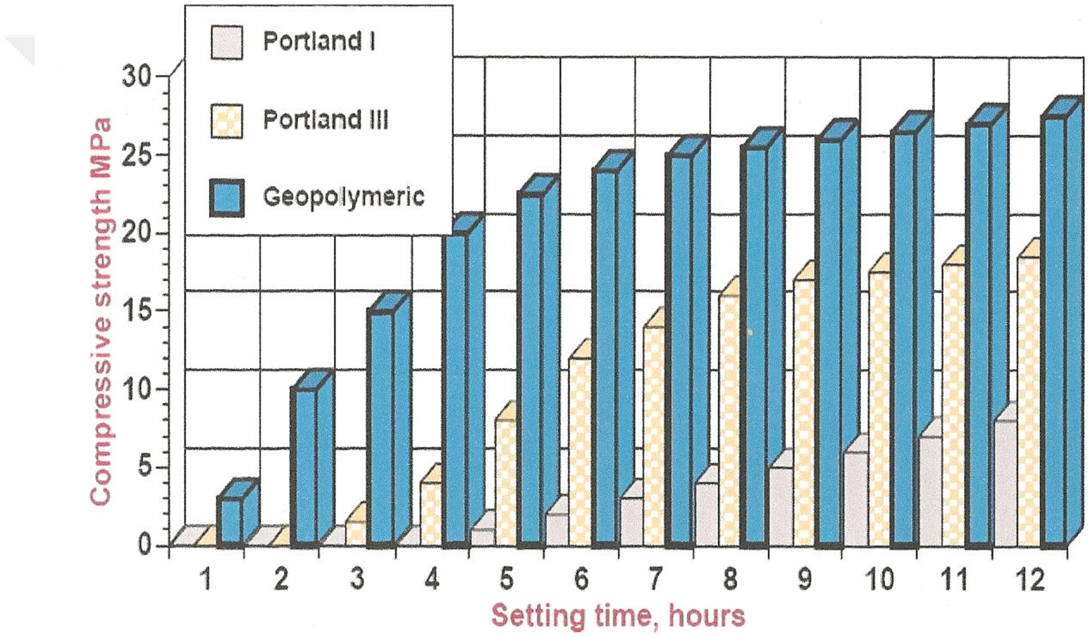

Figure 2.6 Setting at room temperature for OPC cements and GPC (Davidovits, 1991)

From Figures 2.5 and 2.6 explain that strength development of GPC is in a direct correlation with both of curing temperature and time. In other words, by increasing the curing time, temperature will result in increased strength.

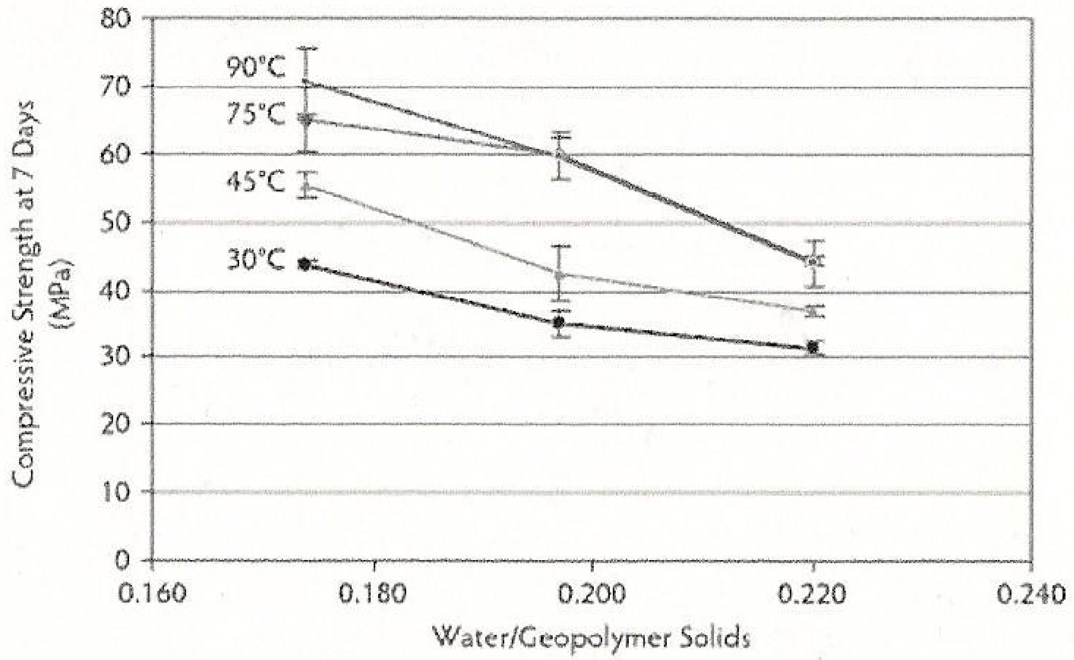

Figure 2.7 Relation between the ratios of water/polymers solids to strength properties (Nguyen, 2009)

Figure 2.7 explain the effect of ratios of water/solids ratio on strength properties at 7days age. As shown in figure above lower ratio of water/solids produces greater compressive strength in all curing temperatures, and also shows how temperatures affected compressive strength. Curing at 90°C with ratio of water/polymer solids of 0.175 produced high compressive strength that achieved to greater than 70 MPa at 7days age.

2.7.3 Tensile Strength

Hardjito and Rangan (2005) reported same to conventional OPC, tensile splitting strength of GPC was only a fraction of the compression strength. Actually, the tensile strength of FA based GPC is greater than the recommended values by Neville (2000) that it is $f_t = 0.3f_c^{2/3}$ for OPC concrete, and standards for Australia (2001) which is $f_t = 0.4f_c^{1/2}$.

According to the researches, tensile strength of GPC is the fraction of its compressive strength. The tensile strength of concrete is relatively low, about 10% to 15% of the compressive strength, sometimes 20%. Thus, the parameters affecting the tensile strength will affect the strength GPC.

2.8 Factors Affecting Geopolymer Properties.

Many factors have been identified as the main parameters that affect GPC characteristics. Palomo et al. (1999) reported that the curing time and temperature together has accelerate reaction in FA based geopolymers, and affected significantly the strength characteristics, also the type of alkaline activator is affected. Longer curing time higher curing temperature and were proved higher results of strength characteristics. Alkaline activator that contains soluble silicates proved to increase reaction rate compared to alkaline solutions containing the only hydroxide.

Van Jaarsveld et al. (2003) reported that the properties of geopolymers determined by source materials, especially that contain calcium oxide CaO, and the H_2O/FA ratio, based on the statistical study, parameters that effect on the process of polymerization for metakaolin-based geopolymers.

Van Jaarsveld et al (2002) reported that the curing condition, calcining condition of kaolin clay and addition water content affected the characteristics of geopolymer. And also they concluded that the very high temperature of curing distorts the GPC and cause cracking, a negative effect on the characteristics of the geopolymer. Finally, they concluded that the moderate curing to enhance the good physical characteristics of the geopolymer.

Van Deventer Xu and (2000) concluded that factors like potassium oxide K_2O, the calcium oxide CaO percentage, the type of alkali activator, the ratio of Si/Al in the source material, the extent of decomposition of Si significantly affected the strength characteristics of geopolymers. The study based on geopolymerisation of natural Si/Al minerals.

Najmabadi (2012) listed the parameters that affected the relation between tensile strengths and compressive are:

- Aggregate type and grading.
- Age.
- Curing.
- Air-Entrainment.
- Method of Test.

2.9 Glass Fibers

According to ACI 116R the term of fiber reinforced concrete (FRC) is concrete that contain fibers randomly oriented. Mehta and Monteiro (2006) defined the FRC is concrete containing fibrous material which improved its durability properties. It contains uniformly distributed short discrete fibers and randomly oriented

Fibers can be classified according to the type of material made off to many type as glass fibers, synthetic fibers, steel fibers, and natural fibers each type which give varying properties to the concrete. In addition, the properties of reinforced fiber concrete changes with varying concretes, distribution, orientation, geometries, and densities (Mehta and Monteiro, 2006).

To control drying shrinkage and cracking due to plastic shrinkage fibers are used in concrete. They also improve other properties of concrete such as reduce bleeding of water and reduce the permeability of concrete. Some types of fibers improve higher shatter, abrasion and impact resistance in concrete. (Mehta and Monteiro, 2006).

Glass fiber can be defined as a material that consists of numerous very fine glass fibers. Glass fibers are manufactured in many different types for different specific uses. Due to high percentage of surface area to weight, Fiberglass is more useful. Hence, the increased space area makes it high susceptible to chemical attack. Due to trapping air within glass particles, good thermal insulation made by blocks of glass fiber, with a thermal conductivity specified by 0.05 W/ (mK). Glass fiber contains silica ratio greater than 50%, and composition with different metal oxides gives the resulting product distinctive properties. (Hartman at el. 1996).

Figure 2.8 Glass fiber

Wallenberger and Bingham (2010) classified glass fiber types as shown below.

- A-glass - Alkali glass
- AR-glass – Alkali Resistant glass.
- C-glass – Corrosive resistant glass.
- D-glass – Low dielectric constant glass.
- E-glass – Alkali free and highly electrically resistive.
- ECR-glass.
- R-glass – A reinforcement glass.
- S-glass – High strength glass.
- S-2 glass.

CHAPTER 3

EXPERIMENTAL STUDY

3.1 Introduction

This chapter deals with process of producing FA based geopolymer mortar (GM) modified with glass fiber. introduction of materials used for production of glass fiber reinforced GM and testing metods where given in details.

In order to produce FA based GM modified with glass fiber, some criteria were assigned for mix design. The focus of the research was to identify the influence of glass fiber reinforcement on the fresh and hardnend properties of GM.

3.2 Materials

3.2.1 Fly Ash

In the research dry FA (ASTM Class F) as the base material was used. The table shown below consists of physical and chemical properties of FA utilized in this research.

Table 3.1 FA physical and chemical properties

Chemical and physical (%)	FA
CaO	2.2
SiO_2	57.2
Al_2O_3	24.4
Fe_2O_3	7.1
MgO	2.4
SO_3	0.3
K_2O	3.4
Na_2O	0.4
Loss on ignition	1.5
Specific gravity	2.25
Specific surface area (m^2/kg)	379

3.2.2 Alkali Activator

In this research a mix of sodium silicate (Na_2SiO_3) solution with sodium hydroxide ($NaOH$) solution was used as alkaline activator. The sodium hydroxide ($NaOH$) used was in technical class in flakes form in approximately 3 mm particle size with specific gravity of 2.13 and pH 14. The molar mass is 40 g/mol. This information was obtained from the supplier Tekkim Kimya San. Ltd, Turkey.

Figure 3.1 Sodium hydroxide (NaOH)

The preparation of sodium hydroxide ($NaOH$) solution was obtained by dissolving sodium hydroxide flakes in water. The mass of $NaOH$ solids in a solution disperse according to the solution concentration expressed in terms of the molar, M. In this research, $NaOH$ with 12M (381 g/kg). For preparation of 1 kilogram solution we need 381 gram of ($NaOH$) flakes and 619 gram of water.

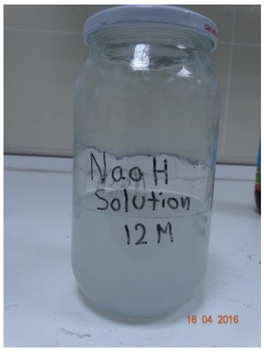

Figure 3.2 Sodium Hydroxide Solutions

Readymade solution of Sodium silicate was obtained from supplier. Sodium silicate solution has the chemical composition of SiO_2=29.4%, Na_2O=14.7%, with water about 55.9% by mass. The specific gravity of sodium hydroxide solution was =1.48 g/cc with viscosity at 20 ^oC was =400 cp.

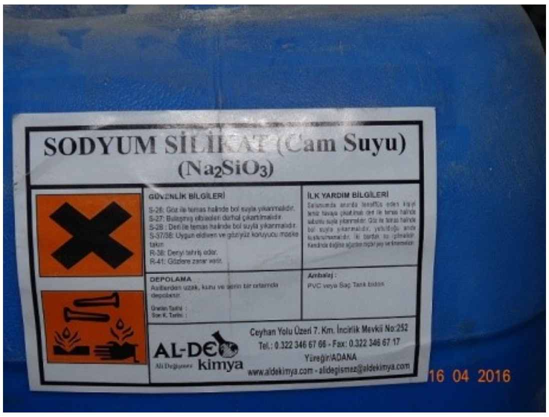

Figure 3.3 Sodium silicate solution

3.2.3 Aggregate

Aggregate was used in research was provided from local river quarry (river sand), just fine aggregate was used (0-4mm), sieve size 4 mm was used to obtain aggregate grade from (0-4mm). Aggregate was saved in laboratory weather; specified gravity of aggregate obtained according to ASTM by using a sample of aggregate and weight of 250 gram by using clean water and glass can, the specific gravity was 2.64.

Figure 3.4 Aggregate

3.2.4 Superplasticizer

In order to improve the flow of the mortar polycarboxilate ether type superplasticizer (SP) in a solution form with a specific gravity of 1.07 was used by amount of 6% of fly ash weight in all mixtures.

Table 3.2 Properties of superplasticizer

Properties	Superplasticizer
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity (kg/1)	1.07
Chemical description	Polycarboxilate ether

3.2.5 Glass Fiber

In order to obtain the main goal of study was using fiber glass to modified and improve the properties of GM. In the study fiber glass was obtained from local factories with length about 13 mm with specific gravity 2.60.

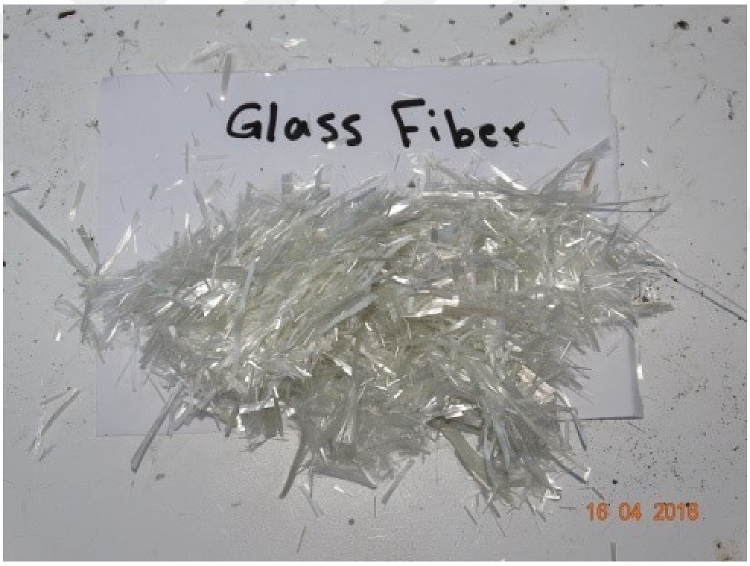

Figure 3.5 Photographic view of glass fiber

3.3 Mix Proportion

The mixing stage has notable effects in the production of geopolymer mortar, inappropriately combined mixture may cause failure such as not hardening or flash setting both of which are failure and causes inapplicability.

In order to avoid this drawback, the selection of mixtures ingredient were summarized as following based on the past researches that were summarized in chapter 2 and also based on results of some trial mixtures in a preliminary study:

- FA used as a based material, 2 series of mixtures based on fly ash was obtained by 600 kg/$m^3$and 700 kg/m^3.
- A mixture of sodium hydroxide (NaOH) solution and sodium silicate solution (Na_2SiO_3) was used as alkaline liquid by ratio 1 to 2.5. The molarity of sodium hydroxide was 12M.
- Ratio of alkaline solution to FA was (1/2) by mass of FA.
- 50 % of weight of mixture was aggregate by size of 0-4 mm.
- Super plasticizer was used 6% by mass of FA.
- Glass fiber was added from range 0.2 to 1.2 by the total weight of mixture.
- Totally 12 mixtures was obtained.

The following tables below shows the mixtures proportion:

Table 3.3 Mix proportions 600 kg/m^3 FA based

#	Mix ID	Fly Ash FA	Aggregates Fine	NaOH Solution	Na_2SiO_3 Solution	Glass Fiber		Superplasticizer
		[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[%]	[kg/m^3]	[%] of FL
1	GPM 0.2%	600	1278.15	85.68	214.2	0.2	5.2	6
2	GPM 0.4%	600	1273	85.68	214.2	0.4	10.4	6
3	GPM 0.6%	600	1267.6	85.68	214.2	0.6	15.6	6
4	GPM 0.8%	600	1262.31	85.68	214.2	0.8	20.8	6
5	GPM 1.0%	600	1257	85.68	214.2	1	26	6
6	GPM 1.2%	600	1251.75	85.68	214.2	1.2	31.2	6

Table 3.4 Mix proportions 700 kg/m^3 FA based

#	Mix ID	Fly Ash FA	Aggregates Fine	NaOH Solution	Na_2SiO_3 Solution	Glass Fiber		Superplasticizer
		[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[%]	[kg/m^3]	[%] of FL
1	GPM 0.2%	700	1052.06	99.96	249.9	0.2	5.2	6
2	GPM 0.4%	700	1046.78	99.96	249.9	0.4	10.4	6
3	GPM 0.6%	700	1041.50	99.96	249.9	0.6	15.6	6
4	GPM 0.8%	700	1036.22	99.96	249.9	0.8	20.8	6
5	GPM 1.0%	700	1030.94	99.96	249.9	1	26	6
6	GPM 1.2%	700	1025.66	99.96	249.9	1.2	31.2	6

3.4 Mixing, Casting and Curing

3.4.1 Mixing

Mixing stage is very important, any mistake or wrong material weighing causes wrong results and waste of time and materials. For weighing materials a sensitive balance was used, and for mixing an automatically controlled electrical mortar mixer of 5 l capacity was used as shown in Figure 3.6. Before mixing the materials were prepared, weighed and packed in suitable containers.

Figure 3.6 Mixer

First solid mix ingredients (aggregate and FA) were mixed dry in mixer pan to at least 3 minutes, then liquid materials (alkaline solution) was added to mixer gradually, then fiber glass was added to mixer, finally the superplasticizer was added and the mixer mixed up to complete 5 minutes.

FA based geopolymer mortar was dark in color. The mixture usually cohesive in terms of workability, Figure 3.7 shows the color and shape of geopolymer mortar. The workability of geopolymer mortar was measured by flow table test as shown in Figure 3.7.

Figure 3.7 Flow table test

3.4.2 Casting

Firstly the molds with dimension of 50x50x50 mm was prepared and lubricated to prevent adhesion of geopolymer mortar with the molds.

The second step was filling the first half of molds with the ready mortar. Manually compaction was done by 25 blows per layer thin mechanical vibration for 25 seconds on vibration table was done to reduce the air bubbles inside the mortar. Same procedure was done for the next layer. Figure 3.8 shows both stage of vibration. After that the top of molds was leveled to get uniform shape and extra materials were removed.

Before curing process the molds were covered by heat resistant film to prevent moisture loss during high temperature curing. Then, curing processes were started.

Figure 3.8 Casting process

3.4.3 Curing

From the previous researches, it was found that the strength of geopolymer acquired by temperature, and significantly increases with the increasing temperature of curing, heat curing was used by using electrical oven as shown in Figure 3.9 with constant temperature at 60 ^{o}C for 48 hrs.

Figure 3.9 Curing Oven

3.5 Testing

3.5.1 Fresh Unit Weight

For obtaining fresh unit weight of geopolymer mortar according to ASTM C l38, a digital scale was used by weighing molds when empty and after casting before casting process, calipers was used to check the dimensions of molds.

3.5.2 Flow

Flow of geopolymer mortar was obtained according to ASTM C1437 by using of flow table instrument to determine the amount of flow of fresh geopolymer mortar. First, mold was placed on its specified place in the middle of the instrument. The mold was filled by first layer about 25 mm thick with fresh geopolymer mortar and compacted with the tampers for 20 times. For second layer same procedure was repeated. The mold was lifted away and immediately the table was dropped from a height of 12.7 ± 0.13 mm for 25 times in 15 sec. the diameter of the geopolymer mortar along the top of table was measured by using a small roller. The flow was obtained as a percentage of the original base diameter. It was calculated by subtracting the initial diameter from the flow diameter measured in two directions after flow. The difference is calculated as the percentage of the initial diameter and recorded as flow of mortar.

Figure 3.10 Flow table test

3.5.3 Compressive Strength

The compressive strength test of GPM was obtained according to ASTM C109, on 3000 kN capacity hydraulic testing machine by (50x50x50) mm cubes and test was done according to ASTM C39 (2012), the test was executed on the specimens at the age of 48 hrs. With loading rate 0.5 kN/sec. Compressive strength was calculated from the average of three samples at each age test.

Figure 3.11 Compressive strength test machine

3.5.4 Splitting Tensile Strength

Split test for geopolymer mortar was obtained according to ASTM C37 on 3000 kN capacity hydraulic testing machine by (50x50x50) mm cubes, the test was executed on the specimens at the age of 48 hrs. With loading rate 0.1 kN/sec. The splitting tensile strength was calculated from the average of three samples at each age test.

3.5.5 Water Absorption

To determine water absorption of geopolymer FA based mortar modified with glass fiber, three cubes was casted by dimensions of 50x50x50 mm with similar method of curing, the test was done on the specimen at age of 7 days, the dimension and density was measured, the specimen were dried by oven at 100 ^oC of temperature for 24 hrs., dimension and weight was measured as first weight. Then the specimens were immersed for 24 hrs. in water then the second weight as saturated surface dry weight was measured. Followed by calculation of water absorption amount of specimens as the percentage increase in weight, by the equation, Water absorption = $((W_2-W_1)/W_1)x100$, Where: W_1 is weight of dry specimen in grams and W_2 is weight of saturated surface dry specimen in grams.

3.5.6 Sorptivity

The sorptivity test was done to obtain rate of water drawn into the pores of geopolymer mortar. For sorptivity test, three cubes were prepared with dimensions of 50x50x50 mm with similar method of curing, the test was done on the specimen at age of 7 days, the specimens were oven dried at 100 ^oC for 24 hours, then the specimen take out in oven and their side coated with silicone sealing in order to ensure that water can ingress only in bottom of specimen, then the mortar specimens were immersed in water as shown in Figure 3.13. It should be observed that water level not more than 3-5 mm above the base of specimen. The increase in the mass of the specimen at 1, 4, 9, 16, 25, 36, 49 and 64 minutes were measured.

Sorptivity can be determined by:

$$I= St^{1/2}$$

Where I is volume of capillary absorbed water per unit area (mm^3/mm^2), S is sorptivity index ($mm^3/mm^2/min^{0.5}$), t is time (minutes)

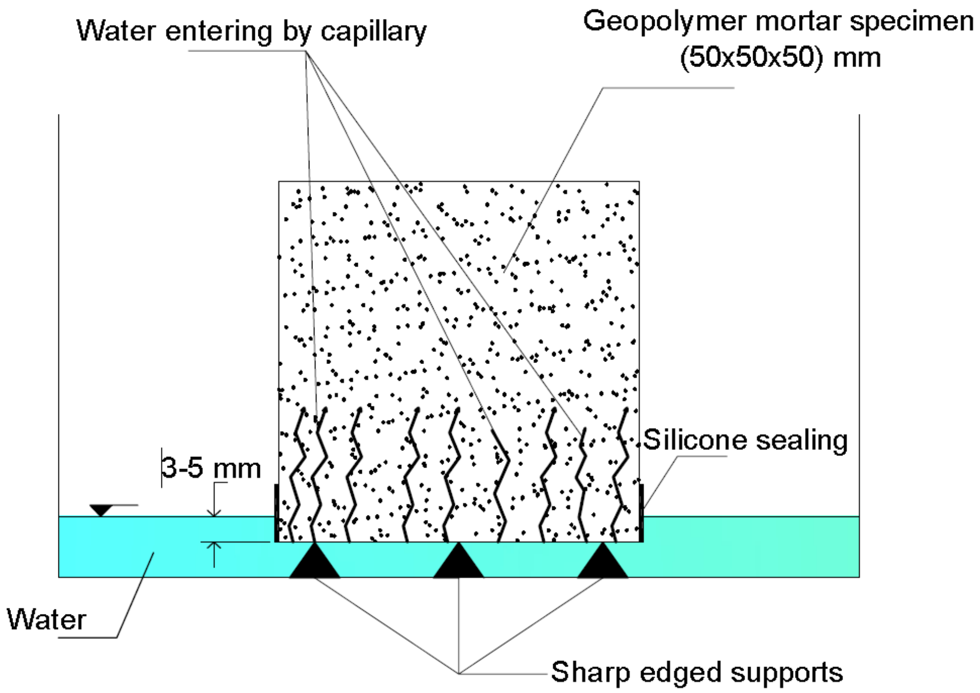

Figure 3.12 Schematic presentation of sorptivity test

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Flow

Flow was obtained as the result of percentage increase in average base diameter of fresh geopolymer mortar. The results shown in the Table 4.1 and Figure 4.1, generally all the mixtures were stiff, cohesive and glossy in appearance compared with the conventional ordinary Portland cement mortar. This is due to the content of sodium silicate (Na_2SiO_3). It was observed the higher flow was obtained with lower level of glass fiber content with higher content of base material. However as shown in Figure 4.1 the flow decrease with increasing glass fiber content, this because of the long shape of fiber glass and its blocking effect on the movement of mortar particles. Additionally, FA improves workability of geopolymer mortar as shown in Figure 4.1 from the results of flow test.

Table 4.1 Effect of glass fiber content and FA on flow

Mix ID	Fiber By Volume	flow %	
		C1	C2
GPM 1	GF-0.2%	10	50
GPM 2	GF-0.4%	8	38
GPM 3	GF-0.6%	6	25
GPM 4	GF-0.8%	5	18
GPM 5	GF-1.0%	4	12
GPM 6	GF-1.2%	2	5

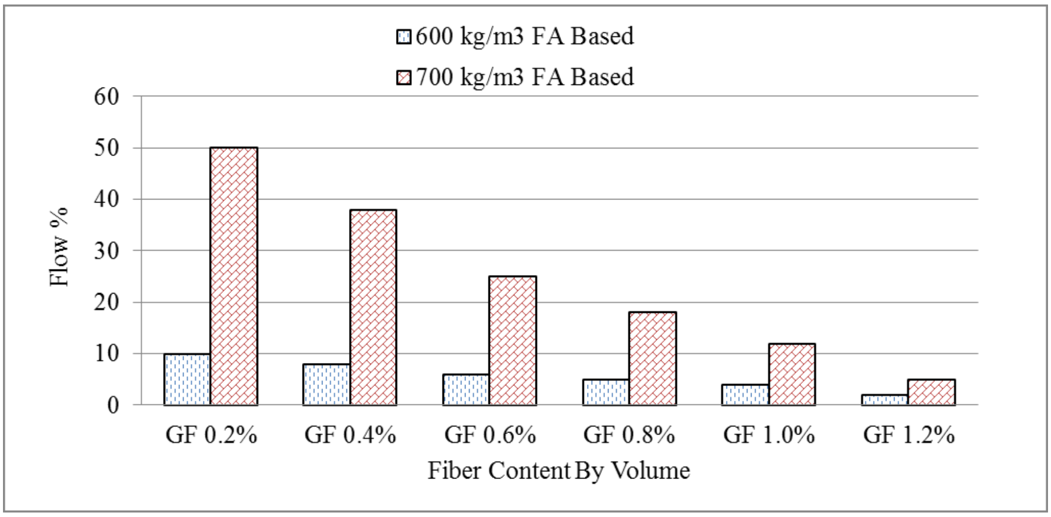

Figure 4.1 Effect of glass fiber content and FA on flow

4.2 Unit Weight

Unit weight of geopolymer mortar was measured during the research. Table 4.2 and Figure 4.2 show the results of geopolymer mortar unit weight.

Table 4.2 Geopolymer mortar fresh unit weight

Mix ID	Fiber By Volume	Fresh Unit Weight [kg/m^3]	
		C1	C2
GPM 1	GF 0.2%	2234	2157
GPM 2	GF 0.4%	2228	2150
GPM 3	GF 0.6%	2225	2144
GPM 4	GF 0.8%	2221	2140
GPM 5	GF 1.0%	2218	2134
GPM 6	GF 1.2%	2214	2131

Table 4.3 geopolymer mortar hardened unit weight

Mix ID	Fiber By Volume	Hardened unit wieght [kg/m^3]	
		C1	C2
GPM 1	GF 0.2%	2187	2094
GPM 2	GF 0.4%	2179	2087
GPM 3	GF 0.6%	2175	2083
GPM 4	GF 0.8%	2170	2080
GPM 5	GF 1.0%	2166	2076
GPM 6	GF 1.2%	2161	2074

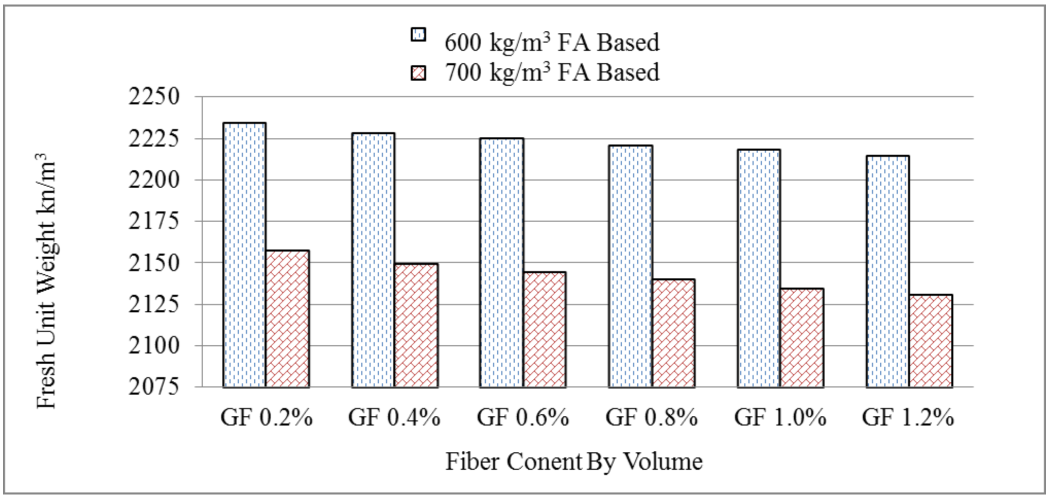

Figure 4.2 Fresh unit weight of geopolymer mortar

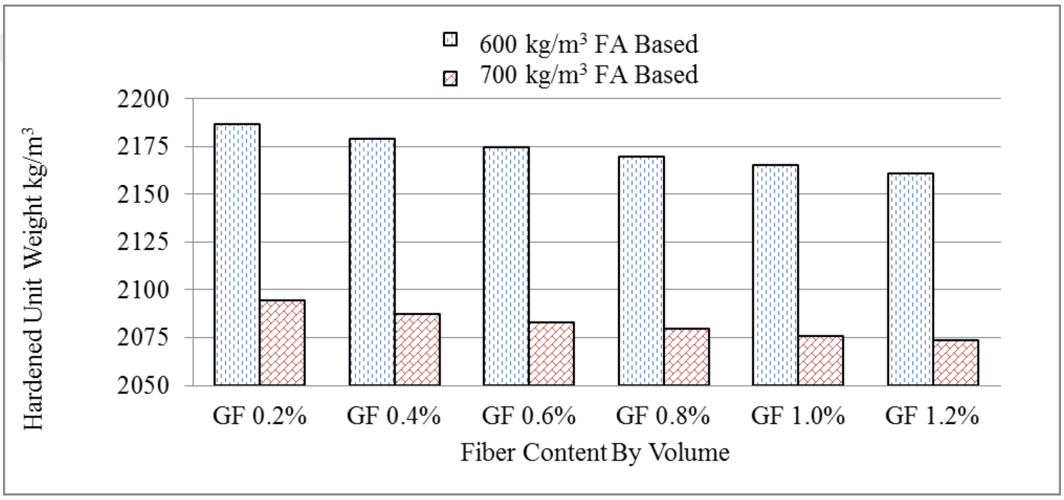

Figure 4.3 Hardened unit weight of geopolymer mortar

As shown in the Table 4.2 the average fresh unit weight was 2223.51 kg/m^3 for GPMs with 600 kg/m^3 Fresh unit weights varied from 2234.44 kg/m^3 to 2214.33 kg/m^3, the decreasing in density is due to increasing of glass fiber content added. However, the change in unit weight due to glass fiber content is not significantly high. The reason for this is that the unit weight of glass fiber is close to unit weight of aggregate used. But comparing with second series of geopolymer mortar in which 700 kg/m^3 of FA was used as based material, the average fresh unit weight was 2142.74 kg/m^3 and comparing with series 1 the unit weight was reduced about 4%. And the fresh unit weight for 700kg/m^3 fly ash based was varied from 2157.33kg/m^3 to 2131.02 kg/m^3.

Hardened fresh unit weight was almost same as fresh density. It was not affected as much as by changing in glass fiber content as changing in FA used as base material. The results are shown in Figure 4.3 and Table 4.3.

4.3 Compressive Strength

The most important characteristics for durability are compressive strength, for that compressive strength considered the most important for geopolymer mortar. The table 4.4 and fig.4.4 shows the tests results.

Table 4.4 Compressive strength results

Mix ID	Fiber By Volume	Compressive Strength MPa	
		C1	C2
GPM 1	GF 0.2%	27.49	29.91
GPM 2	GF 0.4%	27.68	33.15
GPM 3	GF 0.6%	28.62	33.27
GPM 4	GF 0.8%	30.14	34.40
GPM 5	GF 1.0%	33.27	35.37
GPM 6	GF 1.2%	35.69	37.72

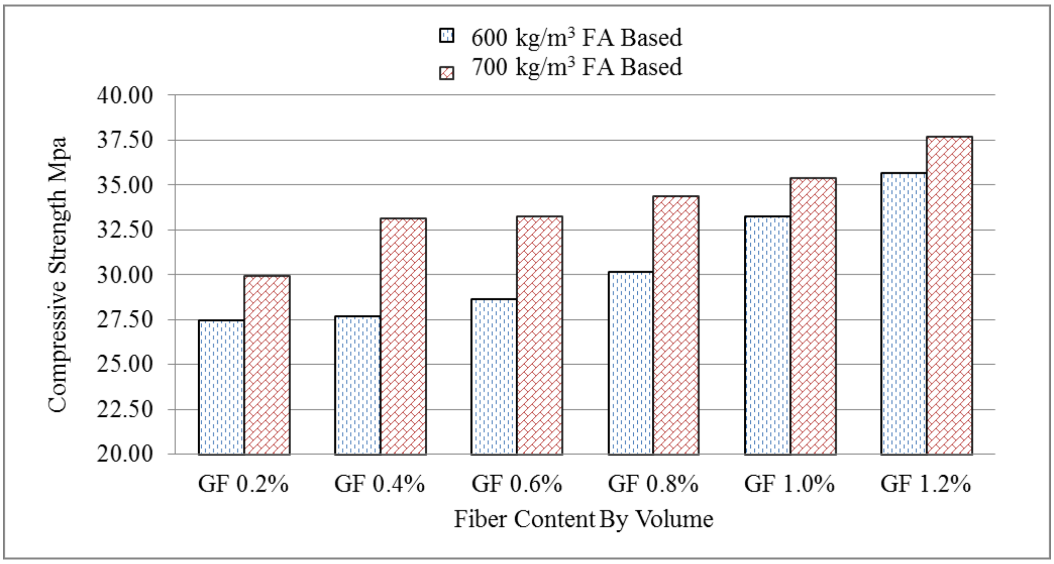

Figure 4.4 Compressive strength results

The average compressive strength was obtained is 30.48 MPa for series 1, which is 600 kg/m^3 FA based, and 33.97 MPa for series 2, which is 700 kg/m^3, FA based, and as shown on the Figure 4.4 the compressive strength increased with increasing of glass content were increased about 30 % for series 1 with glass fiber from 0.2% to 1.2%. and 26% for series 2, this due to the effect of glass fiber members that controls the cracks during the loading processes and improve the strength. Also it was observed that the compressive strength was increased by 11.5% when the base material FA was increased from 600 kg/m^3 to 700 kg/m^3.

4.4 Splitting Tensile Strength.

The test results are shown in Table 4.5 and figure 4.5. The average splitting tests are 4.16 MPa for series1, and 4.14 MPa for series 2.

Table 4.5 Splitting tensile strength

Mix ID	Fiber By Volume	Splitting tensile Strength MPa	
		C1	C2
GPM 1	GF 0.2%	3.55	3.76
GPM 2	GF 0.4%	3.85	4.03
GPM 3	GF 0.6%	4.25	4.08
GPM 4	GF 0.8%	4.36	4.30
GPM 5	GF 1.0%	4.32	4.33
GPM 6	GF 1.2%	4.65	4.33

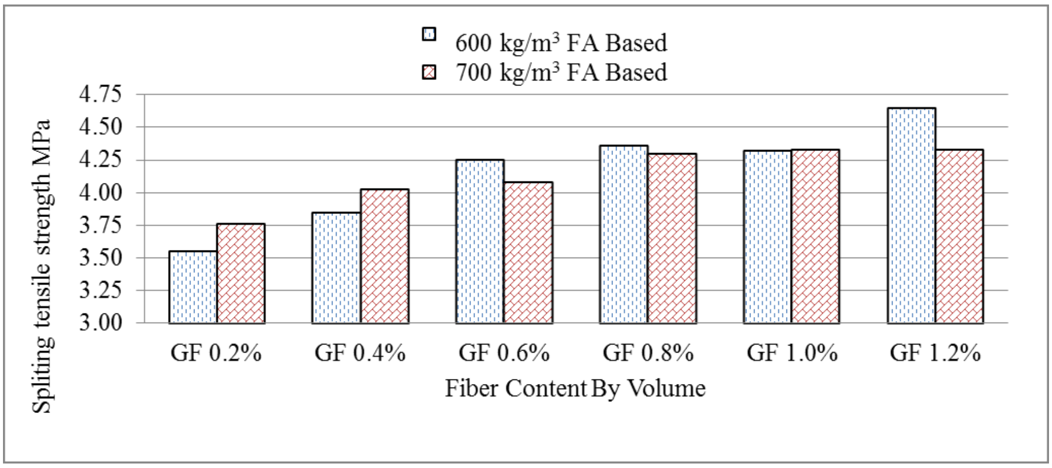

Figure 4.5 Spliting tensile strength

According to the results, it was observed that the splitting tensile was increased by increasing glass fiber from 0.1% to 1.2%. The extreme increase was observed to be 31%. The increasing the of the base material from 600 kg/m^3 to 700 kg/m^3, Seemed to be ineffective for this property. Mechanical properties of materials are varied if variation of parameters affects them in a similar way, thereby providing a means to predict mechanical behavior. Figure 4.6 show the correlation between the compressive strength and splitting tensile strength. Compressive strength increased gradually in relation with increasing of splitting tensile strength.

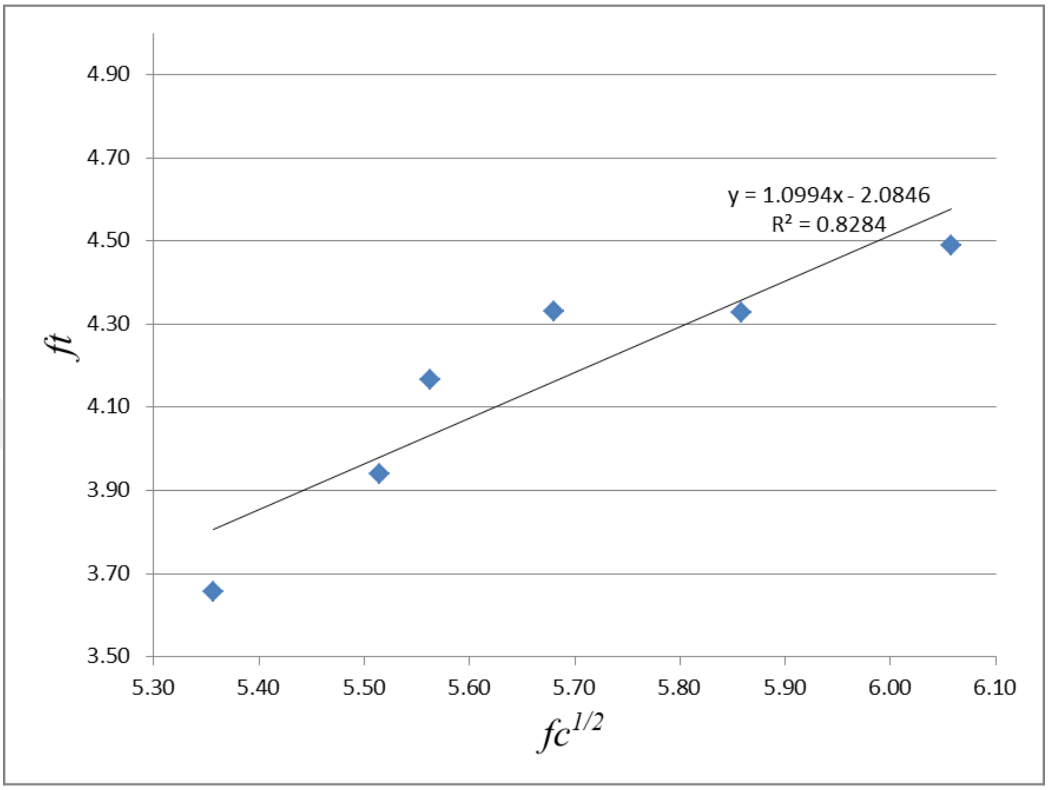

Figure 4.6 Correlation between compressive strength and splitting tensile strength

Generally glass fiber improves the mechanical characteristics of geopolymer mortar or geopolymer concrete, as well as in ordinary concrete. Kizilkanat et al (2015) concluded that the compressive strength and splitting tensile strength increased by increasing of glass fiber content.

Nematollahi et al (2013) also observed that the compressive strength and flexural strength of geopolymer concrete improved by using glass fiber.

4.5 Water Absorption

Absorption should be considered when investigating durability, because it affects the durability of concrete. Table 4.6 and Figure 4.7 shows the results of water absorption.

Table 4.6 Water absorption

Mix ID	Fiber By Volume	Dry unit wieght [kg/m^3]		Saturated unit wieght [kg/m^3]		Weight Gain		Absorption %	
		C1	C2	C1	C2	C1	C2	C1	C2
GPM 1	GF 0.2%	2058	1939	2245	2141	187	202	9.09	10.39
GPM 2	GF 0.4%	2054	1937	2236	2135	182	197	8.88	10.19
GPM 3	GF 0.6%	2047	1934	2227	2127	180	192	8.78	9.94
GPM 4	GF 0.8%	2043	1931	2223	2117	181	186	8.84	9.61
GPM 5	GF 1.0%	2039	1928	2221	2118	182	190	8.9	9.85
GPM 6	GF 1.2%	2035	1925	2217	2117	182	192	8.93	10

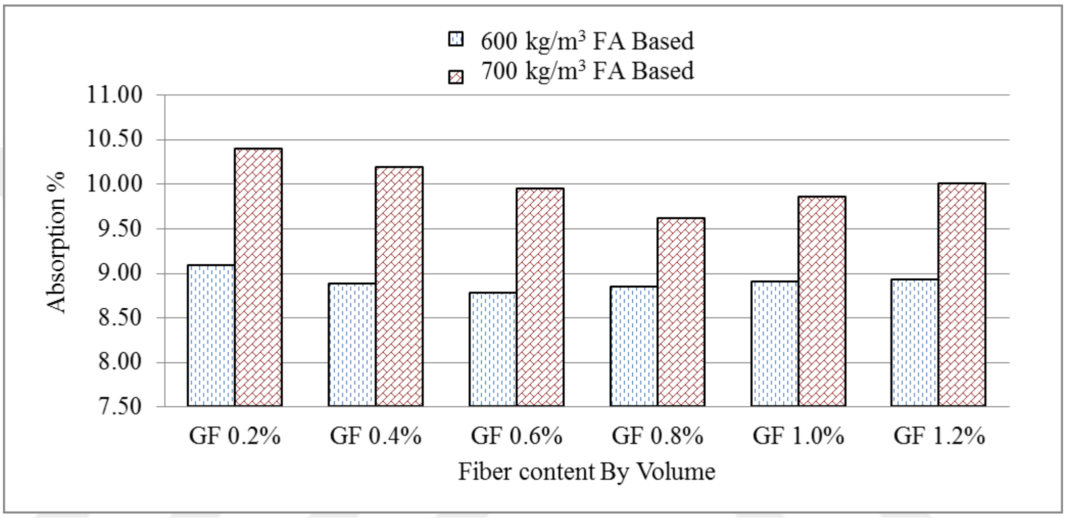

Figure 4.7 Water absorption

Absorption of ordinary concrete or geopolymer concrete refers to the amount of pores inside the concrete. According to the results, the average water absorption about 8.90% for series 1 and 10.00 for series 2. Due to the results of water absorption, there is insignificant change in the results by changing the amount of glass fiber content. This may be the glass fiber distorts the internal structure of geopolymer mortar, for series 1 started from 9.09 % for 0.2 of glass fiber content and decreased with increasing of glass fiber amount up to 0.6% and then increased with increasing of glass fiber content, but the difference are not so much. It can be concluded that the absorption may not be affected by glass fiber. Similar results were obtained for series 2, but generally in average absorption increased with increasing of binder content as well as FA. This may increase the porosity inside the geopolymer mortar.

4.6 Sorptivity

Sorptivity measure the capacity of material to absorb water by capillary action. Table 4.7 and Figure 4.8 shows sorptivity results of FA based geopolymer mortars modified with glass fiber.

Generally sorptivity results are very low compared to ordinary Portland cement mortar. For example in series 1 the average of sorptivity indices is 0.0223 $m/min^{1/2}$, for series 2 the average is 0.0200 $mm/min^{1/2}$. According to the results it was observed that FA based geopolymer mortar modified with glass fiber has low absorption. Moreover, based on the absorption results, there is insignificant change in the results due to changing the amount of glass fiber content. This may due to the fact that the glass fiber distorts the internal structure of geopolymer mortar.

According to the results, moderate absorption with low sorptivity was observed. Absorption amount is due to the amount of porosity inside mortar but it does not indicate that the mortars have high capillarity. This may be due to denser structure of geopolymer matrix.

Table 4.7 Example of sorptivity calculation

time min.	Weight gr.	Gaining gr.	Cumulative gaining wt. Gr.	Vol. of water $(mm)^3$	Surface Area $(mm)^2$	Time $(min)^{1/2}$	I (mm^3/mm^2)
0	279.3	0	0	0	2500	0	0
1	279.3	0	0	0	2500	1	0
4	279.4	0.1	0.1	100	2500	2	0.04
9	279.5	0.1	0.2	200	2500	3	0.08
16	279.6	0.1	0.3	300	2500	4	0.12
25	279.6	0	0.3	300	2500	5	0.12
36	279.8	0.2	0.5	500	2500	6	0.2
49	279.9	0.1	0.6	600	2500	7	0.24
64	279.9	0	0.6	600	2500	8	0.24

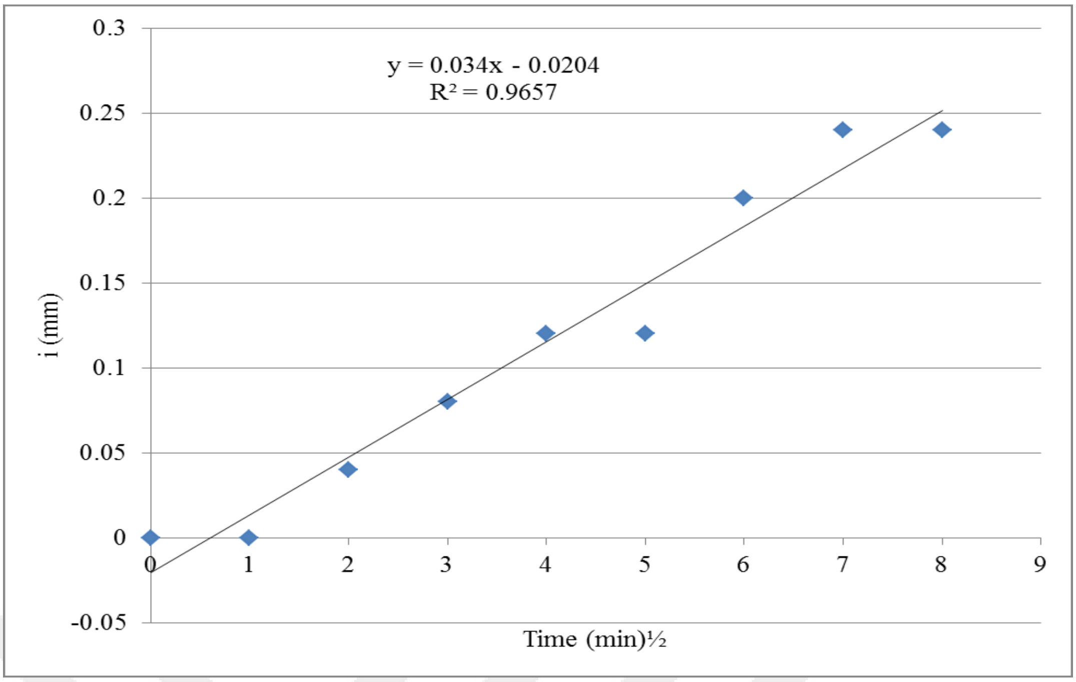

Figure 4.8 Example of sorptivity graph

Table 4.8 Sorptivity results

Mix ID	Fiber By Volume	Sorptivity	
		C1	C2
GPM 1	GF-0.2%	0.0226	0.0200
GPM 2	GF-0.4%	0.0220	0.0198
GPM 3	GF-0.6%	0.0229	0.0191
GPM 4	GF-0.8%	0.0214	0.0204
GPM 5	GF-1.0%	0.0217	0.0203
GPM 6	GF-1.2%	0.0233	0.0204

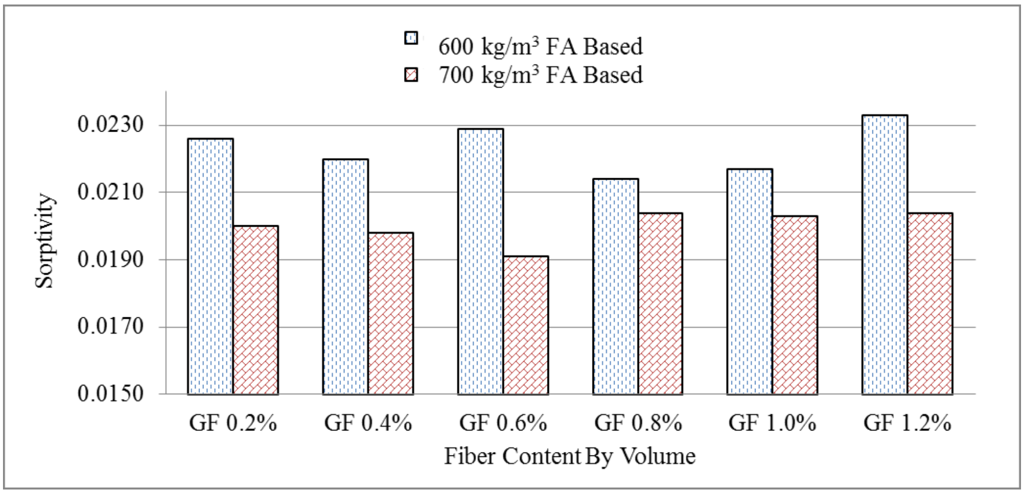

Figure 4.9 Sorptivity values

CHAPTER 5

CONCLUSION

According to the experimental test results, following conclusions are drawn:

1- FA based geopolymer binder will completely eliminate cement in concrete and helps to prevent global warming and to use waste material (FA) effectively.

2- FA based geopolymer concrete can be used in areas where faster final strength achievement is needed as it gains its final strength in about (24-48 hrs.) curing.

3- Glass fiber reinforced FA based geopolymer productions can be offered to manufacture of precast structural elements in construction industry.

4- The unit weight of glass fiber reinforced FA based geopolymer mortar was found approximately similar to that of conventional ordinary Portland cement.

5- Compressive strength of glass fiber reinforced FA based geopolymer increased about 28% by increasing amount of glass fiber content from 0.2% to 1.20%. Splitting tensile strength increased about 31% by increasing amount of glass content from 0.2% to 1.20%.

6- Workability of FA based geopolymer reinforced with glass fiber mortar decreased with increasing of glass fiber content due to blockage of the movement of particles by fibers.

7- Geopolymer mortar can be considered as a resistant construction material against aggressive environments as a result of very low capillary absorption property.

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APENDIX

Figure 1 Photographic view during mixing

Figure 2 Photographic view flow test

Figure 3 Photographic view of molds.

Figure 4 Photographic view of vibrating table.

Figure 5 Photographic view of sealing the molds.

Figure 6 Photographic view of curing cabinet.

Figure 7 Photographic view of compressive strength testing.