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M.Sc. in Civil Engineering

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HASAN KALYONCU UNIVERSITY

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NATURAL & APPLIED SCIENCES

EFFECT OF FA AND GGBFS ON THE PROPERTIES OF GEOPOLYMER MORTER

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IN

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BY

ABDIQANI ADEN

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Hasan Kalyoncu University

Supervisor

Yrd. Doç. Dr. Dıa Eddın NASSANI

By

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

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Abdiqani ADEN

ABSTRACT

EFFECT OF FA AND GGBFS ON THE PROPERTIES OF GEOPOLYMER MORTER

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M.Sc. in Civil Engineering
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Various amounts of natural resources are consumed to manufacture ordinary Portland cement which causes considerable environmental problems for its production. A new technological process called geopolymerization provides an innovative solution in this issue. In addition to potentially reducing carbon emissions, geopolymers can be synthesized with many industrial waste products or natural pozzolans such as fly ash, ground granulated blast furnace slag. In the present study, the experimental test of different proportions of GGBFS and FA in the binder on mechanical and durability properties of geopolymer concrete. To achieve this goal, GGBFS has been used as cement replecement material due to its own strength, while fly ash has been used as a pozzolanic material to enhance the physical, chemical and mechanical propeties of concrete (Swamy, 1986). The geopolymer binder is a mixture contains resource material and alkali activator. Ten mixes have been tested; each mixture has different proportion of FA and GGBFS. It can be concluded that geopolymer concrete with high percentage of GGBFS gain high compressive and tensile strength compared with Geopolymer with high FA. Compressive strength of mix1 (90% FA and 10% GGBFS) is 39.15 Mpa at 7 days age, compressive strength of mix10 (90% GGBFS and 10% FA) is 75.17 Mpa at 7days age. In addition, the duribility of geopolymer mortar, made of these mixes, was also studied, using water sorptivity test. The test results indicated that geopolymer with high percentage of GGBFS has less sorptivity compared with geopolymer with high percentage of FA.

Key Words: Geopolymer, Fly ash and Slag properties, Strength, Sorptivity

ÖZET

UÇUCU KÜL VE ÖĞÜTÜLMÜŞ YÜKSEK FIRIN CÜRUFU JEOPOLİMER MORTER ÖZELLİKLER ÜZERİNE ETKİSİ

ADEN, Abdiqani Mohamed
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Ekim 2017
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Üretiminde önemli çevresel sorunlara neden olan Portland çimentosunun imalatı için çeşitli doğal kaynaklar tüketilmektedir. Jeopolimerizasyon adı verilen yeni bir teknolojik süreç bu konuda yenilikçi bir çözüm getirmektedir. Jeopolimerler karbon emisyonu potansiyelini düşürmenin yanı sıra, uçucu kül, öğütülmüş yüksek fırın cürufu, olan Portland çimentosunun üretimi için,değişik miktarlarda doğal kaynaklar tüketildi.Bunun sonucunda bazı çevresel faktörler ortaya çıkmaktadır. Jeopolimerizasyon denilen yeni prosedürler geliştirildi ve bu konuda yenilikçi çözümler üretildi.Ek olarak karbon emilimini potansiyel olarak azaltmak için jeopolimerler kullanılabilir,bazı endüstriyel atık ürünlerle veya doğal pozzolanslarla örneğin. Cüruf yüksek olan jeopolimer betonun, yüksek külleri Uçur ile Geopolymer'e kıyasla yüksek basınç ve çekme mukavemeti kazandığı sonucuna varılabilir. Karışımın kompresif mukavemeti1 (% 90 külleri Uçur ve% 10 cüruf), 7 günlük yaşta 39.15 Mpa'dır, karışıklığın sıkıştırma gücü10 (% 90 cüruf ve% 10 külleri Uçur), 7 gün yaşlarında 75.17 Mpa'dır. Ayrıca, bu karışımlardan yapılmış jeopolimer harcı dayanıklılığı, su emme testi kullanılarak incelendi. Test sonuçları, yüksek cüruf oranına sahip jeopolimerin yüksek külleri Uçur yüzdesine sahip jeopolimerle karşılaştırıldığında daha fazla sorptiviteye sahip olduğunu gösterdi.

Anahtar Kelimeler: Jeopolimer, uçucu kül ve öğütülmüş yüksek fırın cürufuözellikleri, kuvvet, Sorptivity

To my family, they should receive my greatest appreciation for their enormous love. They always respect what I want to do also give me their full support and encouragement over the years.

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I am also very thankful to Dr. Safie OLEIWI for his guidance, advices and cooperation during experimental study.

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LIST OF SYMBOLS/ABBREVIATIONS

Al	Aluminum
ASTM	American Standard for Testing and Materials
ACI	American concrete Institute
CaO	Calcium Oxide
CH	Calcium Hydroxide
CSH	Calcium Silicate Hydroxide
CO_2	Carbon Dioxide
FA	Fly Ash
f_c	Compressive strength
f_s	Splitting Tensile Strength
GPC	Geopolymer Concrete
GGBFS	Ground Granulated Blast Furnace Slag
KOH	Potassium Hydroxide
K_2SiO_3	Potassium Silicate
NaOH	Sodium Hydroxide
Na_2SiO_3	Sodium Silicate
OPC	Ordinary Portland cement
PC	Portland cement
Si	Silicon

CHAPTER 1

INTRODUCTION

1.1 Background

It is widely known that the production of portland cement consumes considerable energy and at the same time contributes a large volume of CO_2 to the atmosphere. However, Portland cement is still the main binder in concrete construction prompting a search for more environmentally friendly materials.

On the other hand, the climate change due to global warming, one of the greatest environmental issues has become a major concern during the last decade. The global warming is caused by the emission of greenhouse gases, such as CO_2, to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming (McCaffrey, 2002). The cement industry is responsible for about 6% of all CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere (Davidovits, 1994c; McCaffrey, 2002).

In this respect, the geopolymer technology proposed by Davidovits (1988a; 1988b) shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of reducing the global warming, the geopolymer technology could reduce the CO_2 emission to the atmosphere caused by cement industrial by about 80% (Davidovits, 1994c).

One possible alternative is the use of alkali-activated binder using industrial by-products containing silicate materials (Philleo, 1989; Gjorv, 1989). The most common industrial by-products used as binder materials are fly ash (FA) and ground granulated blast furnace slag (GGBFS). GGBFS has been widely used as cement replecement material due to its own strength, while fly ash has been used as a pozzolanic material to enhance the physical, chemical and mechanical propeties of concrete (Swamy ,1986).

The production material such as fly ash and slag within geopolymer concrete also necessary to reduce approximately 5% of global Carbon dioxide emission instead of using OPC, industrial manufacture slag and fly ash increase up to 80% less greenhouse gas emissions. The opportunity of fly ash and Slag create a chance to use burning coal and iron, as a replacement for OPC. Portland cement replacing fly ash and slag as the binder increase the strength of Geopolymer concrete. The fly ash-slag with presence of admixtures increases the high strength geopolymer concrete.

Mechanical properties of geopolymer are better than cement paste. Therefore, not only helps to generate less CO_2 than OPC, but also one of the best behavior of geopolymer is converting waste material such as fly ash and slag useful material for making friendly-economic concrete.

In this work, ground granulated blast furnace slag (GGBFS) is used together with fly ash as a part of the total binder. The GGBFS blended fly ash-based geopolymer with added alkali to form the geopolymer concrete. GGBFS was added with fly ash in order to accelerate the curing of geopolymer concrete in ambient temperature. The manufacture of geopolymer concrete is carried out using the usual practice in concrete technology.

Fly ash based with geopolymer produced in ambient temperature achieved lower strength than slag (Vijay et al.2010). Within the mixtures of fly ash (FA) and ground granulated blast furnace slag (GGBFS) was used with base materials of geopolymer concrete.

As the demand for GPC directly increases with the addition FA, GGBFS also, the curing temperature takes place an important role in the development of strength. Curing temperature of $70C^0$ is constant of all the mixtures.

1.2 Objective of the Research

The aim of the research is to evaluate the effect of fly ash and slag on the properties of geopolymer concrete. The primary objectives of this research are as follows:

1- To make a new green binder to replace cement mortar, with a low-cost, better mechanical strength and improving absorption properties.
2- Study the effect of different proportions of GGBFS and FA in the binder on mechanical properties of geopolymer concrete. .

3- Evaluation of the performance of FA and GGBFS based Geopolymer concrete with respect to the strength properties.
4- Comparing the compression and tensile test result of geopolymer concrete with using different proportion of GGBFS and FA.

1.3 Significance

Geopolymer concrete has significant advantages over the standard OPC concretes and can play a vital role in the context of sustainability and environmental issues.

Development of geopolymer concrete has the potential to reduce the cement production which in turn will reduce the greenhouse gas emissions. Manufacture of fly ash or slag can reduce the CO_2 emission almost by 80% as compared to the manufacture of portlandd cement based concrete (Duxson et al., 2007).

Geopolymer concrete can be reducing approximately 5% of global Carbon dioxide emission instead of using OPC. However, some extra constituents (alkali activators) are necessary to add for enhancement of the setting and strength development characteristics of fly ash and slag based geopolymer concrete. The most common alkaline activator used in geopolymerisation is a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Moreover, heat-cured concrete requires controlled curing environment to achieve the desired mechanical and stength properties. The results of this study will be useful for design of geopolymer concrete for ambient curing conditions. Influences of the important variables in slag blend fly ash based geopolymer concrete cured at ambient condition have been studied.

1.4 Structure of the thesis

The thesis is organized into five chapters:

Chapter 1: Background, objectives, and significance of the current study.
Chapter 2: Gives the introduction of geopolymer concrete and the precious research on geopolymer technology. The factors affecting the strength of geopolymer concrete are also described.
Chapter 3: Presents the experimental work consisting of materials used, testing methodology and the set up used to carry out the tests.
Chapter 4: Presents and discuss the results of the experimental work.

Chapter 5: Summarises the study includes the conclusions and recommendations for further research.

1.5 Summary

Geopolymer is an inorganic binder which can be used as an alternative to cement for manufacture of concrete. Most of the published research on geopolymer concrete is on heat cured concrete. Development of geopolymer concrete for ambient curing condition is essential in order to widen its applications to industry. In the present study, the experimental test of different proportions of GGBFS and FA in the binder on mechanical and durability properties of geopolymer concrete.

CHAPTER2

LITERATURE REVIEW

2.1. Introduction

The development of geopolymer concrete is a vital advantage in concrete technology which provided a clean and environmentally friendly alternative to the traditional cement binders in some engineering applications. Using FA and GGBFS as a source material for the production of geopolymer achieve good economic and environmental benefits, the physical and mechanical properties of GPC always better than OPC. This chapter will include available literature related to geopolymer concrete mortar. It will also present the current and possible usage of geopolymer concrete in different amounts of FA and GGBFS.

2.1.1. Pozzolanic materials

A pozzolan is defined as finely divided siliceous or aluminous material that chemically reacts with the calcium hydroxide at ordinary temperature and in the presence of moisture to form compounds possessing cementitious properties (Malhotra & Mehta, 1996). Fly ash, blast furnace slag is the most common pozzolanic materials used in traditional cement concrete. Replacement of cement by the pozzolanic materials usually reduces the early-age strength of concrete. However, they offer improvements of various late–age properties of concrete.

2.2. Environmental case of geopolymer

Geopolymer concrete can play a vital role in the context of sustainability and environmental issues. Approximately 5% of global CO_2 emissions originate from the manufacturing of cement. According to Lawrence (1998) the production of 1 tonne of portland cement prodeces approximately 1 ton of CO_2 to atmosphere.

On the other hand, other cementitious material such as slag has been shown to release up to 80% less greenhouse emissions than the production of conventional portland cement (Roy & Idon,1982) and there are 80%to 90% less greenhouse gas emissions released in the production fly ash (Duxson et al., 2007).

Therefore a 100% replacement of OPC with GGBFS or FA would significantly reduce the CO_2 emission of concrete production. Previous studies by Davidovits (1991),Rangan (2008) and Collins & Sanjayan (1998) showed that the development of new binders commonly known as geopolymers alternative to traditional cements can be obtained by the alkaline activation of different industrial by-product such as blast furnace slag and fly ash . Geopolymer concretes are characterised by their good mechanical properties and low CO_2 emission.

This finding for material emissions alone is comparable to a case study investigating the carbon dioxide emissions from geopolymer concrete compare to ordinary portland cement concrete in the Australian market. The case study factored in transportation emissions as well as the material emissions and found that production and replacement of geopolymer concrete emit 44-64% less CO_2 than ordinary Portland cement concretes (Nazari et al., 2013). The total CO_2 emissions in the U. S. As well as the emissions due to Portland cement production in the U.S. are illustrated in Figure 2.1 (Fillenwarth, 2013). Thus, total CO_2 emissions worldwide and the emissions due to Portland cement production worldwide are illustrated in Figure 2.2 (Fillenwarth, 2013).

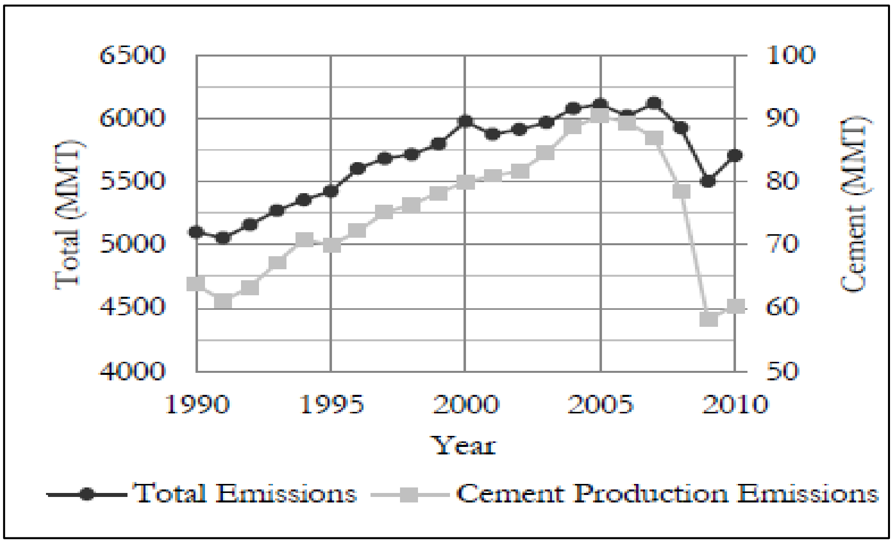

Figure 2.1 U. S. CO_2 emissions (Fillenwarth, 2013)

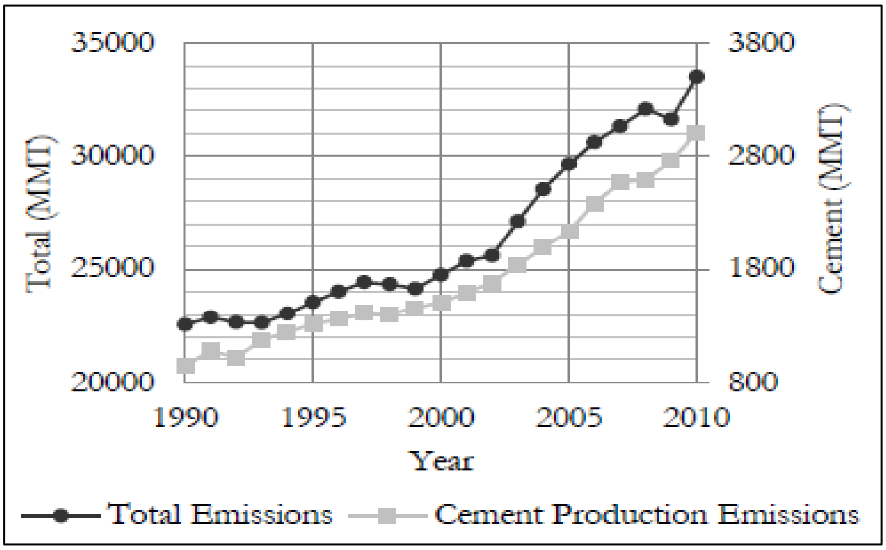

Figure 2.2 Worldwide CO_2 emissions (Fillenwarth, 2013)

These figures indicate that the CO_2 emissions due to Portland cement production in the U.S. have stayed around 1% of the total from 1990 to the present, but the CO_2 emissions due to Portland cement production worldwide has steadily increased from 4% of the total in 1990 to 9% of the total in 2010. From this and knowing geopolymers will produce at least 67% less CO_2 emissions than portland cement, it can be concluded that a complete replacement of portland cement with geopolymer cement will yield at least a 6% reduction in global CO_2 emissions.

2.3. Geopolymer concrete

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The alkali liquids for geopolymers based on sodium silicate and sodium hydroxide and source material such as fly ash, slag etc.

Geopolymer is listed as classified a member of inorganic polymers, the "geopolymer" term was first coined by French scientist Joseph Davidovits (1978) in reference to alumino-silicate polymers with an amorphous microstructure and formed in alkaline environment. It was also conducted that geopolymer binder could be formed by the aluminium (Al) and silicon (Si) in a source material of byproduct materials such as fly ash, slag and husk ash react with alkaline activators -alkaline hydroxide and alkaline silicate.

Rangan (2008) conducted a research on geopolymers as the member of the family of inorganic polymers. The chemical composition of the geopolymers is similar to natural zeolitic materials. It was described that the geopolymerization process is a substantially fast chemical reaction under alkaline activators resulted in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds (Davidovits, 1994b, 1999),

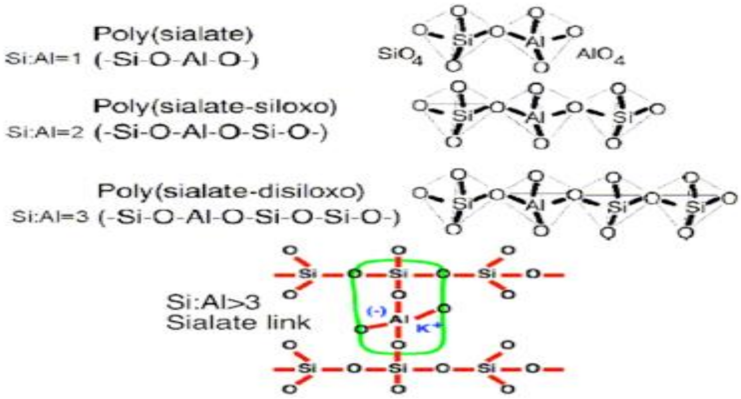

Figure 2.3 Three-dimensional polymeric chain

Rangan (2008) provided a substantial explanation of polymeric chain, and it is reported that water is released by the chemical reaction which occurs during the geopolymer formation. This water leads to the formation of discontinuous nano-pores in the matrix which provides benefits to the performance of geopolymers. This water has no role in the chemical reaction except providing strength to the mix.

Nonetheless, the most popular conceptual model proposed for strength and hardening of geopolymer materials comprises the following stages by Davidovits, 1999; Xu and Van Deventer, 2000.

1-Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.

2- Transportation or condensation of precursor ions into monomers.

3- Setting or polycondensation/polymerization of monomers into polymeric structures.

Palomo et al. (1999) these three steps can intersect with each other and happens at the same time, which makes it hard to separate and test each of them individually.

Yao et al. (2009) benefited from an isothermal calorimetric method for alkali- slag and fly ash mix. However, in the study (Deventer .2012) geopolymerization involves a number of processes including dissolution, reorientation, and solidification as shown in Figure 2.4.

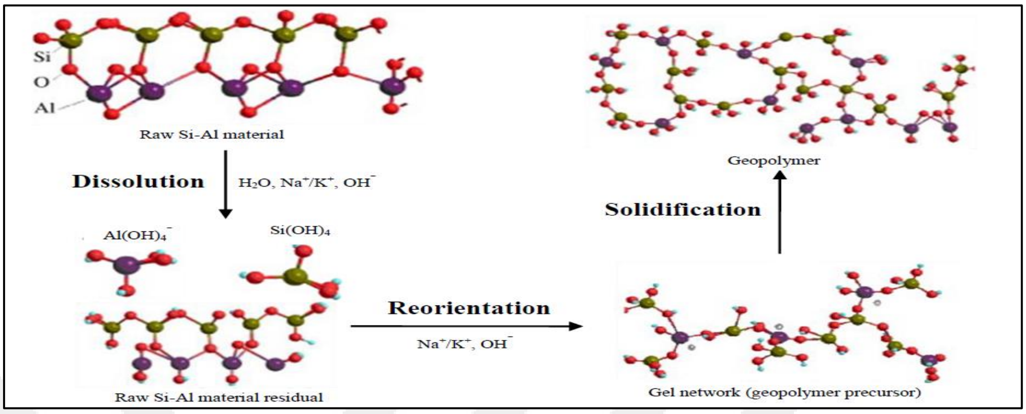

Figure 2.4 Typical reaction mechanism of geopolymerization

Nicholson et al. (2005) asserted that geopolymer concrete is an inorganic polymer formed by reaction of aluminosilicate source and an alkali activator at room temperature. The little energy process cause a fast-setting material exhibiting exceptional strength and hardness. A comparison of the reactions in Figure 2.5 shows that traditional cement is composed of portlandite Ca(OH)2 and calcium silicate hydrate (C-S-H) phases whereas, geopolymer cement is based on an aluminosilicate framework. It was also mentioned that aluminosilicate materials has very high resistant to chemical attack, like by acids, compare to calcium-rich Portland cement. In the polymerization process, there is no calcination step (heating to 1450 ºC) which is mitigating the release of CO_2 as shown in Figure 2.5. Therefore, from this, it can be concluded that geopolymer have more advantage than Portland cement concrete.

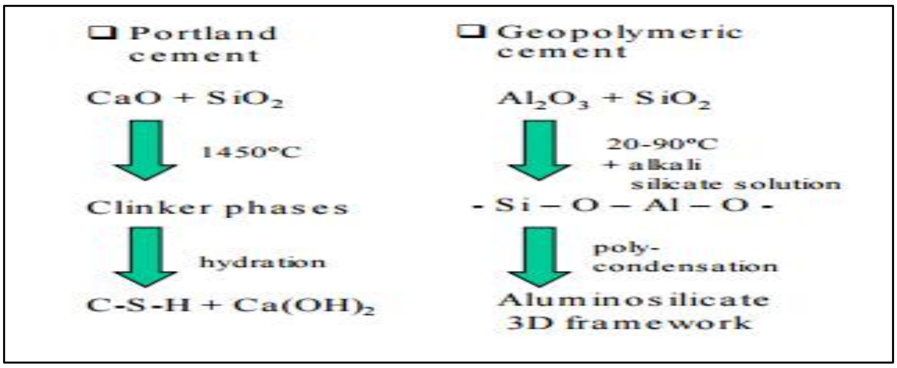

Figure 2.5 Comparison of the reactions of Portland cement and geopolymeric cement

2.4 Components of geopolymer binders

There are two main constituents of geopolymers, namely the alkaline liquids and source materials.

2.4.1 Alkaline Liquids

The common alkaline activator used for producing geopolymer is a combination of sodium silicate with sodium hydroxide and potassium silicate with potassium hydroxide KOH (Xu and Van Deventer, 2000; Davidovits , 1999; Xu and Van Deventer, 2002; Swanepoel and Strydom, 2002; Yao et al., 2009; Temuujin et al., 2010). In addition, single alkaline activators were used by (Palomo et al. 1999; Görhan and Kürklü, 2014).

Palomo et al. (1999) demonstrated that the type of alkaline activator used for activating fly ash or slag significantly affect the reaction development. Furthermore, they stated that high rate reaction occur when alkaline liquid activator solution contains silicate soluble, each, potassium or sodium silicate, in comparison to using only single alkaline hydroxides.

Xu and Van Deventer (2000) asserted that the reaction between the source material and alkaline liquid improved by adding solution to the NaOH solution. Also, after a conduct of the geopolymerization of sixteen natural Al-Si minerals, they established that commonly using the NaOH solution resulted in higher degree of dissolution of the raw material compare to KOH solution.

2.4.2 Resource materials

Davidovits (1988b) demonstrated source material of geopolymers binder should contain the by-product mineral sources for instance rice husk ash, granulated furnace slag and fly ash. The pick of the source materials for producing geopolymers rely on several factors such as accessibility, cost, application type and specific needs of the end users.

In the range of the source materials previously noted, many of them have been investigated in the making of geopolymer concrete. However, the most popular among them in the technology of geopolymers are clay materials kaolinite and metakaolin, and industrial wastes (slag, fly ash).

Xu and Van Deventer (2002) concluded that utilizing a combination non-calcined material (e.g. fly ash and slag) resulted in good improvement in reduction in reaction time and compressive strength.

Deb et al. (2014) concluded that using 90% of GGBFS with 10 % fly ash would obtain high compressive strength (75.17MPa) up to 7days.

An investigation was done by Davidovits (1999), he concluded that calcined materials like fly ash, granulated blast furnace slag will produce high compressive strength than those made from non-calcined materials such as metakaolin clays.

However, using fly ash to produce geopolymer is cheaper than using slag due to the use of the calcination in producing slag.

Swanepoel and Strydom (2002) studied fly ash and slag as a basic component of a geopolymeric binder material, it was showed that fly ash and slag has the potential to be used as raw material in the manufacturing of geopolymer.

Interesting research carried out by Fernandez-Jimenez and Palomo (2003) intended to find out the potential reactivity of fly ash and slag as alkaline solution.

Van Jaarsveld et al. (2003) conducted an investigation about the characteristics of a source material in fly ash and slag. Summarized that the size of particle, alkali content, morphology, calcium content, and origin of fly ash and slag has great effect on the properties of geopolymer. Also, it was demonstrated that the calcium content has vital role in development of strength and final compressive strength, which higher the content of slag led to faster development of strength and at the early age has higher compressive strength.

2.5 Application of Geopolymer

The use of geopolymer technology is primarily to contribute to the reduction of the environmental impact of ordinary Portland cement. However, geopolymer have various other areas of applications from civil engineering field to automobile and aerospace industries as shown in Table 2.1 (Edouard, 2011).

Table 2.1 Fields application of geopolymer (Edouard, 2011)

Area	Applications
Civil engineering	Low CO 2, fast setting cement, precast concrete products and ready mixed concrete
Building materials	Bricks, blocks, pavers, self-glazed tiles, acoustic panels, pipes
Archeology	Archeological monuments by geopolymerization, Repairing & restoration
Composite material	Tooling for aeronautics Functional composite for structural ceramic application
Fire resistant material	Fire and heat resistant fiber composite material Carbon fiber composite
Refractory application	Refractory moulds for metal casting, Use of geopolymer as adhesive refractory, Refractory castables
Utilization of waste	Use of fly ash, blast furnace slag and tailings for geopolymer products
Immobilization of toxic material	Encapsulation of domestic, hazardous, radioactive and contaminated materials in a very impervious, high strength material
Others	Paints, Coatings, Adhesive

In accordance to Davidovits (1999), the type of application of geopolymeric material depends on the Si:Al ratio, as it can be seen in Table 2.2. It appeared from this table that a low Si:Al ratio is suitable for many applications in the civil engineering as shown in Table 2.2.

Table 2.2 Application of geopolymer based on Si:Al (Davidovits, 1999)

Si/Al	Application
1	Bricks, ceramics, fire protection
2	Low CO_2 cements, concrete, radioactive, and toxic waste encapsulation
3	Heat resistance composites , foundry equipments, fibre glass composites
<3	Sealants for industry
20<Si/Al<35	Fire resistance and heat resistance fibre composites

An experimental study was done by Balaguru et al. (1997) on the strength behavior of reinforced concrete beams with carbon fiber fabrics and geopolymer. Their research aimed to demonstrate the ability of geopolymer to be used as substitute to organic polymers for fastening the carbon fabrics to concrete. It was observed that geopolymer provides excellent adhesion both to surface of concrete and in the inter-laminar planes of fabrics.

Comrie et al. (1988) conducted a study to evaluate the applications of geopolymer technology to waste stabilization. This investigation targeted the physical properties of solidified waste and sand mortar mixes, on the basis of compressive strength testing. The results showed that this inorganic binder has the potential to efficiently immobilize hazardous wastes by reducing metal leachability. In addition, it was found that geopolymer technology is extremely effective not only in the case of heavy metals, but also for a wide variety of elements, ions, and compounds (Provis and Van Deventer, 2009).

2.6 Fly ash

2.6.1 Production of fly ash

Fly ash is a by-product from the coal combustion, e.g. in the power plants, or in the production of iron. It has various chemical compositions based on the source coals.

The main oxide components are SiO_2, Al_2O_3, CaO, Fe_2O_3, and SO_3 (Khale and Chaudhary, 2007).

Besides, fly ash is a by-product collected in the de-dusting of gases derived from the combustion of pulverised coal used in power plants. Fly ash is composed of fine particles, and its chemical composition is related to the different types and relative amounts of incombustible materials present in the coal. Generally, the particle of fly ash is spherical, diameter ranged from less than 1 μm to no more than 150 μm (Nawy, 2008). Generally, its constitutive elements are: aluminum, silicon, calcium, magnesium, and iron. Thus are depending on the combustion process and the type of fuel (Edouard, 2011).

Generally, the constitutive elements of fly ash are aluminum, silicon, calcium, magnesium, and iron, although its composition changes with the source of coal. According to ASTM C618, there are two types of fly ash – Class F, usually formed from bituminous coals, and identified as low calcium fly ash - Class C, normally made from lignite or sub-bituminous coals, and known as high calcium fly ash .In order for a fly ash material to be classified as Class C, the silica (SiO_2), the alumina (Al_2O_3), and the iron oxide (Fe_2O_3) constituents should not exceed by much 50% of the composition, while, Class F the summation of this three components can be greater than 70% (ACI committee 226 report).

According to Fernández-Jiménez and Paolomo (2003), the percentage of unburned material in low-calcium fly ash should be less than 5%, reactive silica content SiO2 should be range between 40- 50%, Fe_2O_3 content should be less than 10%, 80-90% particles of low-calcium fly ash should be smaller than 45 μm, and has low CaO content (less than 10%).

It can be noticed that Class F fly ashes possess pozzolanic properties. Soft to the touch, (class F) is in the form of powder from gray to black in color depending on the unburned fuel and iron oxide contents, Whereas class C fly ash have the form of a fine gray powder, with physical properties and/or pozzolanic characteristics. They mainly contain reactive lime, reactive silica, and alumina. The amount of lime (CaO) in this type of ash is high. Therefore they are likely to consolidate without the use of binder.

Van Jaarsveld et al. (2003) mentioned that the high-calcium fly ash resulted in higher compressive strength in the primary age due to forming the calcium-silicate-hydrate gel and other calcium mixtures.

Fly ash is a small gray powder contains regularly of spherical glassy particles. Figure 2.6 shows a characteristic a microscopic image of fly ash elements, by using a scanned electron microscope (SEM).

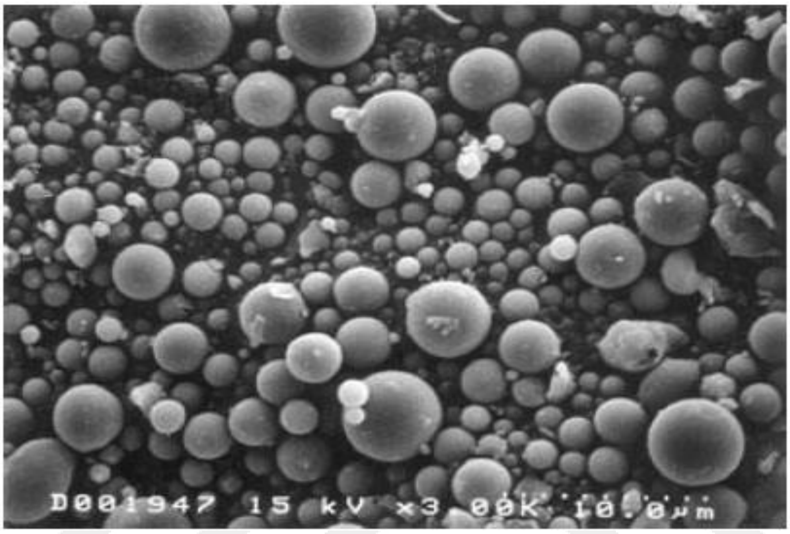

Figure 2.6 Fly ash particles magnification
taken using a scanning electron microscope (Sephaku Ash’s facility, 2012)

Fly ash is generally produced by coa-fired electric and steam genetating plants. Typically, coal is pulverized and blown with air into the boiler’s combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extact heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash, fall to the bottom of the combustion chamber,the lighter fine ash particles, termed as fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices, such electrostatic or filter favric bag houses as shown in (Figure 2.7)

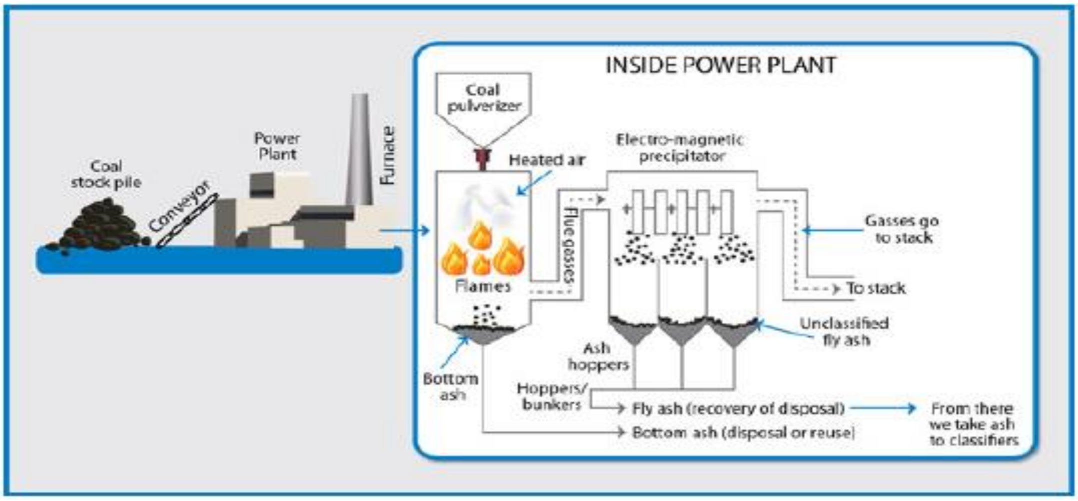

Figure 2.7 the process of producing of fly ash in a power plant
(Sephaku Ash's facility, 2013).

2.6.2 Use of Fly ash in geopolymer concrete

With the availability of quality fly ash in the world, significant benefits have been derived through optimising fly ash contents in concretes -Sirivivatnanon and Khatri 2001-.Use of fly ash in geopolymer concrete can be beneficial to reduce CO^2. Properly cured concrete made with fly ash creates a denser product because the sizes of the pores are reduced by the reaction product of fly ash. Consequently, this increases strength and reduces permeability.

A reduction in the amount of mixing water of concrete can be obtained due to the spherical shape of the fly ash particles. Moreover, concrete placement characteristic can be improved significantly by usig fly ash in the concrete mixtures (Baweja et al.,1998;Samarin et al.,1983). In precast concrete, the benefit of fly ash can be translated into better strength,distinctive corners and edges with a better surface appearance .

2.7 Ground granulated blast furnace slag GGBFS

2.7.1 Production of GGBFS

Ground granulated blast-furnace slag (GGBFS), sometimes simply reffed to as "slag", is a glassy granular material formed when molten blast-furnace slag is rapidly cilled, as by immersion in water. GGBFS consists of silicates and aluminum silicates of calcium and other bases which is developed in a molten Condition simultaneously with iron in a blast furnace.

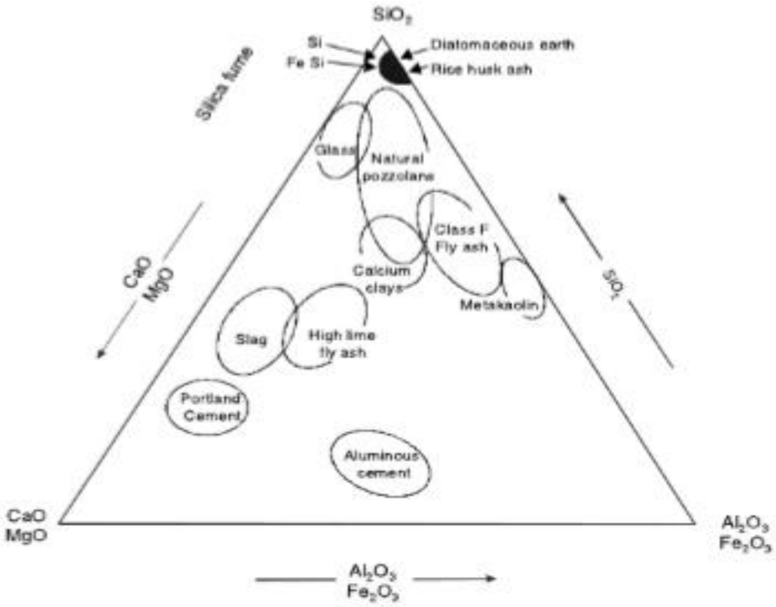

Figure 2.8 Ternary diagram of CaO-Al2O3-SiO2 representing the composition of pozzolanic and cementitious materials (Aïtcin, 2008)

The main components blast furnace slag are CaO -30-50%-, SiO_2 -28-38%-, Al_2O_3 -8-24%-, and MgO -1-18%-. Higher content of CaO in slag generally exhibit an increase in compressive strength of concrete. For a given source of GGBFS, the chemical composition remains relatively constant, especially compared to fly ash. Figure 2.3 shows the relative cementitious and different supplementary cementitious material. Besides, use of GGBFS in concrete has advantage like low heat, higher ultimate strength.

2.7.2. Use of GGBFS in geopolymer concrete

It has been generally shown that concretes containing GGBFS as a cement replacement, at 70C temperatures, develop strengths at a lower rate than that made from Portland cement (Reeves, 1985, Douglas and Zebino, 1986).

That degree of decline in early age strength is a function of a number of variables. These include slag activity (Frearson and Uren, 1986 and Cook and Cao, 1987), method of proportioning and the slag content of the blend. When Portland cement and water are mixed, a chemical reaction called hydration initiates, resulting in the creation of calcium-silicate-hydrate (CSH) and calcium hydroxide (CH). CSH is a gel that is responsible for strength development in Portland cement pastes. CH is a byproduct of the hydration process that does not significantly contribute to strength development in normal Portland cement mixtures. Silicates in the slag combine with the CH by-product of hydration and form additional CSH. This in turn leads to a denser, harder binder, which increases ultimate strength as compared to 100%, Portland cement systems.

2.7.3. Geopolymer binder from slag.

Slags are by-products of metallurgical industry and consist mainly of calciummagnesium aluminosilicate glass. The most commonly produced slags are from the iron and steel industry, called ground granulated blast-furnace slag (GGBFS). The latent hydraulic property of GGBFS makes it suitable for geopolymer binder.

Such slag with the addition of a source of alkali falls within the alkaline-alkali earth system Me2O-MeO-Me2O3-SiO2-H2O (Krivenko, 1994). Thus, GGBFS alone can be used as a source material for geopolymer binders. However, the high CaO content of GGBFS may result in very rapid setting of the binder which may not affect setting and strength of the binder which concrete can be a suitable binder.

2.8. Properties of Geopolymers

Previous studies have reported that geopolymers possess high early strength, low shrinkage Based on laboratory tests, Davidovits (1988b) reported that geopolymer can harden rapidly at room temperature and gain the compressive strength in the range of 20 MPa after only 4 hours and 50-70 MPa after 7 days. Comrie et. al., (1988) conducted tests on geopolymer mortars and reported that most of the 7 days strength was gained during the first 2 days of curing.

In the development of geopolymer materials so many researches have been performed in order to determine the physical and chemical properties of geopolymers, as well as their long-term strength. It should be reminded that the physical properties take into account the behavior of materials subjected to the effect of temperature, electric or magnetic field, or light, whereas the chemical properties characterize the behavior of materials subjected to an environment more or less aggressive. Other properties are the mechanical that reflect the performance of materials deformed by force systems. Obviously, the most properties of geopolymer will be reviewed. Especially, those that will be addressed in this thesis and brief review of other properties will be discussed.

2.9 Superplasticizer

Superplasticizers are the greater essential admixtures enhancing concrete performance. The improvement of new superplasticizers during the last years has determined the greatest important progress is to reduce the problems of concrete structures. Hence, an experimental investigation of geopolymer concrete was directly to determine the optimum dosage for the admixtures and increase the strength of concrete.

In system to reduce the below strength problem and rapid setting time of geopolymer concrete, chemical admixture was combined. Gelenium or superplasticizer was used in this experimental to develop the strength of concrete.

The principal development in concrete structures during the 30 last years has been the use of superplasticizers. However, the logic reasons that superplasticizers are much better development than any other chemical admixture using in concrete structure.

2.10 Factor Affecting Properties of Geopolymer

There are many different ideas which main parameters that affect the properties of geopolymer concrete. This segment presents the review of the research studies done worldwide about the factors affecting geopolymer concrete properties.

Jiang et al. (1992) explained the reason for need the curing treatment is activation of endothermic reaction between fly ash and slag so that the curing temperature is very important for the geopolymerization of the fly ash and slag based geopolymer concrete.

Palomo et al. (1999) stated that the curing temperature was an acceleration reaction of fly ash and slag based geopolymer concrete, its' substantially influence the development of the mechanical strength, with alkaline activator and the time of curing. It was also found that using temperature curing of 70C and curing time resulted in higher compressive strength and tensile strength.

Hardjito (2005) concluded that concentration of (NaOH) solution in term of molar, the compressive strength of geopolymer concrete was also increased. On the other side, the strength of geopolymer concrete improved by the ratio of slag using it. Increasing the volume of slag the compressive strength of geopolymer concrete as well increased. High amount of slag resulted in a higher compressive strength of geopolymer concrete. Nonetheless, the amount of fly ash, it doesn’t affect the compressive strength. Also, they demonstrated that the addition of extra slag increase the strength of geopolymer concrete, and improved hardening stage of geopolymer concrete.

The addition of sodium silicates to the mix design increases mechanical properties beyond the ability of a hydroxide activator alone. However, care must be taken to regulate the ratio between each substance. Previous study indicated that the ratio of sodium silicate to sodium hydroxide plays a vital role on the development of mechanical properties of geopolymer concrete. The higher the mass ratio of sodium silicate-to-sodium hydroxide liquid, higher is the compressive strength of geopolymer concrete (Hardjito et al, 2004)

The water content in the mixture played an important role on the properties of geopolymer binders (Barbosa et al, 2000). The addition of water in geopolymer mixtures improved the strength of the mixtures.

Panias et al. (2007) concluded that slag content is important for geopolymer concrete for the mechanical strengths development. slag plays a vital role for hardening the concrete. Also, fly ash and slag have a great effect on strength of geopolymer, but slag has much adverse effect on compressive strength of geopolymer.

In addition, source material possesses effect on geopolymer properties. Xu and Van Deventer (2003) concluded that using a different amount of slag will be resulted an improving the compressive strength.

Temuujin et al. (2009) conducted that adding sodium silicate and sodium hydroxide improves the mechanical strength of the fly ash or slag with geopolymers cured at room temperature (ambient curing).

De Silva (2007) conducted an experimental study on the role of slag and fly ash on the based geopolymer, stated that setting time will increase by increasing the amount of slag. Moreover, the amount of slag or fly ash was found out to be responsible for higher strength gain, especially at a later age.

Curing effects geopolymer concrete making can be found by the right balancing of temperatures and be curing period. Comparable to Portland cement with geopolymer concrete is more simply reached with heat temperature basis to help alkaline activators of the Pozzolanic material. This research using temperature of $70C^0$ resulted in higher compressive strength for geopolymer concrete (Hardjito and Rangan, 2005). Moreover, using curing temperature increased the strength of geopolymer concrete, but the short time of curing decrease the strength of concrete (Rangan,2001). The investigation results showed that 48hrs of curing developed the resulting in compressive strength (hard to and range, 2005).

Curing temperature effects geopolymer concrete making can be found by the right balancing of temperatures and curing period. the most important improvement of geopolymer concrete is curing temperature. This research using temperature of $70C^0$ resulted in higher compressive strength for geopolymer concrete -Hardjito and Rangan, 2005-. Moreover, a lot of time using curing increased the strength of geopolymer concrete, but if it gains a short time of curing decrease the strength of geopolymer concrete -Rangan, 2001-. The investigation results showed that using curing time for 48hrs developed the strength of compressive strength (hard to and range, 2005).

2.11. Summary

Information available in literature that is relevant to the topic is presented in this chapter. The effect of mix design parameters on the mechanical strength properties of geopolymer concrete obtained from previous studies are gathered and critically discussed. It has been identified that high volume of slag increases the strength of geopolymer concrete. In the present study, the experimental test of different proportions of GGBFS and FA in the binder on mechanical and durability properties of geopolymer concrete.

CHAPTER 3

EXPERIMENTAL WORK

3.1. Introduction

This Chapter describes the experimental work. First, the materials, mixture proportions, manufacturing and curing of the test specimens are explained. This is then followed by description of types of specimens used, test parameters, and test procedures. The aim of this research is to evaluate the effect of different proportions of GGBFS and FA on mechanical and durability of geopolymer concrete. .

3.2 Materials

The materials utilized for producing geopolymer mortar are fly ash and slag as a source material, the combination of sodium silicate and sodium hydroxide as alkaline liquid activator, and superplasticizer in liquid for improving the strength of concrete.

3.2.1 Fly Ash

In the present study low calcium fly ash (ASTM Class F) from local sources was utilized as a source material. Table 3.1 shows physical and chemical compositions of fly ash. Class F fly ash normally produced from burning anthracite or bituminous coal.

Table 3.1 Physical and chemical properties of fly ash

Physical and chemical analysis (%)	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 (LOI)	1.5
Specific gravity	2.25
Specific surface area (m^2/kg)	379

3.2.2. Ground granulated blast-furnace slag (GGBFS)

GGBFS is a glassy granular material. It is a non-metallic product, consisting of silicates and aluminosilicate of calcium and other bases. The chemical and mineral compositions of GGBFS are given in Table 3.2.

Table 3.2 Chemical composition of GGBFS

Sample	GGBFS %
SiO_2	29.96
Al_2O_3	12.25
Fe_2O_3	0.52
CaO	45.45
Na_2O	0.31
K_2O	0.38
SO_3	3.62
P_2O_5	0.04
TiO_2	0.46
LoI[b]	2.39

3.2.3. Aggregate

Aggregates were used as a fine aggregate locally in western part of Turkey's Southeastern Anatolian Region; Gaziantep for producing fly ash and slag based geopolymer mortar.

3.2.4 Alkaline Activator

Sodium based activator (a combination of sodium silicate and sodium hydroxide solution) was chosen as the alkaline activator for activating geopolymer concrete. Sodium activator was picked because they were cheaper than potassium activators. The NaOH used in this study was in pellets from with 97-98% purity and were dissolved in water at 24 hours prior to mixing. Figure 3.1 shows the preparation of alkali solution.

Figure 3.1 Alkaline activator (Sodium silicate and Sodium hydroxide)

3.2.5. Superplasticizer

In order to improve the strength of fresh concrete, high-range water-reducing naphthalene based superplasticizer was added to the mixture, and specific gravity was 1.07. Gelenium 51 was used in this search to develop the strength of concrete. Properties of the superplasticizer is shown in table 3.3

Table 3.3 Properties of superplasticizer

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

3.3 Manufacture Geopolymer Mortar

Alkali activator was prepared by mixing sodium hydroxide and sodium silicate one day in advance to ensure it to cool down in a room at temperature (25°C). Fly ash, slag and aggregate were first mixed together pan mixer for 3 minutes to ensure homogeneity of the mixture. Then, mortar mixer stopped. The liquid components that contain sodium hydroxide solution, sodium silicate and superplasticizer were added to the dry materials and the mixing continued for further about 5 minutes to produce the fresh fly ash and slag based geopolymer mortar. In Figure 3.2 shows the resource material and alkali activator of geopolymer concrete.

Then, the fresh geopolymer mortar was poured into 50x50x50 mm cube molds directly after mixing in to two layers, as described in the ASTM C109 standard. Moreover, for the compaction of the specimens the rod was employed, and each layer of geopolymer mortar was tamped 25 times with a rod. To remove air voids, all the cast specimens were vibrated on a vibrating table for 2 minutes. Figure 3.3 shows adding alkali activators with dry materials.

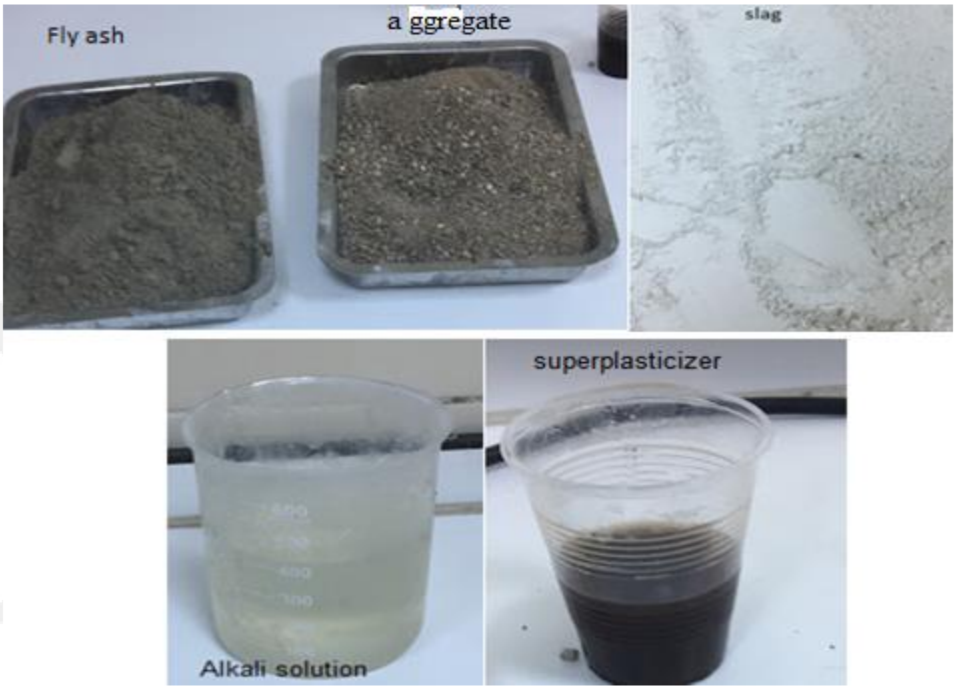

Figure 3.2 Constituents material of geopolymer

Figure 3.3 Adding alkaline activator to the dry components

Before casting the equipment prepared, the fresh concrete was cast into the moulds immediately after mixing, two layers for prismatic specimens. The specimens were covered with vacuum bagging film to minimise the water evaporation during curing temperature.

Figure 3.4 Casting geopolymer mortars

3.4 Curing

After casting, for minimizing water evaporation, the test specimens were wrapped with vacuum bagging film at high temperature. In this study dry heat curing was used, the specimens were cured in oven at temperate (70°C).

After the curing period, 24 hours for specimens tasted after one day and 48 hours for specimens tasted after 7 days. All specimens demolded.

Figure 3.5 Dry (oven) Curing

3.5 Mixture Proportion

In Table 3.4 respectively summarized the detail of mixture proportions based on percentage of fly ash and slag that were tried during the experimental research for producing geopolymer mortar. Ten mixes were tested in this study; each mixture has different proportion of FA and GGBFS as whown in table 3.4. Main feature are:

1- Fly ash and slag was used.
2- Water just used for dissolution NaOH pellets.
3- Na_2SiO_3 was mixed NaOH in all mixtures.
4- Superplasticizer was used.
5- Curing temperature kept at (70°C).
6- Curing period was 24 hours for specimens tasted after one day and 48 hours for specimens tasted after 7 days.
7- Oven dry curing was used.

Table 3.4: Mixtures proportions of geopolymer concrete

Mixture	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6	Mix7	Mix8	Mix9	Mix10	Mix11
Sand	2039	2058	2077.5	2097	2116.5	2136	2155.5	2175	2194.5	2214	2233.5
Fly ash	1200	1080	960	840	720	600	480	360	240	120	0
GGBFS	0	120	240	360	480	600	720	840	960	1080	1200
Water	177	177	177	177	177	177	177	177	177	177	177
Sodium silicate	428.5	428.5	428.5	428.5	428.5	428.5	428.5	428.5	428.5	428.5	428.5
Sodium hydroxide	171.5	171.5	171.5	171.5	171.5	171.5	171.5	171.5	171.5	171.5	171.5
Super plasticizer	72	72	72	72	72	72	72	72	72	72	72

3.6 Experimental Tests for Geopolymer Mortar

3.6.1 Compressive Strength

In the study of strength of materials, the compressive strength is the capacity of a material or structure to withstand loads tending to reduce. According to ASTM C109 for cement mortar cubes were followed. Each mix was cast into several cube molds, by filling the mold halfway and vibrating for 30 seconds, filling the mold the rest of the way and vibrating again for 30 seconds, then leveling off the top. The molds were then covered in plastic and covered again in vacuum wrapping to keep a humid environment during curing. Molds were placed in the oven at 70°C for 48 hours after mixing. A load 3000 kN capacity digital compressive testing machine as shown in Figure 3.6 with a loading rate 0.5 kN/sec was used. For each parameter tested after 1, 7 days, three identical samples were tested in accordance with ASTM C-109 and the mean values of compressive strength are reported in relevant tables and graphs.

Figure 3.6 Compressive strength tests

The compressive strength of the specimens was calculated using the equation:

$$f_c = \frac{P}{A}$$

Where,

f_c= Compressive strength (MPa)

P= maximum force applied (kN),

A=Cross sectional area (mm2)

3.6.2 Splitting Tensile Strength

Hardening fly ash and slag based geopolymer mortar specimens after 48 hours curing at 70^0 C, splitting tensile strength was performed on 3000 kN capacity digital machine in accordance to ASTM C37 with a loading rate 0.1 kN/sec. For every mixture three identical specimen cubic 50x50x50 mm were tested, the result value are given and was reported in various figures and graphs.

Splitting tensile strength of the specimen was calculated using the expression below

$$f_s = \frac{2P}{\pi a^2}$$

Where f_s is splitting tensile strength (MPa), P is splitting load (N), a is dimension of cubic specimen (mm)

3.6.3. Water sorptivity test

Sorptivity can be considered as one of the easier test for evaluating permeability of mortar concrete. Water can penetrate into the concrete or mortar specimens by capillary suction. In addition, it can measure the rate of absorption fluid that was entering the mortar concrete by capillary suction. Sorptivity will be determined by measuring the capillary water sorption by sorption depends on both the capillary pressure and effective porosity. Capillary pressure connected to the size of pores according to Young-Laplace equation, as well as effective porosity relate to the pore space in the gel pores and capillary according to Neville (2000). The sorptivity test evaluates the amount of capillary rise absorbed by mortar or concrete specimens. At 7 days age, for each mix, three identical specimens were tested, then the side specimen 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 3.8. It should be observed the water level was maintained not more than 5 mm from the bottom face of the specimen during the test. Time was recorded immediately after placing the specimens on the support device (initial contact with water). The increase in the mass gain weighted at different time intervals of the prism at 1, 4, 9, 16, 25, 36, 49, and 64. After each time interval the specimen was removed from the pan and wipe out extra water from the surface before taking the weight.

And placing them with dry surfaces on an electric pan balance, So that the absorbing surface would not be touched and then returning them to their sponges within 15 second. Sorptivity test is shown in figure 3.7

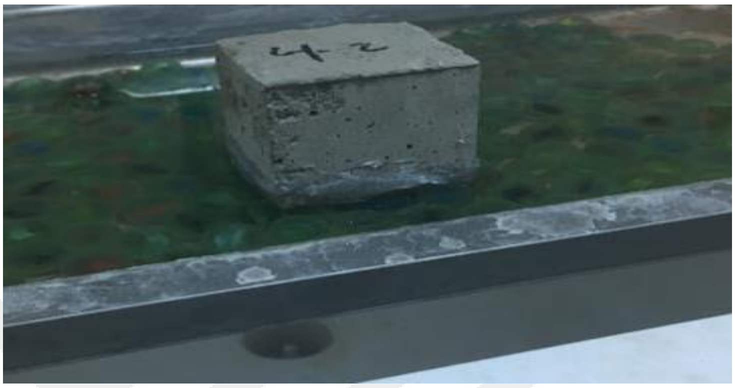

Figure 3.7 Sorptivity test

CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSION

4.1. Introduction

The results of the tests on ten geopolymer concrete mixtures are discussed in this chapter. The geopolymer concrete based on the fly ash and slag were tested to investigate the mechanical and durability properties. Compressive strength and tensile strength were determined at different ages. Ten miexes has been tasted each mix has different proportions of FA and GGBFS.

4.2. Mechanical properties of concrete

4.2.1. Compressive strength

Compressive strength is considered as one of the most important properties of hardened concrete. It is generally the main property value used to investigate the quality of concrete according to ASTM C109. That is why it is important to evaluate whether changes in the mixture composition will affect the early and late compressive strength of concrete. Compressive strength results of GPC for cubic molds 50x50x50 at ages of 1day and 7day given in Table 4.1. Strength developments of the concrete samples over the period are planned in Figures 4.1 and Figure 4.2.

Table 4.1 Compressive strength test

mixtures	Compressive strength	
	1day	7day
Mix1	21.5	39.15
Mix2	26.57	42.43
Mix3	31.31	46.73
Mix4	35.78	50.02
Mix5	39.52	57.73
Mix6	41.73	59.73
Mix7	49.51	63.62
Mix8	55.2	68.69
Mix9	57.29	70.93
Mix10	63.34	75.17
Mix11		

It can be seen from these figures that strength development of the geopolymer concrete increase when the percentage of slag increase. Comparing the strength developments of the geopolymer concrete mixtures of all mixture, it can be seen that the inclusion of GGBFS in the binder has increased compressive strength.

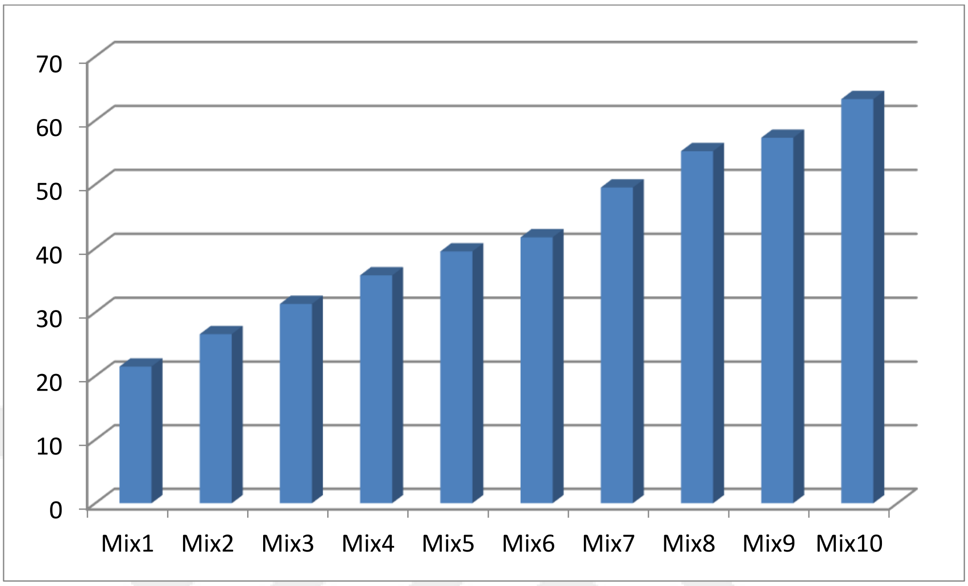

Figure 4.1 compressive strength results after 1day

In mixture GPC2 containing 20% slag and 80% fly ash achieved higher 1-day compressive strength than GPC1 containing 10% slag and 90% fly ash . Moreover, the strength of GPC4 is higher than that of GPC2. Thus, the effect of slag on the compressive strength appears to be more pronounced when the fly ash ratio is reduced. The highest strength increase was achieved in mixture GPC10 with 90% GGBFS and 10% fly ash. Similar strength increase was also observed at 1 days of age with the inclusion of slag in the binder.

In GPC1with no slag in the binder, developed strength at a slow rate when used 100% fly ash. When GGBFS was incorporated in the mixture as a part of binder with fly ash, the strength increased significantly. As shown in Figure 4.2, the compressive strength of geopolymer concrete increased from the early age of 1 day and continued to gain strength up to 7 days. At 7 days, mixture GPC6 and GPC7 having 50% and 60% slag respectively, achieved higher strength, than the geopolymer concrete without slag (GPC1).

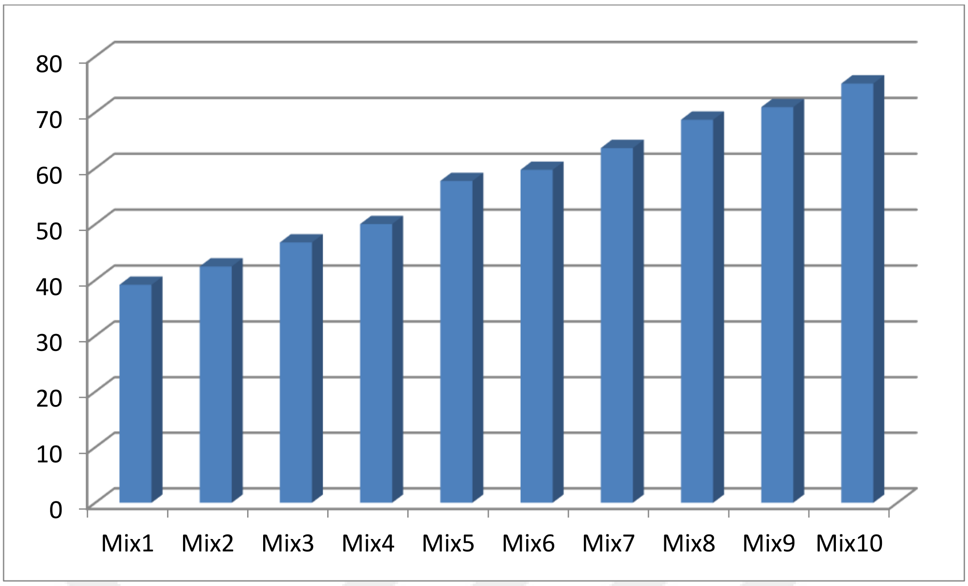

Figure 4.2 compressive strength result after 7day

The improvement of strength of slag blended fly ash based geopolymer concrete is due to the increase of calcium bearing compound in the dissoluted binder which produced reaction product from both slag and fly ash. The strength increase of geopolymer concrete mixtures, GPC9 and GPC10 as compared to GPC8 showed similar trends of GPC5, GPC6 and GPC7. It can be seen that the strength increase when the percentage of slag increase.

4.2.2. Splitting tensile strength

The concrete and mortar is very weak in tension due to its hard brittle nature and is not expected to resist the direct tension. The cracks of concrete improve when subjected to tensile forces. Therefore, it is needed to find out the split tensile strength of concrete for determining the load at which the members of concrete may crack. Results of split tensile strength summarized in Table 4.3.

Table 4.2 Splitting tensile test

mixtures	1day	7day
Mix1	3.06	3.42
Mix2	3.41	3.55
Mix3	3.59	3.67
Mix4	3.77	3.90
Mix5	3.89	4.06
Mix6	4.03	4.20
Mix7	4.34	4.48
Mix8	4.52	4.71
Mix9	4.86	4.96
Mix 10	5.01	5.23
Mix11		

The splitting tensile strengths of the geopolymer concrete are given in Figure 4.3, while the splitting tensile result at age 7days are give in Figure. 4.4.

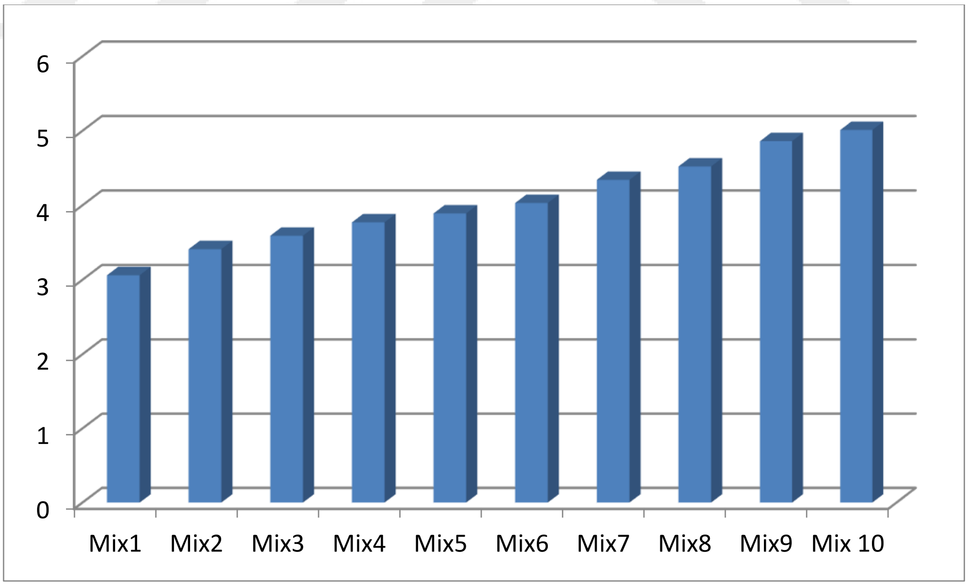

Figure 4.3 Splitting tensile results after 1day

It can be seen from Figure. 4.3 That the splitting tensile strength increased with the increase of GGBFS content in the geopolymer mixtures. Moreover, the rate of strength development is high when the percentage of GGBFS was increased. Geopolymer concrete mix10 with 90% GGBFS and 10% fly ash gained higher tensile strength than mix1 with 10% GGBFS and fly ash ratio of 90%.

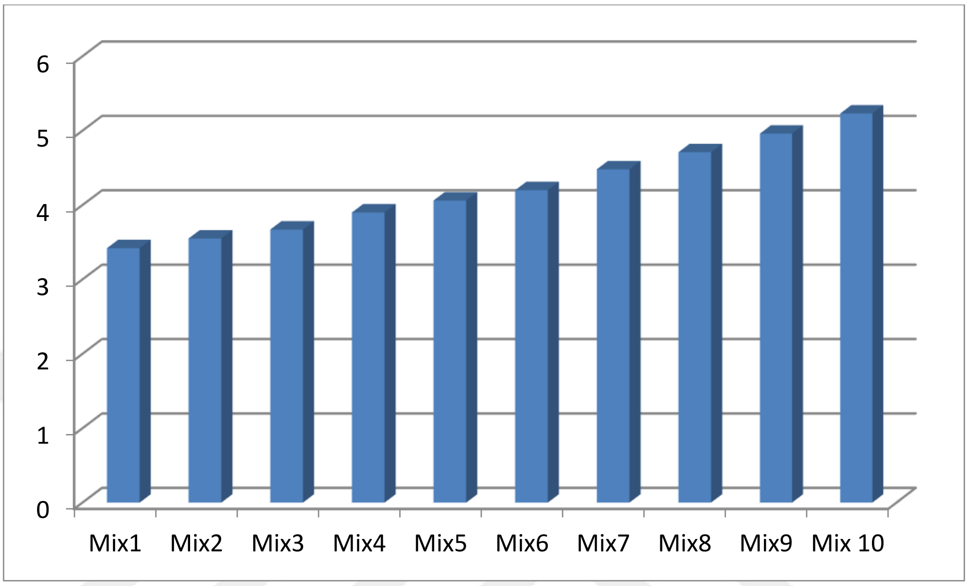

Figure 4.4 Splitting tensile result after 7 days

It is observed that the splitting tensile strength development of geopolymer concrete is relatively slow for mixture GPC1 (fly ash only as the binder).

4.2.3 Water Sorptivity

The sorptivity of a mortar is a measure of the rate of water absorbed by mortar over a time period of determined time. Specifically, it is the gradient of the straight line fitted to the plot of water absorbed by the mortar unit against the square root of time. A major objective in the development of the sorptivity test was to better account for the critical period in mortar bond development, namely the first few minutes when the free water in the mortar can migrate to the pores carrying the early hydration products (Goodwin and West, 1982). This process continue for the 64 minutes allowed for in the total absorption test, nor can it be represented by a 1 minute time period of the IRA test (RedaTaha et al., 2001). Results of sorptivity tests are summarized in Figure 4.5.

The GGBFS geopolymer concrete specimens display a significantly very low water sorptivity than FA. As the proportional of GGBFS increased the sorptivity test decrease

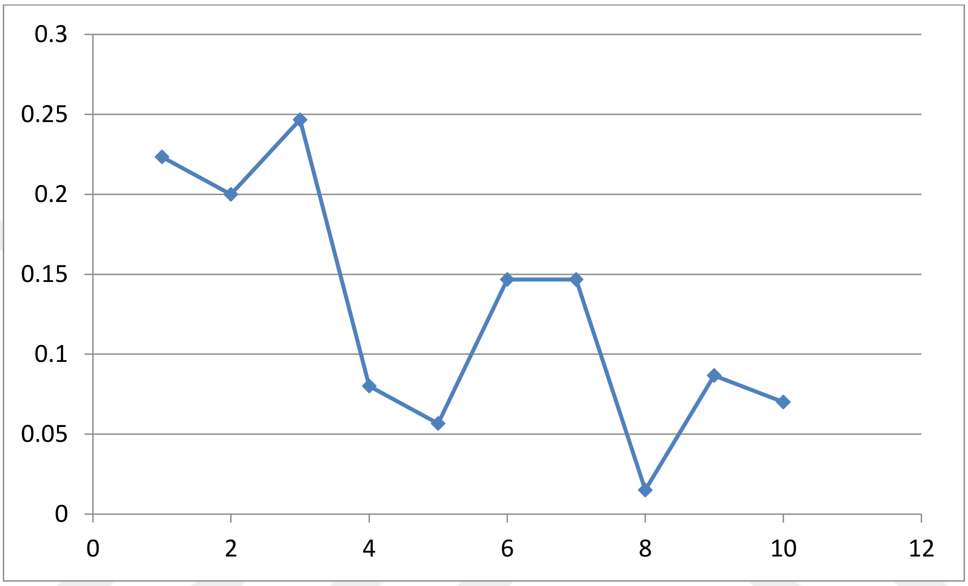

Figure 4.5 Sorptivity test at age 64 min

Similarly, Goodwin (2013) concluded that GGBFS geopolymer mortar has very little water sorptivity than fly ash.

CHAPTER 5

CONCLUSION

5. Introduction

This Chapter presents a brief summary of the study and a set of conclusions drawn from the study. The mechanical properties included in the study are compression and tensile testes while a durability property measured using sorptivity test.

In the present study, the experimental test of different proportions of GGBFS and FA in the binder on mechanical and durability properties of geopolymer concrete. Ten mixes have been tests; each mixture has different proportion of FA and GGBFS. It can be concluded that geopolymer concrete with high percentage of GGBFS gain high compressive and tensile strength compared with Geopolymer with high FA.

Compressive strength of mix1 with 90% FA and 10% GGBFS is 39.15 Mpa at 7 days age. Compressive strength of mix10 with 90% GGBFS and 10% FA is 75.17 Mpa at 7days age. The highest compressive strength of geopolymer mortar was obtained in 90% slag and 10% fly ash at age of 7 days, the lowest compressive strength was observed in 100% fly ash.

According to the results, the splitting tensile strength is only a fraction of compressive strength in percentage of slag and fly ash. It was observed that splitting tensile strength gradually increased with the increase of slag.

Based on the results, the combined fly ash with slag includes (50% slag and 50% fly ash) shows normal compressive and tensile strength, Water sorptivity in geopolymer mortar for all type of fly ash is very low compare to slag geopolymer concrete and mortar, combined fly ash shows very low sorptivity.

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