# Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of fly ash based Geopolymer Concrete made by replacing fine aggregate with coal bottom ash

**Zewdu Sileshi Akalu**

**A Thesis Submitted to the Department of Civil Engineering School of Civil Engineering and Architecture**

**Presented in Partial Fulfillment of the Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)**

**Office of Graduate Studies**

**Adama Science and Technology University**

**June, 2023**

**Adama, Ethiopia**

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# DECLARATION

This thesis entitled " **Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of fly ash based Geopolymer Concrete made by replacing fine aggregate with coal bottom ash**" is my own work and has not been submitted to any university for similar purposes. Proper citations duly acknowledge the references used in this thesis.

Zewdu Sileshi ____________________ ____________________

Signature Date

## RECOMMENDATION OF ADVISOR

I, the principal advisor of this thesis, hereby certify that I have closely advised and supervised the student while developing this thesis and have read the draft thesis entitled "**Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of fly ash based Geopolymer Concrete made by replacing fine aggregate with coal bottom ash**" prepared under my guidance by Zewdu Sileshi.

Therefore, I recommend submitting the thesis to the department for further review and evaluation.

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| Lemma Beressa, Ph.D. | __________________ | _______________ |
| Major Advisor | Signature | Date |

# APPROVAL PAGE

I, the principal advisor of this thesis, hereby certify that the recommendations and suggestions given by the thesis review Committee are appropriately incorporated into the final thesis entitled "**Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of fly ash based Geopolymer Concrete made by replacing fine aggregate with coal bottom ash**" by Zewdu Sileshi.

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| Major Advisor | Signature | Date |

# APPROVAL OF BOARD REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by Zewdu Sileshi Akalu have read and evaluated the thesis entitled "**Experimental Investigation on Physio-Mechanical and Micro-Structural Properties of fly ash based Geopolymer Concrete made by replacing fine aggregate with coal bottom ash**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Masters of Civil Engineering Specialization in Construction Engineering and Management).

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Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC)

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# LIST OF ACRONYMS

| ACRONYMS | FULL NAME |
|---|---|
| AAC. | Alkali Activated Concrete |
| ACI | American Concrete Institute |
| ASG | Apparent specific gravity |
| ASTM | American Society for Testing and Materials |
| BFS | Blast Furnace Slag |
| BSG | Bulk specific gravity |
| CA | Coarse Aggregate |
| CBA | Coal Bottom Ash |
| CC | Conventional Concrete |
| FA | Fly Ash |
| FM | Fineness Modulus |
| GGBFS | Ground Granulated Blast Furnas Slag |
| GPC | Geopolymer Concrete |
| MPa | Mega Pascal |
| NRS | Natural River Sand |
| OPC | Ordinary Portland Cement |
| PCC | Portland Cement Concrete |
| SCM | Supplementary Cementing Materials |
| SEM | Scanning Electron Microscope |
| SHS | Sodium Hydroxide Solution |
| SSD | Saturated Surface Dry |
| SS | Sodium Silicate |
| UWCA | Unit Weight of Coarse Aggregate |
| UWCBA | Unit Weight of Coal Bottom Ash |
| UWFA | Unit Weight of Fine Aggregate |
| XRD | X-Ray Diffraction |
| XRF | X-Ray Fluorescence |

# LIST OF CHEMICAL FORMULAS

| Formula | Name of chemicals compounds |
|---|---|
| $2CaO.SiO_2$ | Dicalcium silicate |
| $3CaO.SiO_2$ | Tricalcium silicate |
| $3CaO.Al_2O_3$ | Tricalcium Aluminate |
| $4CaO.Al_2O_3.Fe_2O_3$ | Tetra-calcium aluminoferrite |
| $CaSO4.2H_2O$ | Calcium sulfate dihydrate |
| CaO | Calcium oxide |
| MgO | Magnesium Oxide |
| $Na_2O$ | Sodium Oxide |
| $K_2O$ | Potassium Oxide |
| CH | Methylidyne |
| C-S-H | Calcium-silicate-hydrate |
| $CO_2$ | Carbon Dioxide |
| $CaCO_3$ | Calcium Carbonate |
| $Ca\ (OH)_2$ | Calcium Hydroxide |
| $H_2O$ | Water |
| $Na_2SiO_3$ | Sodium silicate |
| NaOH | Sodium hydroxide |

# *ABSTRACT*

*The demand for concrete as a material for construction will increase as the need for infrastructure development increases. Such an enormous utilization of concrete in the construction sector calls for a higher use of cement and natural aggregates. Fly ash based geopolymer concrete has a potential to enhance the sustainability of concrete product. Most previous works examined the properties of fly ash-based geopolymer concrete (GPC) subjected to curing at elevated temperatures, and there is lack of knowledge on geopolymer concrete incorporating coal bottom ash replacing fine aggregate. Therefore, the current study aimed to investigate the physio-mechanical, micro-structural properties, and environmental impacts of fly ash-based geopolymer concrete with bottom ash replacing fine aggregate. In this study, the characterization tests for fly ash and bottom ash, compressive strength, flexural strength, water absorption, and microstructural properties of the hardened geopolymer concrete were investigated. To make geopolymer concrete, fly ash and bottom ash, natural river sand, coarse aggregate, NaOH (16 M) flakes, and Na2SiO3 liquids with the ratio of NaSiO3/NaOH =2, were mixed together. The replacement of sand with bottom ash was 0%, 5%, 10%, and 15% by weight. From this test result, Due to the viscous nature of alkaline activators as well as the increased water absorption and surface texture of bottom ash, the workability of the concrete decreased as the amount of bottom ash in the geopolymer concrete mix increased. The compressive strength of concrete was improved by 1.03% for 5% replacement at the age of 28 days as compared to the control sample; however, it decreased between 10 and 15%. In addition, the result has shown a comparable flexural strength between the geopolymer concrete at 5% sand replacement scenario and conventional concrete. Furthermore, the water absorption of the concrete increased as the percentage of replacement increased because of the porous surface of the bottom ash. Hence, from the study, generally a geopolymer concrete of C-25 with acceptable physio-mechanical properties can be produced. while reducing the environmental impact of cement manufacturing, and industrial by-products.*

**Keywords**: geopolymer concrete; ambient curing; fly ash; bottom ash; alkaline activator

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the study

One of the most frequently used building materials is concrete, and Portland cement is typically thought of as the key ingredient in its production. It is known that concrete is the second most used material after water, and it comprises more than 20% of ordinary Portland cement (OPC) (Tayeh et al. 2022). Concrete is more and more in demand as a building material. It is estimated that the production of cement will increase from about 1.5 billion tons in 1995 to 2.2 billion tons in 2010 (Wallah and Rangan 2006). The most adaptable, reliable, and enduring building material is concrete. Next to water, concrete is the most commonly used material, which requires large quantities of Portland cement. In order to meet this demand, the production of Portland cement must increase (Rangan 2008). However, ordinary Portland cement production is second only to the automobile as the major generator of carbon dioxide, which pollutes the atmosphere.

Although OPC is an essential ingredient for concrete and is immensely popular, it greatly contributes to the release of a massive quantity of CO2 into the atmosphere (Janani and Revathi 2015). Coimbatore et al. (2012) state that while producing one ton of cement, approximately one ton of carbon dioxide will be emitted into the atmosphere, which is a major threat to the environment. Moreover, cement production also consumes a significant amount of natural resources. Hence, it is essential to find an alternative binder (Tayeh et al. 2022) also, states that, the rapid development of the construction industry worldwide encourages scholars and academics to search for alternative, sustainable materials in the construction industry.

Such an increase utilization of concrete in the construction sector calls for a higher use of natural aggregates and cement. Granular materials make up at least 75 percent of the total volume of concrete. Natural resources such as river sand are getting depleted (Soman ,et al.2014). The prohibition on mining in some areas and the growing need for natural environment conservation further exacerbate the problem of river sand availability. and the increased demand for environmental preservation. To protect the interests of future generations,it has become essential to find new alternative materials for sustainable development to significantly reduce the consumption of natural resources (Nguyen et al. 2019).

The construction industry has recently developed a new material called geopolymer concrete (GPC), which uses a variety of chemical reactions and compositions as a binding material. The high silica and alumina content of pozzolanic materials (industrial waste like fly ash, ground granulated blast furnace slag (GGBFS), and rice husk ash) act as the mixture's binding materials (Verma et al. 2022). The geopolymer technology shows considerable promise for application in the concrete industry as an alternative binder to Portland cement (L.Krishnan 2014). Geopolymer-based concrete employing fly ash has great potential to replace conventional Portland cement (OPC)-based concrete in the construction sector (Albitar et al. 2015).

Geopolymer is a rising field of research for utilizing by-products. It has paved the way for finding new alternatives for the replacement of cement in concrete (Park et al. 2016). Geopolymer concrete (GPC) is a sustainable material that not only utilizes industrial wastes such as fly ash effectively but also serves as a better alternative to ordinary Portland cement concrete (McLellan et al. 2017). The production of geopolymer concrete is carried out using conventional concrete technology methods. The fly ash-based geopolymer concrete consists of 75% to 80% mass of aggregate, which is bound by a geopolymer paste formed by the reaction of the silicon and aluminum within the fly ash and the alkaline liquid made up of sodium hydroxide and sodium silicate solution with the addition of superplasticizer (Vora and Dave 2013).

In the past years, research has revealed that geopolymers with high compressive strength, good acid resistance, and good fire resistance could be synthesized from a variety of low-cost materials or industrial by-products. These characteristics render geopolymer promising in civil engineering applications as a "green" material (Fan et al. 2018). The compressive strength of geopolymer concrete is very high compared to ordinary Portland cement concrete, and it also showed very high early strength when cured at high temperatures (Nath and Sarker, 2014). The results of the investigation by Nematollahi et al.(2014), indicated that there was an increase in compressive strength with an increase in NaOH concentration. Strength was also increased with an increase in curing time. Compressive strength up to 46 MPa was obtained with curing at $60^{o}$C (Patil, et al. 2014). states that higher temperature curing results in significant strength improvement. At higher temperatures ranging from 60 °C to 90 °C, the geopolymerization is faster. Similarly, extended curing times enhanced the geopolymerization mechanism and achieved greater strength (Seri Iskandar, et al 2018). The amount of calcium content in the fly ash was found to have a significant impact on the resulting hardened geopolymer. Calcium oxide is believed to form calcium silicate hydrate (CSH) along with the aluminosilicate geopolymer gel (Nath, et al. 2015).

The majority of the geopolymer concrete tested so far was either heat-cured or steam-cured at a higher temperature than ambient. Heat curing can only be achieved in precast concrete structures. These characteristics are thought to be a barrier for on-site concrete applications and restrict the use of fly ash-based geopolymers to only precast concrete. Most of the previous studies on geopolymer concrete used some industrial by-products instead of cement, but it is so important to use such industrial by-products partially replaced with fine aggregates in producing geopolymer concrete to reduce the consumption of natural sand. In the current study, the properties of fly ash-based geopolymer concrete with partially replaced fine aggregates by bottom ash, such as compressive strength, flexural strength, and water absorption, were investigated experimentally by curing at an ambient temperature(23-27$^{o}$C). In addition, its production was checked by scanning electron microscope (SEM) images and X-ray diffraction (XRD), as well as the embodied energy and CO2 emission was evaluated.

## 1.2 Statement of the problem

The recent boom in the construction industry has caused a massive elevation in demand for cement, and natural river sand which is the main constituent material in the production of concrete (Cheah and 2019). Globally, the use of concrete increases day by day due to the increasing need for modern infrastructure facilities, which are mostly constructed of concrete (Albitar et al. 2018). In concrete production, particularly in cement production depletion of natural resources which are used as raw material for concrete, releasing of large amount of carbon dioxide which is the main environmental impacting gases and usage of intense energy is the headache of construction industry (Mehta 2022). The contribution of greenhouse gas emissions from Portland cement production is about 1.35 billion tons annually, or about 7% of the total greenhouse gas emissions to the earth's atmosphere, furthermore, Portland cement is also among the most energy-intensive construction materials, after aluminum and steel (Hardjito et al. 2004). Increasing the demand for natural river sand leads for environmental degradation caused by excessive sand mining from rivers (Padmalal et al. 2015). The high demand for natural river sand that is required in the production of concrete leading to excessive exploitation of river beds, causing severe environmental problems (Nguyen et al. 2019).

Most of the previous studies on geopolymer concrete used some industrial by-products instead of cement, but it is so important to use incorporating industrial by-products partially replaced with fine aggregates in producing geopolymer concrete to reduce the consumption of natural sand. In addition, most of the geopolymer concrete tested so far was heat cured at a higher temperature to gain better strength at an early age. The curing temperatures were reported in the range between 40°C and 90°C for complete polymerization reactions (Sumajouw and Rangan 2018), but oven curing can only be achieved in precast concrete structures. These characteristics are thought to be a barrier for on-site concrete applications and restrict the use of fly ash-based geopolymers to only precast concrete. However, it is unclear how varying the percentage of bottom ash used as partial substitute for natural river sand would affect the property of fly ash based geopolymer concrete which is cured at ambient temperature. Thus, this research aims to provide additional information on the physio-mechanical, micro-structural properties, and environmental impact of fly ash-based geopolymer concrete with bottom ash replaced fine aggregate cured at ambient temperature.

## 1.3 Research Objective

### 1.3.1 General objective

The general objective of the study is to investigate physio-Mechanical, Microstructural properties, and embodied energy, $CO_2$ emission of fly ash-based geopolymer concrete(C-25) produced by partial replacement of sand with bottom ash at ambient temperature.

### 1.3.2 Specific Objective

- To assess the properties of Fly ash and Bottom ash through characterization test with respect to ASTM standard.
- To determine the optimal replacement of CBA with NRS through the study of physio-Mechanical properties of fly ash-based geopolymer concrete
- To investigate the Microstructural properties of fly-ash based geopolymer concrete by partial replacement of sand with bottom ash
- To Compare the embodied energy and $CO_2$ emission of conventional concrete with geopolymer concrete made with optimal replacement of sand with CBA.

## 1.4 Research question

- What is the physio-chemical properties of Fly ash and Bottom ash used in the study?
- What is the optimal replacement of CBA with sand in fly ash based geopolymer concrete with acceptable physio-Mechanical properties as C-25?
- What is the Microstructural properties of fly ash based geopolymer concrete by partial replacement of sand with bottom ash?
- What is the embodied energy and CO2 emission of conventional concrete when compared to geopolymer concrete made with optimal replacement of sand with CBA?

## 1.5 Significance of The Study

The significance of the current investigation provides helpful information to stakeholders in the construction industry on decreasing the depletion of natural resources (particularly cement) and reducing the impacts of unwanted by-products of industry like fly ash and bottom ash. Replacing cement with fly ash, can be helpful in decreasing cement demand and eventually minimize CO2 emissions. In addition, replacing fine aggregate with bottom ash reduces large-scale quarrying and the environmental problems arising from filling it inland. As a result of reduced sand consumption, the problems in sand mining can also be reduced. On the other hand, this research can be used as a reference for further study with respect to fly ash-based geopolymer concrete incorporating bottom ash as fine aggregate.

## 1.6 Scope of the study

The study goal was to investigate the properties fly ash-based geopolymer concrete with partially replaced sand by bottom ash, such as compressive strength, flexural strength test, and water absorption test at the age of 7 and 28 days of curing, as well as the microstructural properties of hardened concrete (SEM and XRD) and also the embodied energy and CO2 emission, with the specified combination of bottom ash were compared to the conventional concrete sample. The study was limited to the C-25 grade of concrete.

## 1.7 Organization of the document

The current study is organized into five chapters. The first chapter is an introductory section that covers the study’s background, problems, objectives, scope, and significance. The second chapter provides a concise review of concrete, cement, fly ash, bottom ash, geopolymer concrete, and the application and properties of geopolymer concrete. The third chapter discusses the materials utilized and the experimental methodologies used to conduct various experiments. The fourth chapter contains the results of various tests as well as their discussion. Lastly, the final chapter presents the study’s conclusion and a researcher’s recommendations.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.1 Concrete

Among all the materials used for construction, concrete is one of the most important materials in the industry (Mehta 2022). Science and technology have greatly benefited humans as a result of civilization's rapid advancement and industrialization; among these benefits is the construction industry's explosive rise (Janani and Karner 2015). To ease various challenges in the building business, several innovative technologies have developed quickly. Major forces that were responsible for economic and social transformations in society are population growth, industrialization, urbanization, globalization of the market economy and consumerism, and environmental pollution. The forces are interconnected. Their combined impact has triggered another force, namely climate change, which is threatening to cause serious damage to human civilization on Earth. Global warming is the most important sustainability issue in the public's mind today (Suhendro 2014).

One of the most sustainable building materials in the construction sector is the use of supplementary cementing material (SCM), such as fly ash, ground-granulated blast furnace (GGBF) slag, or silica fume, which: recovers an industrial byproduct through beneficial use when incorporated into concrete; prevents the disposal of industrial byproducts; lowers the amount of Portland cement in concrete, reducing greenhouse gas emissions and the need for natural resources; and extends the service life of structures by making concrete more durable (Gjorv and Sakai,2014). Mehta (2022) suggested using fewer natural resources, less energy, and reducing carbon dioxide emissions in order to manufacture concrete that is environmentally friendly.

## 2.2 Concrete making materials

### 2.2.1 Cement

Cement has been used in construction for thousands of years, dating back to ancient civilizations such as the Egyptians and the Romans. However, the modern cement industry began in the early 19th century, when the first commercial manufacturing plant was established in England (Mohsen 2015). When mixed with water, it forms a paste that hardens and sets due to hydration reactions and processes, allowing it to gain strength after hardening (Demissew, A. 2020). Almost all types of cement produced globally are used in combination with sand, gravel, and water to make concrete and mortar (Colin et al. 2014). It is a necessary substance for today's civilization because it is an important part of concrete, a necessary ingredient for the construction of homes and infrastructure (Cao, Z. 2017).

The characteristics of cement used in construction are hydraulic or non-hydraulic. Hydraulic cement, such as Portland cement, hardens due to hydration, whereas non-hydraulic cement will not set in moist or underwater environments. Instead, when dry, it solidifies and reacts with carbon dioxide in the air (IE, 2018). According to cement chemistry, hydration is the reaction of cement with water. Partial hydration of the cement can occur even in humid air, while for complete hydration, the cement must be mixed with sufficient water (Hewlett and Liska 2019).

#### 2.2.1.1 Ordinary Portland cement

Portland cement is by far the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with other materials (such as clay) to 1450 °C in a kiln, in a process known as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix to form calcium silicates and other cementitious compounds (Mohsen 2015).

#### 2.2.1.2 Ingredients and Their Functions of Ordinary Portland Cement

According to Gagg, (2014) the principal raw materials used in the manufacture of Ordinary Portland Cement are as indicated in Table 2.1 below

Table 2. 1 Chemical constituents of Portland cement

| Ingredient | Percentage Composition |
|---|---|
| Lime (CaO) | 60 to 67% |
| Silica (SiO2) | 17 to 25% |
| Alumina (Al2O3) | 3 to 8% |
| Iron oxide (Fe2O3) | 0.5 to 6% |
| Magnesia (MgO) | 0.1 to 4% |
| Sulphur trioxide (SO3) | 1 to 3% |
| Soda and/or Potash (Na2O+K2O) | 0.5 to 1.3% |

Source: (Gagg, 2014)

Table 2. 2 Major compounds of ordinary Portland cement

| Compound | Abbreviated designation |
|---|---|
| Tricalcium silicate (3CaO.SiO2) | C3S |
| Dicalcium silicate (2CaO.SiO2) | C2S |
| Tricalcium aluminate (3CaO.Al2O3) | C3A |
| Tetra calcium alumina ferrite (4CaO.Al2O3.Fe2O3) | C4AF |

#### 2.2.1.3 Physical Property Of OPC

Table 2. 3 Physical property of ordinary Portland cement

| **Si. No.** | **Property of Cement (OPC)** | **Values** |
|---|---|---|
| 1 | Specific gravity | 3.14 |
| 2 | Absorption capacity | 3% |
| 3 | Initial setting time | 180 minutes |
| 4 | Final setting time | 290 minutes |
| 5 | Normal Consistency (%) | 31.5 |

Source: (Mukherjee, et al. 2012)

Table 2. 4 chemical constituents of national ordinary Portland cement

| Oxide | Weight By Percent (%) in National OPC Cement |
|---|---|
| CaO | 60-66 |
| $SiO_2$ | 17-25 |
| $Al_2O_3$ | 3-8 |
| $Fe_2O_3$ | 0.5-6 |
| MgO | 0.1-0.4 |
| $K_2O$ | 0.4-1.3 |
| Na2O | 0.4-1.3 |
| LOI | 1.3-3 |

Source: (Adem bedaso 2021)

## 2.3 Fly Ash

Fly ash is described as "the finely split residue that comes from the burning of ground or powdered coal and that is conveyed by flue gasses from the combustion zone to the particle removal system" in the American Concrete Institute (ACI) Committee 118R (2004). Before the combustion gases are released into the environment, fly ash is taken out of them by the dust collecting system either mechanically or via electrostatic precipitators (Beskopylny et al. 2021). Fly ash particles typically have a diameter of less than 1$\mu$m and no more than 150 $\mu$m are spherical, and are finer than Portland cement and lime. A by-product of industry known as an environmental pollution is fly ash, which is produced when coal is burned for energy. Fly ash particles are typically spherical and finer than Portland cement and lime, ranging in diameter from less than 1$\mu$m to no more than 150 $\mu$m. Fly ash, generated during the combustion of coal for energy production, is an industrial by-product that is recognized as an environmental pollutant. Fly ash has good potential for use in the construction industry (Azad and Samarakoon 2021).

As a waste product from burning fossil fuels (coal combustion) for the thermal generation of power, fly ash is created in enormous quantities. Currently, around 900 million tons of fly ash are produced annually throughout the world, and between 30 and 40 percent of this waste is used for a variety of tasks, including the production of cement and concrete (Basu et al. 2009). Harison, et al. (2014) claim that the combustion of black coal and brown coal, respectively, results in the production of several forms of fly ash, including Class F and Class C. Concrete, lightweight aggregate, bricks, and other building materials like Class F and Class C are made from Class F and Class C materials. Additionally, fly ash is employed in the construction of earth-filled dams and roads (Harison et al. 2014).

### 2.3.1 Classification of fly ash

According to ASTM C 618-99 Fly ash is classified into three as below

**Class N-**Raw or calcined natural pozzolans that comply with the applicable requirements for the class as given herein, such as some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, calcined or uncalcined; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales.

**Class F**-Fly ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class as given herein. This class fly ash has pozzolanic properties.

**Class C-**Fly ash normally produced from lignite or subbituminous coal that meets the applicable requirements for this class as given herein. This class of fly ash, in addition to having pozzolanic properties, also has some cementitious properties. ASTM prescribes the total composition of silicon oxide ($SiO_2$) plus alumina oxide ($Al_2O_3$) plus iron oxide ($Fe_2 O_3$)

are minimum 70% (by weight) for class F fly ash and class N and 50% (by weight) for class C fly ash

### 2.3.2 Chemical and physical Properties of Fly Ash

#### 2.3.2.1 Chemical Properties of Fly Ash

The chemical properties of fly ash are influenced to a great extent by the properties of the coal being burned and the techniques used for handling and storage (Ahmaruzzaman 2015) Table 2.5 below shows the chemical composition of fly ash characterized by (Ahmaruzzaman 2015)

Table 2. 5 chemical composition of coal fly ash

| Component (Wt. %) | Bituminous | Sub-Bituminous | Lignite |
|---|---|---|---|
| $SiO_2$ | 20-60 | 40-60 | 15-45 |
| $Al_2O_3$ | 5-35 | 20-30 | 10-25 |
| $Fe_2O_3$ | 10-40 | 4-10 | 4-15 |
| CaO | 1-12 | 5-30 | 15-40 |
| MgO | 0-5 | 1-6 | 3-10 |
| $SO_3$ | 0-4 | 0-2 | 0-10 |
| $Na_2O$ | 0-4 | 0-2 | 0-6 |
| $K_2O$ | 0-3 | 0-4 | 0-6 |
| LOI | 0-15 | 0-3 | 0-5 |

Source: (Ahmaruzzaman 2015)

Table 2.6 below shows The chemical composition of the sample obtained with the help of an X-ray fluorescence (XRF) by (Kesharwani et al. 2017).

Table 2. 6 chemical composition of fly ash by XRF

| **Compound** | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|
| **Content %** | 59 | 21 | 3.7 | 6.9 | 1.4 | 1 | 0.9 | 4.62 |

Source: (Kesharwani et al. 2017).

Table 2.6 below shows the chemical composition of the sample obtained with the help of an X-ray fluorescence (XRF) by (Gupta et al. 2017), and (Shaikh et al, 2015)

Table 2. 7 Chemical composition of coal fly ash

| Component (Wt. %) | Composition | |
|---|---|---|
| | By (Gupta et al. 2017) | by (Shaikh et al, 2015) |
| $SiO_2$ | 53.36 | 51.5 |
| $Al_2O_3$ | 26.49 | 23.63 |
| $Fe_2O_3$ | 10.86 | 15.3 |
| CaO | 1.34 | 1.74 |
| MgO | 0.37 | 1.2 |
| $SO_3$ | 0.8 | 0.84 |
| $Na_2O$ | 1.43 | 0.38 |
| $K_2O$ | 1.7 | 0.28 |
| LOI | 1.39 | 1.78 |

Source: (Gupta et al. 2017) and (Shaikh et al, 2015)

According to a study carried out by Hardjito et al. (2005), the chemical composition of the fly ash was determined by the x-ray fluorescence (XRF) analysis method. The chemical analysis shows that fly ash is mainly composed of silicon dioxide (53.36%), alumina oxide (26.49%), and iron oxide (10.86%), with small amounts of calcium oxide (0.37%), magnesium oxide (0.77%), and sulfate (1.70%). Loss on ignition of fly ash was 1.39%, which fulfilled the criteria specified in ASTM C 618-00,

#### 2.3.2.2 Physical Properties of Fly Ash

Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly amorphous in nature. In general, the specific gravity of coal ashes lies around 2.0 but varies to a large extent, from 1.6 to 3.1. This variation is due to a combination of several factors, such as particle shape, gradation, and chemical composition (Bhatt et al. 2019). The particle size distribution of most bituminous coal fly ash is generally similar to that of silt (less than 0.075 mm or No. 200 sieve). Although sub-bituminous coal fly ash is also silt-sized, it is generally slightly coarser than bituminous coal fly ash. The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area may vary from 170 to 1000 m2/kg. The color of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash (Ahmaruzzaman 2015).

Table 2. 6 Physical properties of fly ash

| | |
|---|---|
| Color | Black grey |
| Bulk density (g/cm$^3$) | 0.994 |
| Specific gravity | 2.288 |
| Moisture (%) | 3.14 |
| Average particle size (mic.m) | 6.92 |

Source: (Kasarani et al. 2017).

### 2.3.2 Use of fly ash in concrete

According to Anita Bhatia, et al. (2016), coal fly ash is a common industrial waste product that has been used to improve the ultimate compressive strength and workability of fresh concrete. For this straight forward reason, it is quickly spreading throughout the world as a standard component of concrete; it is now present to some extent in half of all concrete. One of the best examples of industrial ecology, or the efficient use of waste resources and eventual abolition of the concept of waste, is the use of fly ash as a performance-enhancing component in concrete (Anita Bhatia et al. 2016). The use of fly ash in concrete contributes to the reduction of greenhouse emissions, which has negative impacts on the economy. It has been observed that 0.9 tons of CO2 are produced per ton of cement production. Also, the composition of cement is 10% by weight in a cubic yard of concrete. to avoid pollution and reuse the material; thus, concrete is an excellent substitute for cement as it is cheaper because it uses waste products, saving energy consumption in production (Rafieizonooz et al. 2016). Bakri et al. (2011) stated that fly ash was used as a geopolymer to produce precast structures, non-structural elements, concrete pavements, concrete products, and the immobilization of toxic waste that is resistant to heat and aggressive environments.

## 2.4 Coal Bottom Ash

Coal-based thermal power plants all over the world face serious problems in the handling and disposal of the ash produced. The utilization of fly ash is about 30% in various engineering requirements that are for low technical applications such as in the construction of fills and embankments, backfills, pavement bases, and subbase courses (Nguyen et al. 2019). Coal bottom ash is a coarse, granular, and incombustible byproduct from coal-burning furnaces. It is composed mainly of silica, alumina, and iron, with small amounts of calcium, magnesium sulfate, etc. The appearance and particle size distribution of coal bottom ash are similar to those of river sand. Bottom-ash-based artificial lightweight aggregate offers potential for large-scale utilization in construction work. The other advantage of using bottom-ash is that it can be dust-free, and the sizes of bottom-ash can be controlled easily so that it meets the required grading (Singh and Siddique 2016a).

According to the study of Singh and Siddique (2016),coal bottom ash is a suitable material to be used as a partial replacement of sand in the manufacturing of concrete. These properties are comparable to those of natural aggregates, such as gravel and sand, which make coal bottom ash a suitable substitute for these materials in road construction and concrete production. Coal bottom ash has also been used as an alternative to clay in the manufacture of bricks and ceramic tiles (Ibrahim et al. 2015).

### 2.4.1 Physical Properties of Bottom Ash

According to Ramzi et al. (2016), several tests have been conducted and it was found that the particle size distribution curve between bottom ash and sand was similar, even though the grain size of bottom ash was similar to coarse to fine grains and part of it was sand-like material. Unlike natural river sand, bottom ash produced angular and irregular shapes and had a rough texture, while some of the particles showed spherical-shaped and popcorn-type particles.

Table 2. 7 Physical Property of Bottom Ash

| **Properties** | (Kim, et al. 2015) | (Thang et al.2018) | (Azad et al. 2021) | (Nguyen et al. 2019) |
|---|---|---|---|---|
| Specific Gravity | 2.2 | 2.4-2.7 | 2.27 | 1.93 |
| Water Absorption | 7% | <2 | - | 10.06% |
| Fineness Modulus | 2.85 | - | 2.3 | 2.7 |
| Color | - | Grey | black grey | - |
| Bulk Density | - | 1200-1600 | - | - |
| particle size | - | angular | - | - |

Meanwhile, the density of bottom ash is lower than the density of natural river sand as a result of the porous structure of bottom ash. Due to the porous structure, the specific gravity of coal bottom ash, which is 2.21, is lower than the specific gravity of river sand, which is 2.81. This shows that natural river sand and bottom ash are different in terms of physical and chemical properties. However, the Ramzi tests showed that bottom ash is a recommended industrial waste that has the potential to be used in concrete as a replacement for fine aggregates since the physical and chemical properties of bottom ash are almost similar to those of natural river sand (Ramzi et al. 2016),

## 2.5 Geopolymer concrete

Geopolymer is a new environment-friendly cementitious material, and the development of geopolymer can reduce the carbon dioxide emissions caused by the development of the cement industry (Davidovits, 2022). It was proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term "geopolymer" to represent these binders. (Duxson et al.2007) GPs are alternative binding materials that are produced using materials such as ground granulated blast furnace slag (slag) and fly ash (also known as pulverized fuel ash). These materials are activated or hardened using solutions of alkali silicates and/or hydroxide. Geopolymers, as inorganic polymer materials, are also known as alkali-activated materials (AAMs).

According to the Geopolymer Institute (2010), the name geopolymer was formed in 1978 by a French Professor Davidov to represent a broad range of materials characterized by networks of inorganic molecules. The geopolymers depend on thermally activated natural materials like metakaolinite or industrial byproducts like fly ash or slag to provide sources of silicon (Si) and aluminum (Al). These silicon and alumina are dissolved in an alkaline activating solution and subsequently polymerize into molecular chains and become the binder (Geopolymer institute, 2010).

In geopolymer concrete, a by-product material rich in silicon and aluminum, such as low-calcium (ASTM C 618 Class F) fly ash, is chemically activated by a high-alkaline solution to form a paste that binds the loose coarse and fine aggregates and other unreacted materials in the mixture (Hardjito 2004). Geo-polymer concrete utilizes an alternate material called fly ash as a binding material instead of cement. Fly ash reacts with alkaline solutions (e.g., NaOH) and sodium silicate (Na2SiO3) to form a gel that binds the fine and coarse aggregates (Janani et al. 2015).

### 2.5.1 Geopolymer Concrete making materials

#### 2.5.1.1 Aggregate

According to Narayanan et al. (2017), geopolymer concrete uses mixed aggregate, in saturated surface dry (SSD) conditions, local aggregates consisting of 20 mm (0.78 inches), 10 mm (0.39 inches), and 7 mm (0.273 inches) coarse aggregates were utilized. Coarse and fine aggregate of approximately 75% to 80% of the entire mixture by mass is used in geopolymer concrete mixtures; this value is similar to that used in OPC concrete(Rangan 2014).

#### 2.5.1.2 Source materials

The silicon (Si) and alumina content of the raw materials for geopolymers based on alumina-silicate should be high (Al). These could be organic minerals, like clays and kaolinite. By-products including fly ash, silica fume, slag, rice-husk ash, red mud, etc. could also be used as source materials. The selection of the raw materials used to create geopolymers is influenced by a number of variables, including cost, kind of application, and end-user demand (Rangan 2008). Among the by-product materials, only fly ash and slag have been proven to be potential source materials for making geopolymers (Hardjito et al. 2004).

#### 2.5.1.3 Alkaline activator

The common materials used as alkaline solutions in producing fly ash-based geopolymers are sodium silicate and potassium hydroxide, usually either of these materials is mixed with sodium hydroxide to produce the alkaline solution, and the molarity (M) of the alkaline solution is 7 to 16 M. The mass ratio of sodium silicate to that of hydroxide solution significantly affects the compressive strength of geopolymer concrete. It has been reported that a value between 2 and 2.8 is very appropriate for the development of good compressive strength (Jindal, et al. 2017). A ratio of 2 is very much appropriate in the development of low-calcium fly ash-based geopolymer concrete to achieve desired strength and durability properties (Jindal et al. 2017a). The alkaline solution was prepared a day before it was mixed with fly ash. Then, the materials are mixed together with fine aggregate and coarse aggregate to form concrete, and the curing process is done (Bakri et al. 2011). According to the study conducted by Hardjito, et al.(2004),a combination of sodium silicate solution and sodium hydroxide (NaOH) solution can be used as the alkaline liquid. It is recommended that the alkaline liquid be prepared by mixing both solutions together at least 24 hours prior to use.

#### a) Sodium Hydroxide Solution

Sodium hydroxide, also known as lye and caustic soda, is an inorganic compound, the reaction happens faster quickly and the gels are less smooth when there is NaOH in the activating solution (Assi et al. 2020). Fly ash dissolves differently depending on the kind and concentration of solution, claim Patankar, et al. (2014), In general, NaOH solution leaches Al+3 and Si+4 ions more readily than KOH solution. Alkali concentration is crucial for regulating the strength of hardened geopolymer concrete as well as the leaching of alumina and silica from fly ash particles after geopolymerization.

Table 2.10 Quantities of SH solids and water to produce of SHS of given Molarity

| Molarity (M) | For preparation of 1kg of Sodium hydroxide solution | | |
|---|---|---|---|
| | SH solid (gm) | water (gm) | SHS (gm) |
| 8 | 255 | 745 | 1000 |
| 9 | 281 | 719 | 1000 |
| 10 | 306 | 694 | 1000 |
| 11 | 331 | 669 | 1000 |
| 12 | 354 | 646 | 1000 |
| 13 | 377 | 625 | 1000 |
| 14 | 400 | 600 | 1000 |
| 15 | 422 | 578 | 1000 |
| 16 | 443 | 557 | 1000 |
| 17 | 464 | 536 | 1000 |
| 18 | 485 | 515 | 1000 |
| 19 | 505 | 495 | 1000 |

Source:(Perry, Green, and Maloney 2014)

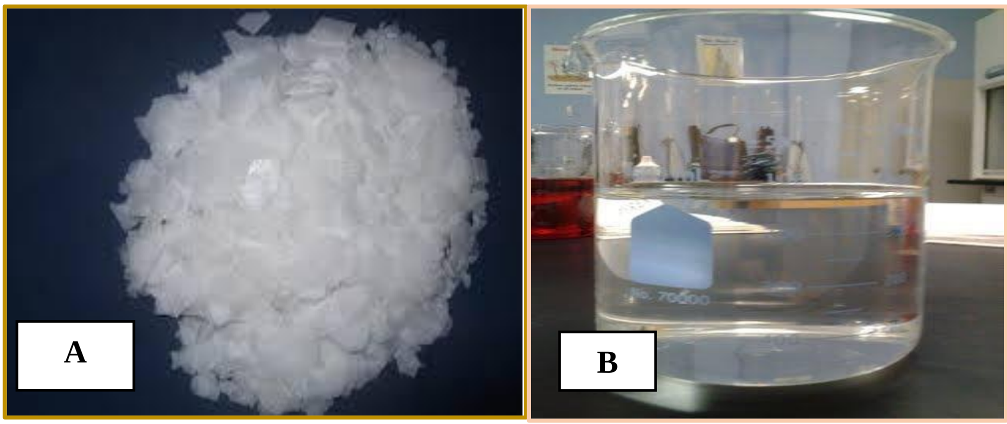



Figure 2. 1 Sodium hydroxide. a) NaOH flakes b) NaOH solution

**b) Sodium Silicate**

Sodium silicate solution, also known as waterglass, is expressed as Na2SO3 (Assi et al. 2020). Sodium silicate is an activator that plays an important role in the geopolymerization process, reactions occur at a high rate when alkaline activators contain soluble silicate. (Patankar, et al. 2014). Sodium silicate is the common name for compounds with the formula

Na2SiO3. Also known as water glass or liquid glass, these materials are available in aqueous solutions and in solids form (Chindaprasirt et al. 2014).

Sodium silicate solution, also known as waterglass, is expressed as $Na_2SO_3$ (Assi et al. 2020) Sodium Silicate is activators play important role in the geopolymerisation process. Reactions occur at high rate when alkaline activator contains soluble silicate.(Patankar, et al. 2014). Sodium silicate is the common name for compounds with the formula $Na_2SiO_3$. Also known as water glass or liquid glass, these materials are available in aqueous solution and in solid Form (Chindaprasirt et al. 2014).

$$Na_2CO_3 + SiO2 \rightarrow Na_2SiO_3 + CO_2$$

A chemical reaction occurs with the excess Ca $(OH)_2$ (Portlandite) present in the concrete that permanently binds the silicates with the surface, making them far more durable and water repellent. This type of activator plays an important role in the polymerization process.

**2.5.1.4 Mineral Additives**

Geopolymer concrete is produced by the reaction between an alkali activator and an aluminosilicate source, which forms a three-dimensional network of geopolymeric gel. However, the production of geopolymer gel requires additional minerals and additives that can influence the properties of the final product. One commonly used mineral additive in fly ash-based geopolymer concrete is metakaolin (Gill et al. 2020). According to Mullah et al. (2018), the combination of fly ash and metakaolin can improve the workability, strength, and durability of the geopolymer concrete, Mullah et al. (2018), also reported that the concrete with a 20% replacement of fly ash with metakaolin achieved a compressive strength of 60 MPa after 28 days.

Another mineral additive that can be used in fly ash-based geopolymer concrete is ground granulated blast furnace slag (GGBFS). GGBFS is a by-product of the ironmaking industry that contains reactive glassy phases, such as calcium silicates and aluminosilicates (Nath and Sarker 2014b). In the stride of improving fly ash-based geopolymerization at room temperature, some studies aimed to enhance the reactivity of fly ash in an alkaline environment by increasing the fineness of fly ash (Martinez-Ramirez,et al. 2015) and by incorporating some additional materials such as silica fume, rice husk ash, metakaolin, blast furnace slag, Portland cement, lime, nano-particles, and waste by-products from different industries (Jindal, et al.2017) and also (Patil et al. 2014) have reported that the addition of

OPC in high calcium fly ash enhances the attributes of geopolymer concrete cure in steam and thus facilitated the hydration process due to the presence of OPC in the binder.

### 2.5.2 Application of Geopolymer Concrete

According to Kheradmand, et al.(2018), geopolymer concrete has shown promising performance in various applications, such as in the precast concrete industry, where it has been used as a replacement for conventional concrete in the production of precast concrete elements. Geopolymer concrete can also be used for the repair and rehabilitation of existing concrete structures.

In a study conducted by Harison et al.(2014), it was found that geopolymer concrete was able to effectively repair concrete spalling and corrosion damage in reinforced concrete beams. Geopolymer technology is more advanced in precast applications due to the relative ease of controlling requirements for handling sensitive materials in addition to the controlled high-temperature curing environment that is beneficial to geopolymers. As a result of this, earlier applications of geopolymer concrete were in the production of railway sleepers and sewer pipes (Almutairi et al. 2021). However, structural elements such as columns, beams, and even tunnel segments can also be made of geopolymer concrete. High durability and resistance to the aggressive environment, which is typical for geopolymer concrete, are very desired in sewer pipe production (Wallah and Rangan 2006).

Rangan (2021)mentioned that geopolymer concrete is a great alternative for Portland cement concrete even in applications where steel reinforcements are used, and also that geopolymer concrete has been reported to satisfy the requirements of concrete in harsh environments such as sulfate soils. The first residential building made of alkali-activated concrete was built in 1989 in Lieptsk, Russian Federation, and has 20 floors.

## 2.6 Physical Property of Aggregate

### 2.6.1 Grading

ACI Education Bulletin E1-07 described Grading; Grading refers to the distribution of particle sizes present in an aggregate. The grading is determined in accordance with ASTM C 136, “Sieve or Screen Analysis of Fine and Coarse Aggregates.” A sample of the aggregate is shaken through a series of wire-cloth sieves with square openings, nested one above the other in order of size, with the sieve having the largest openings on top, the one having the smallest openings at the bottom, and a pan underneath to catch material passing the finest sieve. Coarse and fine aggregates are generally sieved separately. That portion of an aggregate passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 µm (No. 200) sieve is called "fine aggregate" or "sand," and larger aggregate is called "coarse aggregate." Coarse aggregate may be available in several different size groups, such as 19 to 4.75 mm (3/4 in. to No. 4), or 37.5 to 19 mm (1-1/2 to 3/4 in.).

#### 2.6.1.1 Significance of Aggregate Grading

ASTMC 136 described that this test method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates.

Table 2. 8 Coarse Aggregate grading limit

| Sieve size | Percentage passing by mass ASTM C136 |
|---|---|
| 20 mm | 100 |
| 19 mm | 95 to 100 |
| 12.5 mm | 40 to 80 |
| 9.5 mm | 20 to 55 |
| 4.75 mm | 0 to 10 |
| Pan | -- |

IS sieves with (4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm, 0.15 mm, and pan) are used for grading fine aggregate (Table 2.12).

Table 2. 9 Fine aggregate grading limit

| Sieve size | Percentage passing by mass ASTM C136 |
|---|---|
| 4.75 mm (No. 4) | 98 to 100 |
| 2.36 mm (No. 8) | 80 to 100 |
| 1.18 mm (No.16) | 50 to 85 |
| 0.6 mm (No.30) | 25 to 60 |
| 0.3 mm (No.50) | 5 to 30 |
| 0.15 mm (No.100) | 0 to 10 |
| pan | --- |

### 2.6.2 Water Absorption and specific gravity of fine aggregate and coarse aggregate

The specific gravity of an aggregate is used in mixture proportioning calculations to find the absolute volume that a given mass of material will occupy in the mixture. Absolute volume of an aggregate refers to the space occupied by the aggregate particles alone; that is, the volume of solid matter and internal aggregate pores, excluding the voids between particles (Zaniewski et al. 2012). The presence of silt or clay in fine aggregates beyond a specific proportion necessitates the use of extra cement to coat other concrete ingredients.

**Absorption:** - the increase in the weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry weight. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ± 5°C for sufficient time to remove all uncombined water(ASTM C128 2001).

### 2.6.3 Unit Weight

According to ASTM C 125 Unit weight, the bulk density (previously "unit weight" or sometimes "dry-rodded unit weight") of an aggregate is the mass of the aggregate divided by the volume of particles and the voids between particles.

### 2.6.4 Silt Content of fine aggregate

Silt is made up of tiny soil grains and minerals that are effortlessly carried and deposited by water. Each particle is bigger than a clay particle but smaller than a grain of sand. Some of these tiny granular particles are conveyed as silt by runoff water during periods of intense rainfall. Water runoff carries silt, which is deposited as sediment in lowlands, rivers, or ponds (Bashir and Science 2018). Sand's silt content can have a major impact on its strength and endurance, According to a study by Ayodele et al. (2015), the silt content in sand can have a significant impact on its strength and durability. The researchers found that as the silt content increases, the compressive strength and shear strength of the sand decrease.

## 2.7 Mixture proportion

The majority of the reported investigations on geopolymer material up to this point dealt with the characteristics of paste or mortar made of geopolymer, which were assessed using tiny specimens. Additionally, the full compositional data of the geopolymer paste mixtures were not published, (Varsha V.et al. 2018).

Hardjito et al. (2004) used four different solutions with a solution-to-fly ash ratio by mass of 0.25 to 0.30 to study the geopolymerization of low-calcium ASTM Class F fly ash (molar Si/Al = 1.81). The solutions had molar SiO2/K2O or SiO2/Na2O ratios between 0.63 and 1.23. The samples measured 10x10x60 mm. After curing the specimens for 24 hours at 65oC, the mixes that combined sodium hydroxide and sodium silicate solution produced the best compressive strengths of more than 60 MPa. According to (Xu and Van Deventer 2010), for the geopolymer reactions to take place, there should be about a 0.33 mass ratio of alkaline solution to alumina-silicate powder. Upon combining with alkaline liquids, a thick gel immediately developed.

As there are no code provisions for the mix design of geopolymer concrete, the conventional method used in the making of normal concrete is adopted to prepare geopolymer concrete (Narayanan , et al. 2017).Bakri et al. (2011) stated that the ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, is 0.4 to 2.5, the molarity of sodium hydroxide (NaOH) solution is in the range of 8M to 16 M, and coarse and fine aggregates make up approximately 75% to 80% of the entire mixture by mass. This value is similar to that used in OPC concrete.

## 2.8 Properties of Geopolymer Concrete

The superior properties of geopolymer concrete, based on (Kumar et al. 2014) it sets at room temperature, is non-toxic, bleed-free, has a long working life before stiffening, is impermeable, has a higher resistance to heat, resists all inorganic solvents, and has a higher compressive strength. Geopolymer cement was superior to Portland cement in terms of heat and fire resistance, as the Portland cement experienced a rapid deterioration in compressive strength at 300$^{o}$C, whereas the geopolymer cements were stable up to 600$^{o}$C (Davidovits 2002), It has also been shown that, compared to Portland cement, geopolymer cement has extremely low shrinkage. The presence of alkalis in normal Portland cement or concrete could generate a dangerous alkali-aggregate reaction. However, the geopolymeric system is safe from that phenomenon even with a higher alkali content. As demonstrated by Davidovits based on the ASTM C227 bar expansion test, geopolymer cements with much higher alkali content compared to Portland cement did not generate any dangerous alkali-aggregate reactions where Portland cement did.

### 2.8.1 Workability

Water also plays an important role in geopolymer concrete, just as it does in normal concrete. The use of water in geopolymer is to improve the workability, but it will increase the porosity of concrete due to the evaporation of water during the curing process at elevated temperatures (Sathia et al. 2008). According to Cheah et al.(2015), the water-to-geopolymer binder ratio is the ratio of the total quantity of water (quantity of water present in solution and extra water added in the mix) to the geopolymer binder (quantities of fly ash, sodium silicate, and sodium hydroxide solutions), it is observed that the flow increases with an increase in the water-to-geopolymer binder ratio while maintaining other parameters constant.

Patankar et al. (2014) discovered that an increase in sodium hydroxide and sodium silicate concentrations will reduce the flow of mortar. The workable flow of geopolymer mortar was in the range of 110 ± 5 to 135 ± 5%. To improve the workability of mortar, superplasticizer or extra water can be added. However, the use of superplasticizers had an adverse effect on the strength of geopolymers. As such, extra water gives more strength than the addition of superplasticizer. However, with the amount of bottom ash in fresh geopolymer mortar greater than 75%, workability decreases. This is most probably due to the angular shape and rough texture causing high inter-particle friction in the bottom ash, although the water content increased in the mixture (Nath et al. 2015).

### 2.8.2 Density (unit weight)

Mass per unit volume is preferred to the outmoded phrase unit weight because aggregate unit mass plays a major role in determining concrete's density. The density of the low-calcium fly ash-based geopolymer concrete varied only slightly between 2130 and 2430 kg per $m^3$, as the types of aggregates in all the mixes were the same (Hardjito 2004).

### 2.8.3 Compressive Strength

The compressive strength test method, as described in ASTM C 39-99, involves applying a compressive axial force on molded cylinders or cores at a rate that is within a specified range until failure takes place. By dividing the greatest force attained during the test by the specimen's cross-sectional area, the compressive strength of the specimen is determined. The amount of uniaxial compressive stress at which a material entirely fails is what Kumar & Hanitha (2016) define as a material's compressive strength. Then, the cubes are tested between the loading surfaces of the 2000 KN compressive testing machine in such a way that the load is applied directly to the smooth surface up until the load fails It is determined by the ratio of failure load to the cross-sectional area of the specimen.

Nath and Sarker (2014) conducted research on geopolymer concrete using GGBFS and fly ash. The study stated that compressive strength at all ages up to 180 days increased with the increase in slag content. The strength gain slowed down after the age of 28 days and continued to increase at a slower rate until 180 days. The 28-day compressive strength reached up to 51 MPa in geopolymer concrete containing 20% slag and 80% fly ash in the binder and 40% activator liquid with a SS/SSH ratio of 1.5 when cured at $60^oC$.

According to the study of Djwantoro Hardjito (2010) Geopolymer mortar with lower bottom ash content (0%–25%) decreases in compressive strength after exposure to elevated temperatures from 400 °C to 1000 °C, whereas geopolymer mortar with higher bottom ash content (50%–100%) increases in compressive strength after exposure to elevated temperatures from 400 °C to 1000 °C. However, the compressive strength of geopolymer mortar with 10% bottom ash is comparable to that of geopolymer mortar without bottom ash (Singh and Siddique 2016a).

Nematollahi and Sanjayan (2014) conducted experiments on fly ash-based geopolymer concrete by varying the concentration of NaOH and curing time. A total of nine mixes were prepared with NaOH concentrations of 8M, 12 M, and 16M and curing times of 24 hrs, 48 hrs, and 72 hrs. Compressive strength, water absorption, and tensile strength tests were conducted on each of the nine mixes, the results of the investigation indicated that there was an increase in compressive strength with an increase in NaOH concentration. Strength was also increased with an increase in curing time. Compressive strength up to 46 MPa was obtained with curing at 60$^{o}$C (Shaikh and Vimonsatit 2015).

### 2.8.4 Flexural Strength

Flexural strength, also known as modulus of rupture, bend strength, or transverse rupture strength, is a material property defined as the stress in a material just before it yields in a flexure test, in accordance with ASTM C39.

Based on the study carried out on geopolymer concrete beams by Mathew and Joseph (2018), Even though the cube compressive strength of geopolymer concrete is not reduced between 600 °C and 800 °C (because of polymerization of initially unreacted materials), the load-carrying capacity of geopolymer concrete beams reduces rapidly beyond 600 °C. The primary factor contributing to the loss of load-carrying capacity of geopolymer concrete beams exposed to temperatures above 600 °C is the strength reduction of the reinforcing steel.

### 2.8.5 Water absorption

The water-absorption characteristics of the concrete play an important role in the durability of the structure. Ingress of water deteriorates concrete, and in reinforced concrete structures, corrosion of the spalling of the concrete ultimately reduces the life span of the structure (Luhar et al.2015). According to Luhar et al. (2015), test results for water absorption indicate that the water absorption of geopolymer concrete is less than that of control concrete.

Although the difference in percentage of weight gain is very small (0.15% difference). In addition, Mishra et al. (2008) revealed that the results of water absorption tests at 7 days and 28 days, curing at 100 degrees Celsius, respectively, the decrease in water absorption was observed at 7 days with an increase in NaOH concentration from 8M to 16M and also with an increase in curing time from 24 to 72 hours, with the exception of the 16 M NaOH concentration.

A study was conducted by Sathia et al.(2008) to determine the relative porosity or permeability characteristics of the concretes and was carried out according to ASTM C 642-82 for 28 days. The specimens used for the test were 100-mm cubes. The percentage absorption was calculated using the equation Absorption (%) = (w2 - w1)/ w1 x 100 (2). Where w1 is the weight of the specimen after complete drying at 105 °C and w2 is the final weight of the surface dry sample after immersion in water for at least 24 hours, The final absorption results of these mixes show that the geopolymer concretes had a lower absorption rate compared to normal concretes and also decreased with increasing strength (Sathia and ganesh babu 2008b).

Table 2.13 Summary of Geopolymer Concrete Test Result by Different Authors

| Si. No | Author | Type Of Concrete | Activator | Curing Temp. | Remarks |
|---|---|---|---|---|---|
| 1 | Rebuy Brham et al. (2013) | Fly Ash Based GPC Grade M25 | NaOH 12M $Na2sO_3/NaOH$ 2.5 | 60oC | Compressive Strength Test at 28 day 38.62MPa |
| 2 | kumareval et al. (2015) | Fly ash-based GPC Grade M20 | NaOH 8M $Na_2SiO_3/NaOH$ 2.5 | 60oC | Compressive Strength Test At 28 day 26.36MPa |
| 3 | Anurag et al. (2014) | Fly Ash-based GPC Grade M30 | NaOH 16M $Na_2SiO_3/NaOH$ 1.5 | 100ºC | Compressive Strength Test At 28 days 45MPa water absorption test,72hr 4% |
| 4 | Nath pradi et al. (2017) | Fly Ash+30% GGBFS based GPC Grade M30 | NaOH 14M $Na_2SiO_3/NaOH$ 2.5 | 75ºC | compressive strength test at 28 days 58MPa |
| 5 | Djwanto et al. (2010) | FA based GPM With 10%BA as fine aggregate Grade M40 | KOH 12M $K_2SiO_3/KOH$ 1.5 | 60ºC | Compressive Strength Test at 28 Days 60MPa |
| 6 | l. krishmani et al. (2014) | FA 85%+GGBFS15% Based GPC Grade M25 | NaOH 12M $Na_2SiO_3/NaOH$ 1.5 SP 3% | 200ºC | Compressive Strength Test at 28 days 45.5MPa |
| 7 | S. Kuma ravel et al. (2014) | FA +GGBFS 25% Based GPC Grade M40 | NaOH 12M $Na_2SiO_3/NaOH$ 2.5 SP 2% | 60ºC | Compressive Strength Test at 28 days 48MPa |
| 8 | George Mathew et al. (2018) | FA based GPC Grade M30 | NaOH 10M $Na2SiO_3/NaOH$ 2.5 SP 2% | 200ºC | Compressive Strength Test at 28 days 42.5MPa |
| 9 | Salmabarus et al. (2015) | FA based GPC Grade M25 | NaOH 14M $Na_2SiO_3/NaOH$ 2 SP 2% | 75ºC | 2.74% water absorption test |

### 2.8.6 Microstructural Properties

#### 2.8.6.1 Scanning Electron Micro-Scope (SEM)

SEM analysis allows for the observation of the internal microstructure of the concrete, including the size and shape of the different phases and the porosity of the material. SEM considered one of the most versatile examination systems that provide a trusted tool for analysis of microstructural characteristics of the solid materials (Al-Shathr, et al. 2015).

#### 2.8.6.2 X-ray diffraction (XRD)

X-ray diffraction (XRD) is a common method used in the testing of concrete. XRD helps to identify the chemical composition of the materials within the concrete, including the mineralogy of the cement and the presence of any hydration products(Anon 2019).

### 2.8.7 Embodied energy and CO2 emission of geopolymer concrete

The building industry consumes the rawest resources of any industry. Raw material production consumes energy and releases carbon dioxide (CO2) into the atmosphere. As reported by Taffeses et al. (2019) construction consumes more than 35% of global energy and emits more than 40% of CO2. Energy and CO2 emissions are "embodied" within the concrete materials. Concrete has an average life duration of 50 years, and its embodied energy and carbon dioxide emissions are estimated to be 4,273.90 $MJ/m^3$ and 343.55 $kg/m^3$, respectively (Syngros, et al. 2017).

Waste generation is one of the negative consequences of concrete production, which accounts for a significant portion of global carbon emissions, one of the causes of global warming is CO2 emissions into the atmosphere, as a result, using geopolymer concrete reduces carbon emissions by reducing the amount of concrete utilized (Habert, et al. 2011). The embodied energy of fly ash is zero as collection of fly ash from flue gas is mandatory in India. GGBS will have to be grinded after quenching, embodied energy of fly- ash GGBS based geopolymer concrete is found to be 1265.73 MJ and that of OPC based concrete is calculated as 2083.33 MJ (Bennet et al. 2013).

Energy analyses indicate that geopolymer cement concrete can be produced with a smaller energy footprint than Portland cement concrete, this distinction is important relative to both the economics of production and the proportional relationship of energy use to greenhouse gas generation, greenhouse gas emissions from Portland cement manufacture are sourced both from the carbon liberated from the cement source materials as well as the fuels used to heat the kiln, Producing geopolymer cement from industrial byproduct eliminates both these greenhouse gas sources (Venkatarama et al. 2012).

## 2.9 Research Gap

From the literature review, most of the previous studies on geopolymer concrete used some industrial by-products instead of cement alone, but it is so important to use such industrial by-products partially replaced with fine aggregates in producing geopolymer concrete to reduce the consumption of natural sand. At present, there is lack of information on the properties of geopolymers available, especially geopolymers with bottom ash as the fine aggregate. As a result, a study on the properties of fly ash-based geopolymer concrete with bottom ash as sand replacement should be needed.

In addition to this, most of the geopolymer concrete tested so far was heat cured at a higher temperature to gain better strength at an early age. The curing temperatures were reported in the range between 40°C and 90°C for complete geopolymerization reactions (Bharat Bhushan, 2018), but heat curing can only be achieved in precast concrete structures. These attributes limit the broader utilization of fly ash-based geopolymers to only precast concrete and are believed to be a hurdle for on-site concrete applications. Due to this, the current study focused on the experimental investigation of the properties of fly ash-based geopolymer concrete with partially replaced fine aggregates by bottom ash, such as compressive strength, flexural strength, and water absorption, which were investigated experimentally by curing at an ambient temperature. In addition, its production was checked by X-ray diffraction (XRD) and scanning electron microscope (SEM) images.

# CHAPTER THREE
# MATERIALS AND METHODS

This chapter addressed the materials and procedures utilized to conduct this study based on required material specifications and various standards and methods.

## 3.1 Materials

### 3.1.1 Cement

For this study Muger grade 42.5N OPC cement was chosen to match the specified specifications for the concrete. It was purchased from a supplier in Addis Abeba, Ethiopia, that met ASTM C150 (2016) specifications. It was carefully preserved in an airtight container to protect it from moisture, atmospheric agents, and humidity during the experimental period.

### 3.1.2 Fine Aggregate

Natural river sand (Metehara) that had been sieved through a 4.75 mm sieve and retained at 150 microns according to ASTM C33 (2018) was utilized in this experiment . Silt, clay, and other organic contaminants should be absent from the sand.

### 3.1.3 Coarse Aggregate

The coarse aggregate used to make up the concrete samples in this work consists of crushed gravel, which was collected from a local quarry (kurfa crusher site) and confirms the requirements of ASTM C33. Generally, the coarse aggregate used for the experiment should be strong, durable, free from vegetable matter, have less than 5% water absorption, and not be sharp and angular as per ASTM C33.

### 3.1.4 Water

Potable water, which meets the ASTM C1602 (2006) standard, was utilized for the current research and obtained from the ASTU water supply.

### 3.1.5 Fly Ash

The fly ash used for this investigation was sourced from the Ayika Adis Textile Factory in Ethiopia, Oromia, and Alemgena. The source location was chosen because of the high availability of fly ash and its closeness to Adama, where the experimental work was carried out. Ayika Adis Textile Factory uses local coal, which is extracted and supplied from the Achebo area. Fly ash was employed, which was passed 86% through a sieve opening of 75 micrometers.

### 3.1.6 Bottom ash

The bottom ash used for this study was collected from the Ayika Adis Textile Factory in Ethiopia, Oromiya, and Alemgena.

### 3.1.7 Alkaline Activator

Sodium hydroxide (pellets with 98% purity) and sodium silicate ($Na_2O$= 14.7%, $SiO_2$=29.4%, and water 55.9% by mass) for this study the Molarity of NaOH and the ratio of $Na_2SiO_3$/NaOH is 16M and 2 utilized, respectively which is Taken as constant based on the literature review (Naragnan, et al.2017, kumaravel, et al. 2015), (Anurag, et al. 2014), (Rebuy brhan, 2013), (Bakri, et al. 2011) which is best and recommended by different authors. The NaOH solids were dissolved in water to make the solution. Activator was purchased from a local supplier from Addis Ababa, Ethiopia.

## 3.2 Research Methods

Methods in material research refer to a logical and coherent scheme in which experimental investigations are carried out. The current study uses both qualitative and quantitative research methods to interpret and discuss the research output. The research design being employed was an experimental research design; this section clearly outlines the research procedures employed and the type of test conducted to accomplish research objectives..

### 3.2.1 Methods of data analysis

The outcomes of the tests result from the laboratory were quantitatively and qualitatively analyzed based on the standard requirements or specifications. Origin, X'pert high score plus, Excel software was used to analyze the results

### 3.2.2 Method of data presentation

Furthermore, analyzed data was presented through the table, figures, and chart.

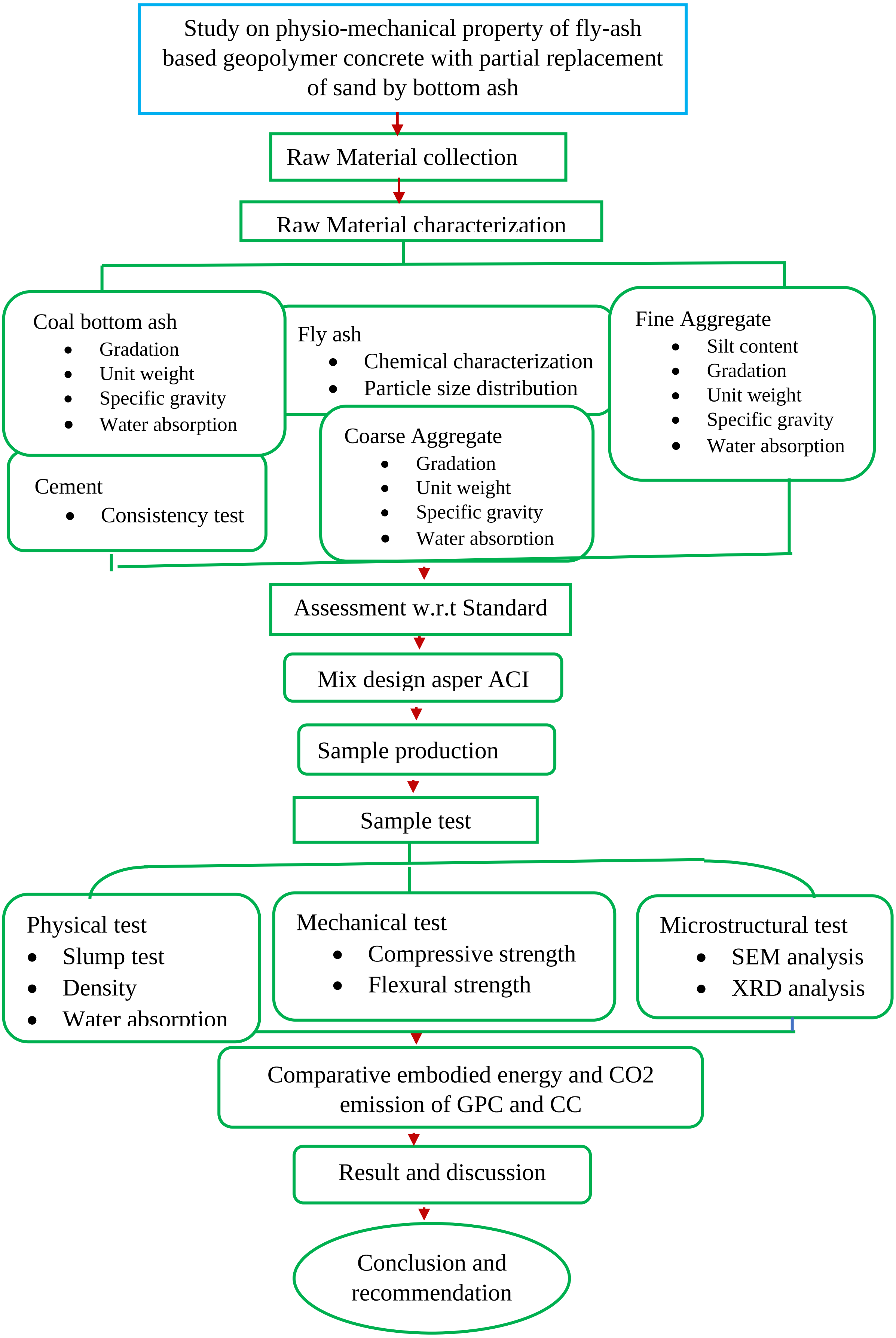



Figure 3. 1 Experimental work flow chart

### 3.2.1 Preparation of fly ash and bottom ash

**a) Preparation of Fly Ash**

Primarily, the fly ash was collected from Ayika Adis Textile Factory in Ethiopia, Oromiya, and Alemgena. and packed for transportation. Then transported to Adama Science and Technology University, stored in a construction laboratory room, and placed around a clean area, the fly ash size was reduced to the required size for sieving by grinding. After grinding was done, the larger particles were separated from the smaller particles by sieving. To separate the finer particles from the coarser ones, the crushed coal fly ash was sieved through a 75$\mu$m sieve.


Figure 3. 2 Coal Fly Ash Preparation

**b) Preparation of  Bottom Ash**

Primarily, the bottom ash was collected from the Ayika Adis Textile Factory in Ethiopia, Oromiya, and Alemgena. and packed for transportation. Then transported to Adama Science and Technology University, stored in a construction laboratory room, and placed around a clean area to assess the particle size distribution of granular material sieves having 4.75 mm, 2.36 mm, 1.18 mm, 0.6mm, 0.3 mm, 0.15 mm, and pan sizes from top to bottom, the procedure was done in accordance with ASTM C136 (2006). To gate the size of fine aggregate

Figure 3. 3 Coal bottom as

### 3.2.2 Test for Cement

### 3.2.2.1 Normal consistency test for cement

The consistency of cement test is used to evaluate how much water should be added to cement in order to achieve standard or normal consistency. The normal consistency test of cement is recommended to be measured using the ASTM C187 (2016) method. As a result, a vicat apparatus was used to determine the typical consistency. This test was performed according to the instructions in ASTM C 187(2016).

1. 400 grams of cement were measured.
2. Water amounting to a percentage of cement (27%) was added to the cement and mixed.
3. Within 5 minutes, properly combine the paste. Gauging time is the time it takes to get cement paste after adding water.
4. Filled the paste in the Vicat mold appropriately and removed any surplus paste witha trowel.
5. Then, the Vicat mold on the glass plate were placed, the plunger lightly touches the surface of the Vicat mold.
6. The plunger was allowed to sink into the test mold after it has been released.
7. The note of the plunger's penetration from the bottom of the mold where taken, as indicated on the scale.
8. The experiment was Repeated with varied percentages of water until the Vicat apparatus scale reading is between 5-7 mm.
9. The water added is right, and the penetration is between 5 mm and 7 mm.

Figure 3. 4 Normal consistence of cement

### 3.2.3 Test for Fly Ash

#### 3.2.3.1 particle size distribution test for fly ash

This test was carried out to determine the percentage of fine particles of fly ash, Due to lack of 45 $\mu m$ sieve size the test was conducted by using 150 µm and 75 µm sieve size.

#### 3.2.3.2 Chemical Composition Analysis

Chemical composition analysis is conducted for a wide range of purposes. The analysis provides valuable information about the elements of a test sample. A chemical composition analysis takes place to determine the amount of different oxides in the sample. This analysis can be done using different methods. For this research, a complete silica analysis was conducted at the laboratory of the Ethiopian Geological Survey.

### 3.2.4 Tests for Fine Aggregate

#### 3.2.4.1 Silt Content of Natural River Sand

Clay, silt, loam, and dust are commonly found in sand. The presence of such particles in sand reduces concrete's compressive strength and long-term durability. As a result, testing the silt content of sand and comparing it to acceptable limits is critical. The major goal of this test was to figure out how much silt was in the sand. And in the bottom ash, for this experiment, sample sand, sample bottom ash, clean water, a graduated jar, a spoon, a dish for taking a sand and a bottom ash sample, and a funnel were used. The following are detailed procedures that were followed based on ASTM C 117.

**Test Procedure for Silt Content**

1) The researcher took a graduated cylinder having a capacity of 1000 ml.
2) 300 ml of sand was poured into the cylinder.
3) Approximately 3/4 of the jar was filled with water.
4) The jar was shaken vigorously for about a minute.
5) The jar was left for an hour to allow the silt to settle on the layer of sand.
6) The amount of fine forming a separate layer on the top was measured.
7) The silt content was calculated based on Equation 3.1.

$$\text{Silt content} = \frac{\text{Silt deposited above the sand (A)}}{\text{Amount of clean sand (B)}} \text{X}100 \quad \text{.......... Equation 3.1}$$

Figure 3. 5 Silt content of natural river sand

**3.2.4.2 Sieve Analysis of Fine Aggregate**

The aim of this test was to determine the fineness modulus of fine aggregate with the help of a series of IS sieves having (4.75 mm, 2.36 mm, 1.18 mm, 0.6mm, 0.3 mm, 0.15, and pan) sizes from top to bottom, respectively, 500 g of fine aggregate, a balance, sieve shaker, shovel, and sieve brush. The test procedure was in accordance with (ASTM C136). The range of fineness modulus is between 2.3-3.1 (ASTM C33).

Test Procedure for Grading Fine Aggregate and detail results are illustrated under appendix A1.2.2

Fineness modules (FM) = $\frac{\sum comulative\ retained}{100}$ ………………Equation 3.2

**3.2.4.3 Unit Weight, Specific Gravity, and Water Absorption of Fine Aggregate**

The mass of a particular volume of a material divided by the mass of an equal volume of water is called specific gravity, and it indicates how much heavier the material is than water. The difference between the weight of the aggregate in the surface-dried saturated state and the weight of the oven-dried aggregate is used to calculate the water absorption of an aggregate. The density of fine aggregate varies depending on whether it is wet, dry, or loose. The specific gravity and water absorption capacity of fine aggregate were calculated using the ASTM C128 standard in this experiment. The range of specific gravity is 2.3–3.1(ASTM C128 (2001)

A) Unit Weight of Fine Aggregate (UWFA) Test Procedure

1. Half-filled the measure, then used fingertips to smooth the top. With the tamping rod distributed equally throughout the surface, tamp the aggregate layer with 25 strokes. Filled

the measured to its halfway point, leveled, and rod as usual. Finally, completely filled the measuring cup with rod as described above.

2. Using fingers, the aggregate's surface leveled such that any tiny protrusions of the large pieces of coarse aggregate roughly equal the surface's larger voids below the top of the measure.

3. Avoid allowing the rod to forcefully strike the bottom of the measure when rodding the first layer. The second and third layers in rodding only exert enough force to

4. The fine aggregate was weighed and the data were recorded as follow:

X: Fine aggregate plus cylinder weight = 10335 g.

Y: Weight of empty cylinder = 3440 g

V: Cylinder volume = 0.005 m3

$$\text{UWNRS}= \frac{X-Y}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.3}$$

B) Specific Gravity and Water Absorption of Fine Aggregate Preparation of The Test Specimen and test procedure with detail result were illustrated under appendix A1.2.4

a) The following data were recorded:

X: Weight of dry specimen in air = 490 g

Y: Weight of water-filled pycnometer = 1500g

Z: Weight of the saturated surface-dry specimen = 500 g

W: Pycnometer weight with specimen and water to calibration mark = 1815 g

$$\text{Bsg} = \frac{Z}{Y+Z-W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.4}$$

$$\text{Asg} = \frac{X}{Y+X-W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.5}$$

$$\text{WA(\%)} = \frac{Z-X}{X} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.6}$$

### 3.2.4 Test for Bottom Ash

#### 3.2.4.1 Sieve Analysis of Bottom ash

The aim of this test was to determine the fineness modulus of Coal Bottom Ash with the help of a series of IS sieves having (4.75 mm, 2.36 mm, 1.18 mm, 0.6mm, 0.3 mm, 0.15, and pan) sizes from top to bottom, respectively, 500 g of Coal Bottom Ash, a balance, sieve shaker, shovel, and sieve brush. The test procedure was in accordance with (ASTM C136) which is used for sand. The range of fineness modulus is between 2.3-3.1 (ASTM C33).

Test Procedure for Coal Bottom ash and detail results are illustrated under appendix A1.1.1

Fineness modules (FM) = $\frac{\sum comulative\ retained}{100}$ ………………Equation 3.7

A) Unit Weight of Coal Bottom Ash (UWCBA) Test Procedure

1. The measure was filled one-third full and the surface was leveled with fingers. The layer of bottom ash was rodded with 25 strokes using the tamping rod, evenly distributed over the surface. Then, the measure was filled to two-thirds capacity, leveled, and rodded as before. Finally, the measuring cup was filled to overflowing and rodded as mentioned above.

2. The surface of the coal bottom ash was leveled with fingers in a way that any slight projections of the large pieces of coarse aggregate approximately balanced the larger voids in the surface below the top of the measure.

3. The Coal Bottom Ash was weighed and the data were recorded as follow:

X: CBA plus cylinder weight = 9750 g.

Y: Weight of empty cylinder = 3440 g

V: Cylinder volume = 0.005 m3

UWBA= $\frac{X-Y}{V}$………………………………………… Equation 3.8

B) Specific Gravity and Water Absorption of Coal bottom ash Preparation of The Test Specimen and test procedure with detail result were illustrated under appendix A1.1.3

a) The following data were recorded:

X: Weight of dry specimen = 485(g)

Y: Weight of pycnometer filled with water = 1500(g)

Z: Weight of the saturated surface-dry specimen = 500(g)

W: Weight of pycnometer with specimen and water to calibration mark = 1825(g)

Bsg = $\frac{Z}{Y+Z-W}$……………………………………Equation 3.9

Asg = $\frac{X}{Y+X-W}$………………………………… Equation 3.10

WA (%) = $\frac{Z-X}{X}$ ……………………………… Equation 3.11

### 3.2.5 Tests for Coarse Aggregate

#### 3.2.4.1 Sieve Analysis of Coarse Aggregate

The aim of this test was to determine the fineness modulus of coarse aggregate with the help of apparatus like a series of IS sieves of sizes (20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan) from top to bottom, respectively, 2,000 g of coarse aggregate, a balance, sieve shaker, shovel, and sieve brush. The test procedure followed was in accordance with (ASTM C136).

**Sieve Analysis for Coarse Aggregate Test Procedure according to ASTM C136**

1) 20 kg of coarse aggregates were weighed.
2) A representative sample was selected by quartering.
3) From the quartered sample, 2 kg was taken.
4) The empty sieves were weighted and the data was recorded properly.
5) Placed the 2 kg of sample on the top sieves (which have a large opening size).
6) smashed the sample for about 10 minutes in a sieve shaker.
7) Each sieve, together with the aggregate retained on it, was measured and the weight retained on each sieve was calculated.
8) The gradation chart was filled in and the fineness modulus was computed. The range of fineness modulus of coarse aggregate according to ASTM C33 is 5.5-8.

Fineness modules (FM) = $\frac{\sum comulative\ retained}{100}$ ………………Equation 3.12

Figure 3. 6 Sieve analysis for coarse aggregate

**3.2.5.2 Unit Weight, Specific Gravity, and Water Absorption of Coarse Aggregate**

Specific gravity is the ratio of the weight of a certain amount of coarse aggregate to the weight of the same amount of water. This is a measure of the strength or quality of a particular material. Low-density aggregates are generally weaker than high-density aggregates. Water absorption capacity represents the maximum amount of water that the aggregate can absorb. It gives an idea of the internal structure of the aggregate and the strength of the aggregate. The density of coarse aggregate varies depending on the source, nature, and condition, like wet or dry. The researcher determined specific gravity and water absorption capacity based on the ASTM C127 (2015) standard. The unit weight of aggregate ranges from 1200 to 1750 kg/$m^3$ (ASTM C29).

A. **Unit Weight of Coarse Aggregate (UWCA**)

1. The measure was filled one-third full and the surface was leveled with fingers. The layer of aggregate was rodded with 25 strokes using the tamping rod, which was evenly distributed over the surface.

2. The surface of the aggregate was leveled with fingers in such a way that any slight projections of the large pieces of the coarse aggregate approximately balanced the larger voids in the surface below the top of the measure.

3. When rodding the first layer, the rod was not allowed to strike the bottom of the measure forcibly. In rodding, only enough force was used in the second and third layers to cause the tamping rod to penetrate the previous layers of aggregate.

4. The coarse aggregate was weighted, and the data was recorded as follows.

X = aggregate plus cylinder weight = 11380g

Y = Weight of the empty cylinder = 3440 g.

V = Volume of the cylinder (m3) = 0.005 m3

The unit weight of coarse aggregate can be computed by using Equation 3.13

$$UWCA= \frac{X-Y}{V} \text{ ........................................... Equation 3.13}$$

B) Specific Gravity and Water Absorption of Coarse Aggregate Preparation of the test procedure with detail result were illustrated under appendix A1.3.3

The researcher recorded the following data.

A: Weight of oven dry specimen = 2997(g)

B: Weight of Saturated in the water = 1900(g)

C: Weight of the saturated surface-dry specimen = 3051(g)

The Bsg, Asg, and water absorption of coarse aggregate can be computed based on the following Equation:

$$Bsg = \frac{C}{C-B} \text{ ......................... Equation 3.14}$$

$$Asg = \frac{A}{A-B} \text{ .........................Equation 3.15}$$

$$WA (\%) = \frac{C-A}{A} \text{ .................... Equation 3.16}$$

Summary of test result

Table 3.1 below shows the test result of the raw materials used in the study; details are tabulated under appendix A1.3

Table 3. 1 Summary of raw material test result

| Types of Tests | Fine aggregate | Coarse aggregate | Coal bottom ash | Fly ash |
|---|---|---|---|---|
| Silt content | 0.85% | | | |
| Fines modulus | 2.77 | 7.04 | 3.08 | |
| Bulk specific gravity | 2.7 | 2.67 | 2.04 | |
| Apparent specific gravity | 2.8 | 2.73 | 3 | |
| Compacted Unit Weight | 1379kg/m3 | 1587kg/m3 | 1222kg/m3 | |
| Loose unit weight | 1320kg/m3 | 1544kg/m3 | 1202kg/m3 | |
| Water absorption | 2.04% | 1.80% | 3.95% | |
| (Chemical composition) SiO2+ Al2O3+Fe2O3 | | | | 82.88 >70 |

### 3.2.5 Mix Design

Concrete mix design is the process of finding the right proportion of cement, fine aggregate, and coarse aggregate for concrete to achieve the desired strength. As there are no code provisions for the mix design of geopolymer concrete, the density of geopolymer concrete is assumed as 2400 Kg/m3. conventional method used in the making of normal concrete is adopted to prepare geopolymer concrete (Krishna & Prasad, 2017).

The mix ratio depends on the mix design. Therefore, the concrete mix design can be specified as concrete mixture = cement: fine aggregate: coarse aggregate for C-25 concrete grade. Because C-25 grade of concrete is suitable for many constructions application, especially for structural elements. The amount of cement, fine aggregate, coarse aggregate, and water was determined by the properties of the concrete ingredients and the test results obtained from the ingredients. Different percentage of bottom ash (0%, 5%,10% and 15%) were partially replaced by natural river sand) The proportioning of concrete ingredients was done in accordance with ACI 211.1 details of mix design calculation procedures are illustrated under appendix A1.4

Table 3. 2 Summary of calculated batch for 1m$^3$ of concrete

| Ingredient | Quantity in kg/m$^3$ |
|---|---|
| Water | 185.86kg |
| Cement | 376.78kg |
| Fine aggregate | 850.47kg |
| Coarse aggregate | 975.58kg |

Table 3. 3 Mix ratio for C-25 concrete grade

| Ingredients | Cement | Fine Aggregate | Coarse aggregate |
|---|---|---|---|
| Amount / m$^3$ | 376.78/376.78 | 850.47 /376.78 | 975.58 /376.78 |
| Ratio | 1 | 2.21 | 2.61 |

### 3.2.5.1 Quantity of sodium hydroxide and sodium silicate

**NB.** In Geopolymer concrete the alkaline solution is used in place of water and the fly ash can be replace the cement.

Quantity of the alkaline solution

Total alkaline solution = 185.86 kg

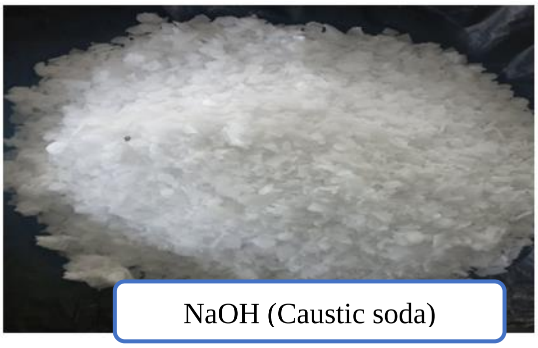
The researcher used 16M of sodium hydroxide and sodium silicate with the ratio sodium silicate to sodium hydroxide 2 which is taken as constant

$$\text{Quantity of sodium hydroxide solution} = \frac{\text{Total Alkaline Solution}}{\text{Ratio of Sodium Silicate To Sodium Hydroxide}+1}$$

$$= \frac{185.86}{2+1} \quad = \underline{62\ \text{kg/m}^3}$$

Quantity of sodium silicate = quantity of sodium hydroxide x ratio of sodium hydroxide to sodium silicate

$$= 62 \times 2 = \underline{124\ \text{kg/m}^3}$$



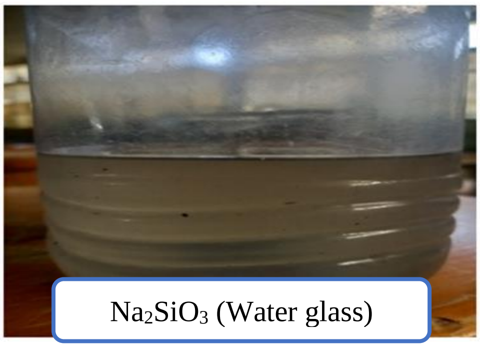




Figure 3. 7 Sample of NaOH and Na2SiO3

### 3.2.6 Preparation of alkaline solution

The sodium hydroxide (NaOH) solids were dissolved in water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. According to (Perry et al. 2014) to prepare 1kg of NaOH solution with a concentration of 16M, NaOH solids (in flake or pellet form) was measured as 443 grams per kg of NaOH solution Perry et al.2014 prepares 1kg of NaOH solution and the authors identified the quantity of NaOH solids and amount of water for different concentration which is shown in the Table 2.11 The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior to use to prepare the alkaline liquid. On the day of casting of the specimens, the calculated quantity of NaOH solids and water were mixed together for about 3-4minutes and then again mixed with the required quantity of sodium silicate gel for about 4-5minutes and then left at room temperature for 24 hours before use.


Figure 3. 8 Preparation of Alkaline Solution

In the table 3.7 below under Mix code column M-0, M-1, M-2, M-3 and M-4 represents CC(Control), BA 0%, BA 5%, BA10%, and BA 15% respectively, the reason for using 0%, 5%, 10%, and 15% of coal bottom ash in the study was, the so far study were used the coal bottom ash as partial replacement of sand in conventional concrete up to 30% replacement (Singh and Siddique 2016). Hence, there is no clear information on percentage replacement of coal bottom ash in fly ash based geopolymer concrete which is cured at ambient temperature, the researcher used 0%, 5%, 10%, and 15% of coal bottom ash in this study.

Table 3. 4 Summary of mix design for production of 1m$^3$ of conventional concrete

| Mix Designation and Mixture Proportion (Kg/m3) | | | | | |
|---|---|---|---|---|---|
| Mix Code | Cement | Coarse aggregate | Fine Aggregate | W/C | Water |
| M-0 | 376.78 | 975.58 | 850.47 | 0.491 | 185.86 |

Table 3. 5 Summary of Mix design for production of 1m$^3$ of geopolymer concrete

| Mix Designation and Mixture Proportion (Kg/m$^3$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mix Code | Cement | Fly ash | OPC | CA | Fine Aggregate | | $Na_2SiO_3$ | NaOH | W/C | Water |
| | | | 3% | | BA | NS | | | | |
| M-1 | - | 365.48 | 11.3 | 975.58 | - | 850.47 | 124 | 62 | 0.491 | - |
| M-2 | - | 365.48 | 11.3 | 975.58 | 42.52 | 807.95 | 124 | 62 | 0.491 | - |
| M-3 | - | 365.48 | 11.3 | 975.58 | 85.05 | 765.42 | 124 | 62 | 0.491 | - |
| M-4 | - | 365.48 | 11.3 | 975.58 | 127.6 | 722.9 | 124 | 62 | 0.491 | - |

**Note**. The above BA, and NS represents Bottom Ash, Natural Sand respectively and OPC 3% were used as additive

The reason of using 3% OPC as additive was pozzolanic materials at lower temperature has low early strength development. Cement contains calcium oxide, which reacts with water to form calcium hydroxide. This early-age hydration reaction can lead to the initial development of strength in the geopolymer concrete, ensuring that it gains some structural integrity during the early stages of curing.

#### 3.2.6 Batching and Mixing

#### 3.2.6.1 Batching

Batching in concrete refers to the process of measuring and combining different ingredients such as cement, water, aggregates, and admixtures in specific proportions to produce a consistent and uniform quality of concrete mix.

#### 3.2.6.2 Concrete Mixing

Cement, fine aggregate, coarse aggregate, water, and other elements are mixed to create concrete in order to produce functional and high-quality concrete. That's what ASTM C 192-98 said. After molding the test specimens, mix concrete in a suitable mixer in batches large enough to leave around 10% extra. The description of a machine mixing process appropriate for drum-type mixers. Since the effects of such variation were not being investigated, there was no variation in the mixing order and process from batch to batch. Machine mixing types were employed in this study. To produce uniform, high-quality concrete in this investigation, the elements for the concrete were mixed together in a mixer.

**Machine Mixing:** Size, operation, cleanliness, and moisture of the mixer were examined in accordance with ASTM C 192-98. Before the mixer began to rotate, coarse aggregate, fine aggregate, fly ash, and alkaline solution were then added while the mixer was running. After putting all the components in the mixer, mix the concrete for 3 minutes, then let it rest for 3, then mix it again for 2 minutes. To ensure that the discharged batch, as used, was properly proportioned, measures were made to account for mortar retained by the mixer. To eliminate segregation, deposit machine-mixed concrete in the clean, damp mixing pan and remix by shovel or trowel until it appears to be uniform

Figure 3. 10 concrete mixer

Table 3. 6 Number of samples for compressive strength, flexural strength and water absorption test

| Mix Code | Compressive Strength | | Flexural Strength | | Water Absorption | |
|---|---|---|---|---|---|---|
| | for 7 days | for 28 days | for 7days | for 28 days | for 7days | for 28 days |
| M-0 (Control) | 3 | 3 | 3 | 3 | 3 | 3 |
| M-1 (BA 0%) | 3 | 3 | 3 | 3 | 3 | 3 |
| M-2 (BA 5%) | 3 | 3 | 3 | 3 | 3 | 3 |
| M-3(BA 10%) | 3 | 3 | 3 | 3 | 3 | 3 |
| M-4(BA 15%) | 3 | 3 | 3 | 3 | 3 | 3 |
| Sub-Total | 15 | 15 | 15 | 15 | 15 | 15 |
| Grand Total | 30 | | 30 | | 30 | |

## 3.3 Fresh Concrete Test

### 3.3.1 Slump Cone Test for Workability of Concrete

ASTM C143 (2012) indicated that workability of a sample of freshly mixed concrete determined by, sample of freshly mixed concrete was placed and compacted by rodding of three equal layers in a mold shaped as the frustum of a cone and padding the cone by rod 25 times then the mold was raised, and the concrete allowed subsided. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete. Standard test method for Slump of Hydraulic-Cement Concrete used was used Geopolymer concrete.

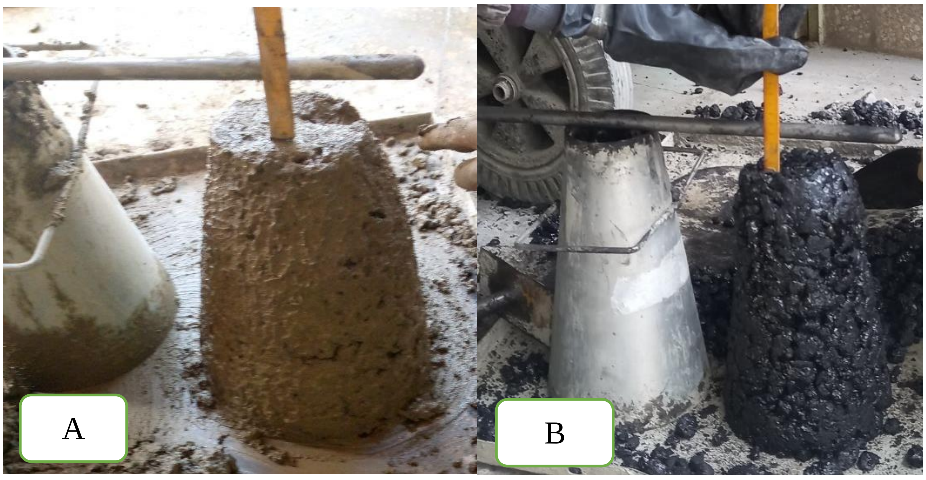



Figure 3. 9 Slump Test (A) conventional (B) geopolymer concrete

### 3.3.2 Mould preparation, Casting and Curing of concrete

#### Mold preparation

Molds for specimens or fasteners thereto in touch with the concrete shall be composed of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing Portland or other hydraulic cements, according to ASTM C192 (2014), the size and tolerances required by the method for which the specimens are needed must be met by the molds. Molds must maintain their dimensions and shape under all usage scenarios. mold samples as close as possible to the location where they were kept for the first 24 hours. Molds that are put on a stable surface without vibration or other disturbances. When transporting specimens to a storage location, avoid jarring, hitting, tilting, or leaving scars on the specimens' surfaces.

#### Concrete casting

Using a scoop, blunted trowel, or shovel, the concrete was poured into the molds. To make sure that each scoop, trowelful, or shovelful of concrete removed from the mixing pan was representative of the batch, they were all carefully chosen. To avoid segregation during the molding of the specimens, concrete was mixed again in the mixing pan using a shovel or trowel. The scoop or trowel was moved all the way around the top edge of the mold. In order to achieve symmetrical distribution of the concrete and minimal segregation of coarse aggregate within the mold, the concrete is discharged. In addition, the concrete was spread with a tamping rod before consolidation began. The operator tried to add a quantity of concrete during the placement of the last layer that was exactly fill the mold after compaction.

The experimenter prepared concrete specimens by incorporating major concrete ingredients such as cement, fine aggregate, coarse aggregate, water, fly ash, alkaline activator and with five different percentage of Bottom Ash Replacement as by natural river sand (0%, 5%, 10%, and 15%). the researcher mixed, placed, and compacted the concrete in different layers and demolded the control samples (cement concrete) after 24 hours and that of fly ash based geopolymer concrete after 48 hours because of late early strength of the geopolymer concrete at an ambient temperature($23^{o}$-$27^{o}$)

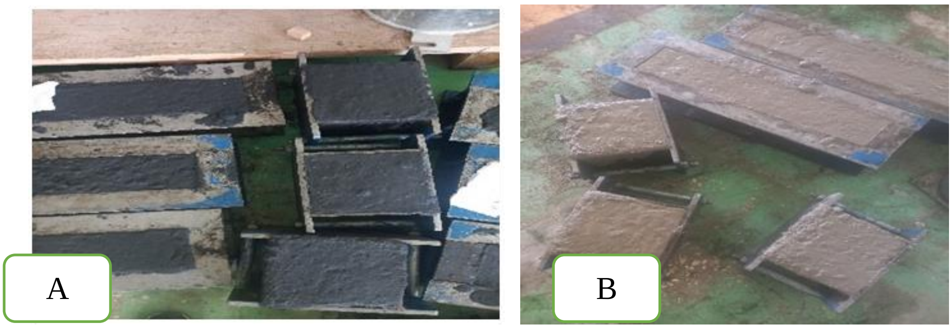



Figure 3. 10 concrete casting (A) Geopolymer concrete (B) conventional concrete

**Curing of concretes**

Curing temperature has an important influence on hardening and geopolymerisation of fly ash based geopolymer concrete. For this study Ambient temperature curing method was used for geopolymer concrete and water curing for control ordinary Portland cement

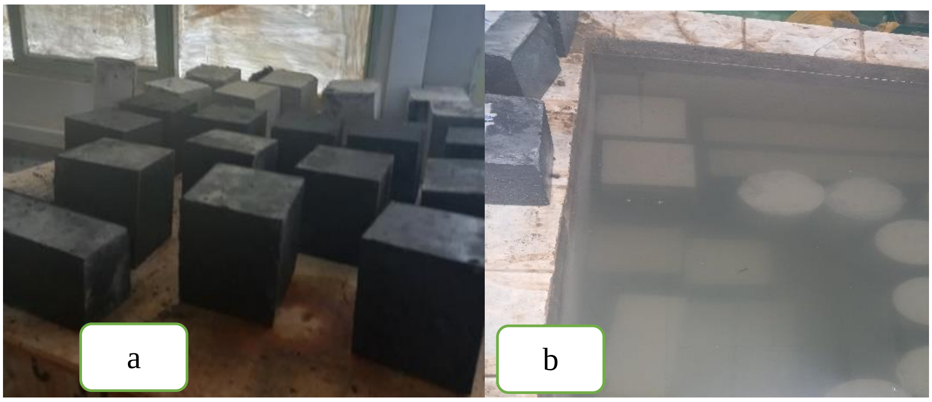



Figure 3. 11 Curing of Concrete. Geopolymer concrete air curing(a), Conventional concrete(b)

## 3.4 Hardened Concrete Test

Hardened concrete is one of the most durable and robust building materials available, capable of supporting structural and service loads. One of the goals of hardened concrete testing is to guarantee that the concrete used has the strength and durability required.

### 3.4.1 Compressive Strength Test

Compressive strength is the ability of hardened concrete to withstand axial loads without any cracks or deflection. Therefore, the aim of this test was to determine the compressive strength of concrete for conventional and geopolymer concrete. The balance, mold, temping road, compressive test machine, trowel, shovel, and brush were used in the test. A concrete cube of sample size 150 x 150 x 150 mm was cast to investigate the compressive strength of geopolymer concrete and normal concrete. The researcher determined the compressive strength after 7, and 28 days of curing by using an automatic compressive strength test machine at Adama Science and Technology University, Construction Material Laboratory, in accordance with (ASTM C39 2018). To undergo the compressive strength test, the cast cubes were taken out of the curing water after 7 and 28 curing periods and wiped-out excess water from the surface for conventional concrete and for geopolymer concrete the compressive strength test were conducted after 7 and 28days air curing. The test machine was then cleaned, placed the sample in the test machine, and applied the load at a rate of 14 N/mm2/minute, having a load capacity of 3000 KN. When the specimens failed, the maximum load was recorded.

The test results were compared to the target mean and characteristic strengths. The target mean strength is determined by designing the concrete mix according to the code. The characteristic strength is the value of concrete strength at which no more than 5% of the test results fall below the value. The strength range between the highest and lowest individual test results was calculated and found to be below 15% of the mean. An invalid result implies that the test technique has one or more flaws. There were no incorrect results in this study. Aside from that, no more than 5% of individual test results fell below the characteristic compressive strength.


Figure 3. 12 compressive strength test

### 3.4.2 Flexural Strength test

The test was carried out at Adama Science and Technology University, Construction Material Laboratory as per ASTM C78 standard specification requirement. The balance, mold, temping road, compressive test machine, trowel, shovel, and brush were used in the test. A 100*100*500mm moulds made from steel. Three samples for 7 and three samples for 28-day test from each mix was casted. After 24 hours the moulds are removed and the specimens are cured in curing tank using potable water up to the date of test for conventional concrete and for geopolymer concrete also Three samples for 7 and three samples for 28-day test from each mix was casted. After 48 hours the moulds are removed and the specimens are cured in ambient temperature up to the date of test. A two-point loaded flexural strength testing machine having 100KN was used.

Figure 3. 13 flexural strength test

### 3.4.3 Water Absorption Test

This research examined the water absorption of GPC and CC at curing periods of 7 and 28 days to determine the water tightness of concrete. The water absorption test procedure followed was: after 7 and 28 days of curing, the samples were taken out of the curing water and dried at a temperature of 105°C for 24 hours, weighed, then immersed in curing water for 72 hours, weighed again, based on (ASTM, C1585) and the highest water absorption limit is 10%. The increase in weight as a percentage of the original weight is expressed as water absorption. The water absorption and percent reduction can be computed based on the formula:

Water absorption % = $\frac{A-B}{B}$X 100%    Equation …………………….3.18

Where; A = Weight of saturated surface dry concrete, B = Weight of oven-dry concrete


Figure 3. 14 Water Absorption test. Oven dry(a), submerged(b)

### 3.4.4 Characterization of Concrete via SEM and XRD

the interior morphology of concrete was studied using SEM. After 28 days of curing, a concrete sample from fly ash based Geopolymer concrete with partial replacement of fine aggregate by 5% Bottom ash and control concrete was obtained from the middle of the concrete and submitted to SEM image analysis at 10 kV by mounting small broken samples on brass stubs, the test was conducted in ASTU at biology department laboratory room.

In addition, to identify the phase present in the fly ash based geopolymer concrete with fine aggregate replacing by bottom ash, the crystal structures, and their abundance as well as the composition of geopolymer concrete. concrete samples from the top, bottom, and middle are taken after 28 days of curing of a sample containing 5% of bottom ash and conventional concrete The samples were then pulverized and sieved to make powder. The powdered samples were subjected to X-ray diffraction at a 2θ angle. The XRD peaks were named from XRD data and by using X'pert High score plus software

### 3.4.5 Environmental Evaluation of fly ash based geopolymer Concrete and conventional concrete

Environmental impact of fly ash based geopolymer Concrete incorporating bottom ash as fine aggregate, and conventional concrete were compared in this study. The environmental impact was, evaluated in terms of carbon dioxide emissions and embodied energy consumption for 1 $m^3$ of concrete.

# CHAPTER FOUR
# RESULTS AND DISCUSSION

## 4.1 Material Test Result and discussion

### 4.1.1 Characterization of fly ash

#### 4.1.1.1 Chemical Composition of local fly ash

Table 4. 1 Complete Silicate Analysis Result by laboratory of the Ethiopia Geological Survey.

| Oxides | Fly ash (%) |
|---|---|
| $SiO_2$ | 49.34 |
| $Al_2O_3$ | 30.52 |
| $Fe_2O_3$ | 3.02 |
| CaO | 0.14 |
| MgO | 0.24 |
| $Na_2O$ | 0.01 |
| $K_2O$ | 0.62 |
| MnO | 0.01 |
| $P_2O_5$ | 0.17 |
| $TiO_2$ | 0.67 |
| $H_2O$ | 1.32 |
| LOI | 11.14 |
| $SiO_2$+ $Al_2O_3$+$Fe_2O_3$ | 82.88>70 |

According to Table 4.1above chemical composition, the fly ash can be categorized as a class F-type pozzolanic fly ash under ASTM C 618-00 since it meets the requirements for that classification. For instance, the total amount of SiO2, Al2O3, and Fe2O3 was higher than 70%, or 82.88, the amount of CaO was lower than 10%, or 0.14, and the loss on ignition (LOI) value was discovered to be 11.14 percent, which was lower than the standard's maximum point of 12 percent. The fly ash utilized in this study complied with ASTM C 618 standards for pozzolana, class F fly ash, or low calcium fly ash. the utilization of Class F pozzolan with up to12.0% loss on ignition may be approved by the user if either acceptable performance records or laboratory test results are made available.

#### 4.1.1.2 Particle Size Distribution of Fly Ash

This test was carried out to determine the percentage of fine particles of fly ash and cement that pass through a sieve opening of 75 µm.

Table 4. 2 Particle Size of Fly ash

| Sieve size (µm) | Wt. of sieve(g) | Fly Ash | | |
|---|---|---|---|---|
| | | Wt. of sieve and retained (g) | Wt. of retained (g) | Percent finer (%) |
| 150 | 279 | 279 | 0 | 0 |
| 75 | 273 | 287 | 14 | 14 |
| Pan | 253 | 339 | 86 | 86 |
| Total | | | 100 | 100 |
| | | Cement | | |
| 150 | 279 | 279 | 0 | 0 |
| 75 | 273 | 288 | 15 | 15 |
| Pan | 253 | 338 | 85 | 85 |
| Total | | | 100 | 100 |

As shown in Table 4.2 above, 86% of fly ash was passed through a sieve opening of 75 µm, whereas 85% of cement passed. As a result, fly ash is finer than cement, implying that fly ash has a larger specific surface area than cement. This indicates that fly ash has higher reactivity and pozzolanic properties.

**4.1.2 Normal Consistency test for cement**

Normal consistency, or standard consistency, is defined as the consistency that allows the Vicat plunger of 10 mm in diameter to penetrate to a point of 5 mm to 7 mm from the bottom of the Vicat mold (ASTM C 187). From the test result, the normal consistency of cement paste was 27%, as the Vicat plunger penetrated about 7 mm. This indicates that the amount of water needed to make a cement paste is 27% of the weight of the cement

### 1.1.3 Characterization of Bottom Ash

**4.1.3.1 Particle Size Distribution of Bottom Ash**

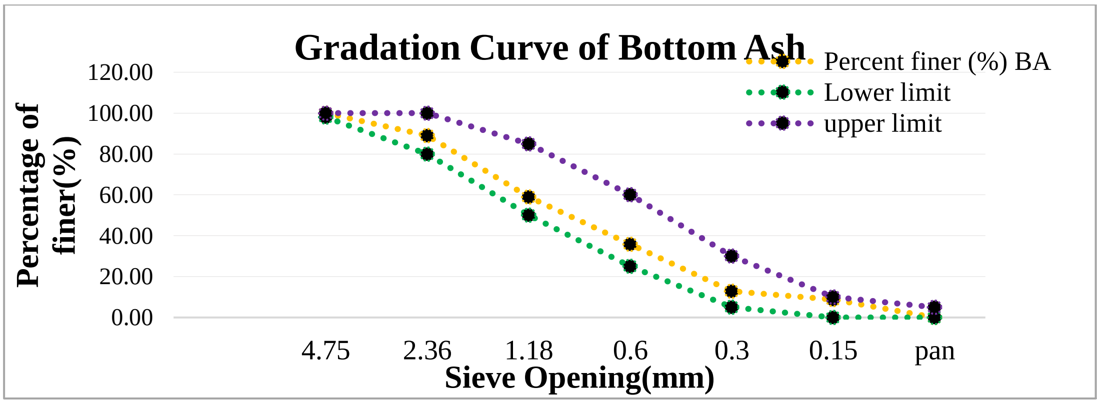



Figure 4. 1 gradation curve of bottom ash

The particle size distribution of bottom ash is shown in Figure 4.1. The results showed that the curve is a smooth curve, revealing that the particle size distribution of bottom ash was in the range of the ASTM requirement for fine aggregate.

#### 4.1.3.2 Density and Specific Gravity

Table 4. 3 Summary of Test Result for Bottom Ash

| Material Type | Types Of Tests | Test Result |
|---|---|---|
| Bottom Ash | Compacted unit weight | 1222kg/$m^3$ |
| | Loose unit weight | 1202kg/$m^3$ |
| | Bulk specific gravity | 2.04 |
| | Apparent specific gravity | 3 |
| | Water Absorption Capacity | 3.95% |
| | Fineness modules | 3.08 |

From the test results, the density values of bottom ash were less than the density of natural river sand. From the analysis, it was found that the density of coal bottom ash, as shown in Table 4.3 above, is 1222 kg/m3, which is slightly lower than the density of natural river sand, which is 1379 kg/$m^3$. According to the study of (Singh and Siddique 2016), coal bottom ash is a suitable material to be used as a partial replacement for sand in the manufacturing of concrete. Besides that, some researchers found that bottom ash has the potential to be used as a lightweight aggregate due to its low particle density, which is lower than river sand (Karner,et al.2016). From previous studies, the specific gravity of bottom ash is between 1.39 and 2.66, which differs for each power plant station. Meanwhile, the specific gravity of coal bottom ash, which is 2.04, is lower than the specific gravity of river sand, which is 2.7. It can be concluded that the physical property test results in Table 4.3 and Figure 4.1 indicated that the bottom ash used for concrete making as fine aggregate was according to ASTM requirements such as ASTMC 29, ASTMC 125, ASTMC 136, and ASTMC 33. The test results indicate that FM was between 2.3 and 3.1 and absorption capacity was between 0.5 and 4%. Therefore, the computed unit weight of fine aggregate was within the range (1200 to 1750) kg/$m^3$ that is specified by ASTM C29, which fulfills the standard requirement of fine aggregate.

### 4.1.4 Physical Property of Fine Aggregate

Table 4.4 and Figure 4.2 below show a summary of the physical properties of natural river sand, and the gradation curve of natural river sand respectively, details are presented under Appendix 1.2

Table 4. 4 Summary of Test Result for Natural River Sand.

| **Material Type** | **Types of Tests** | **Test result** |
|---|---|---|
| **Natural River sand** | Silt content | 0.85% |
| | Compacted unit weight | 1379kg/m$^3$ |
| | Loose unit weight | 1320kg/m$^3$ |
| | Bulk specific gravity | 2.7 |
| | Apparent specific gravity | 2.8 |
| | Water Absorption Capacity | 2.04% |
| | Fineness modules | 2.77 |

Table 4.4 above, physical property test results showed that the fine aggregate used in concrete production complied with ASTM standards including ASTMC 29, ASTMC 70, ASTMC 125, ASTMC 136, and ASTMC 33. According to the test findings, FM was within the range of 2.3 and 3.1, and the absorption capacity was within the range of 0.5 and 4 percent, which satisfies the requirements for fine aggregate. As shown in Figure 4.2, the gradation curve of the natural river sand was set between the ASTM lower and higher limits.

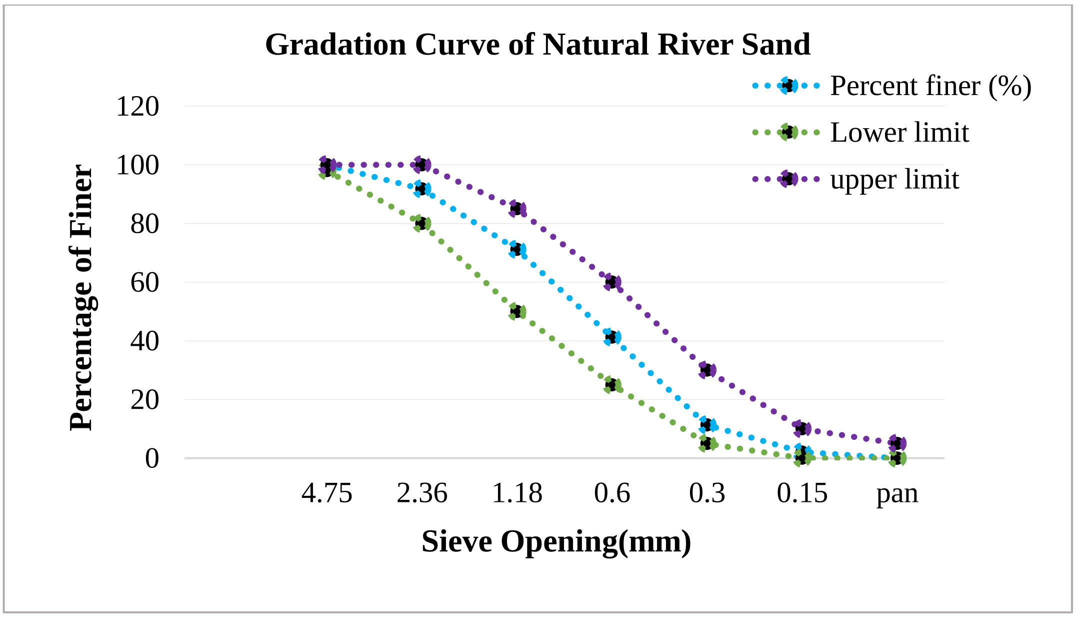



Figure 4. 2 Gradation curve of natural river sand

The particle size distribution curve between bottom ash and sand was similar, even though the grain size of bottom ash was similar to coarse to fine grains and part of it was sand-like material (Ramzi,et al.2016). Figure 4.3 below shows that the gradation curve of both natural river sand and bottom ash

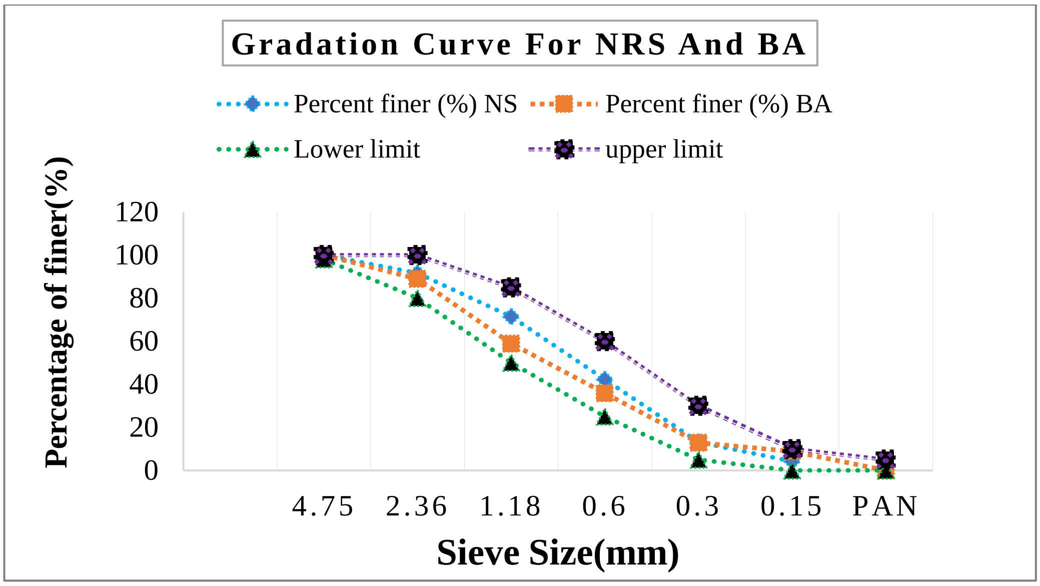



Figure 4. 3 Gradation curve of natural river sand and bottom ash

### 4.1.5 Physical Property of Coarse Aggregate

Table 4. 5 Summary of Test Result for Coarse Aggregate

| Material Type | Types of Tests | | Test result |
|---|---|---|---|
| Coarse aggregate | Loose unit weight | | 1544 kg/m$^3$ |
| | Compacted unit weight | | 1587 kg/m$^3$ |
| | Bulk specific gravity | | 2.65 |
| | Apparent | | 2.73 |
| | Water Absorption Capacity | | 1.80% |
| | Fineness Modules | | 7.04 |
| | Size of aggregate | Max. size | 20mm |
| | | Nominal Max. size | 19mm |

According to Table 4.5 above, all calculations and formulas used to find the result in Table 4.5 were from ASTM standards, which are illustrated in Appendix A1.3. summary of physical property test findings, the coarse aggregate utilized in the study to make concrete met the standards of ASTMC 29, ASTM C 127, ASTMC 136, and ASTMC 33. From the table 4. 5 the aggregate was well graded between the upper and lower ASTM limits, with a water absorption capacity of 1.8%, a maximum size of aggregate of 20 mm, a nominal maximum size of 19 mm, and a fineness modulus of 7.04

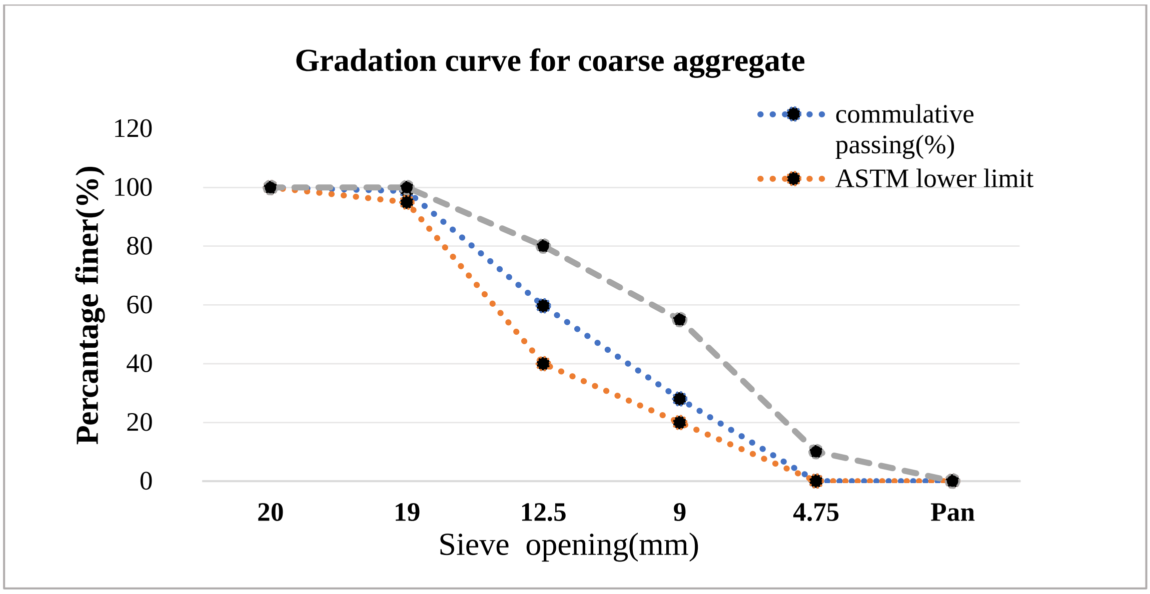



Figure 4. 4 Gradation curve of coarse aggregate

Table 4. 6 Sample production scenario

| Mix Designation and Mixture Proportion (Kg/0.405387m3) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mix Code | Cement | Fly ash | OPC (additive) 3% | CA | Fine Aggregate | | $Na_2SiO_3$ | NaOH | W/C | Water |
| | | | | | BA | NS | | | | |
| M-0 | 30.55 | - | - | 79.097 | - | 68.95 | - | - | 0.491 | 15.069 |
| M-1 | - | 29.632 | 0.916 | 79.097 | 0.00 | 68.95 | 10.05 | 5.03 | 0.491 | - |
| M-2 | - | 29.632 | 0.916 | 79.097 | 3.45 | 65.51 | 10.05 | 5.03 | 0.491 | - |
| M-3 | - | 29.632 | 0.916 | 79.097 | 6.90 | 62.06 | 10.05 | 5.03 | 0.491 | - |
| M-4 | - | 29.632 | 0.916 | 79.097 | 10.35 | 58.61 | 10.05 | 5.03 | 0.491 | - |
| Total | 30.55 | 118.53 | 3.66 | 395.49 | 20.69 | 324.08 | 40.21 | 20.11 | | 15.07 |

**Note:** M-0 = conventional concrete (control) M-3= geopolymer concrete with 10% BA

M-1= geopolymer concrete with 0% BA M-4= geopolymer concrete with 15% BA

M-2= geopolymer concrete with 5% BA

## 4.2 Test on Fresh concrete

### 4.2.1 Slump Test for Workability of Concrete

Table 4. 7 Slump value of Geopolymer concrete and conventional concrete

| No | Mix-Designation | Observed Slump (mm) |
|---|---|---|
| 1 | M-0 (Control) | 35 |
| 2 | M-1 (BA 0%) | 24 |
| 3 | M-2 (BA 5%) | 21 |
| 4 | M-3 (BA 10%) | 20 |
| 5 | M-4 (BA 15%) | 17 |

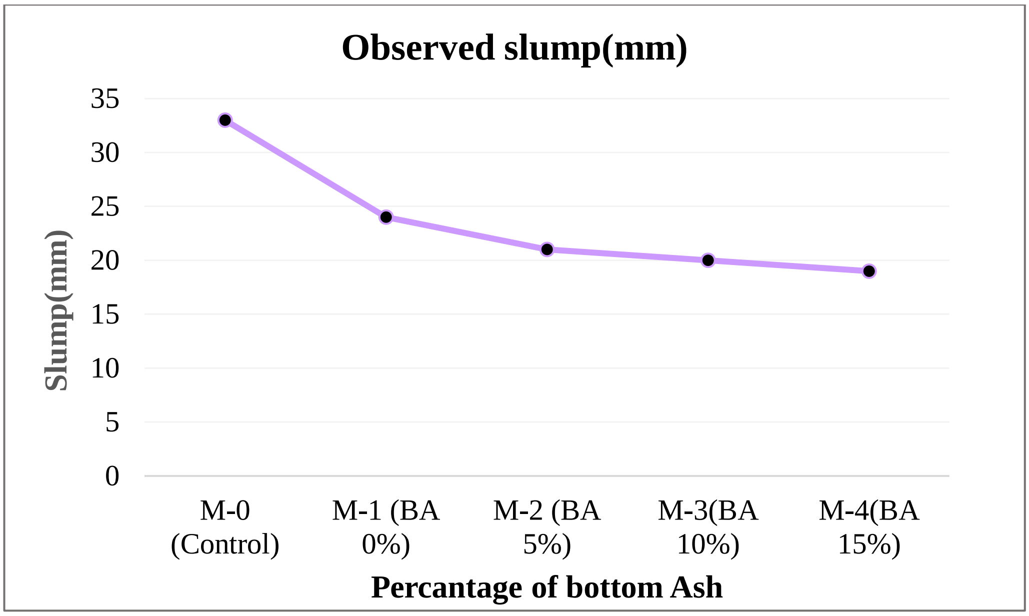



Figure 4. 5 slump value of GPC and CC

Workability test results indicated that the slump value of the geopolymer concrete with class F fly ash was less compared to ordinary Portland cement concrete and slightly reduced as the percentage of the bottom ash increased; this is most probably due to the angular shape and rough texture causing high inter-particle friction of the bottom ash, although the water content increased in the mixture. In addition to this, the chemical activator used for the production of geopolymer concrete has a lower water content because of its inherent nature. According to Patankar et al.(2014) An increase in sodium hydroxide and sodium silicate concentrations will reduce the flow of mortar. So, this causes the geopolymer mixture to be more viscous and less free-flowing than conventional concrete, leading to a lower slump value. Table 4.7 below indicates the observed slump values of geopolymer concrete and conventional concrete.

## 4.3 Hardened Concrete Test Result

### 4.3.1 Density of cube Geopolymer Concrete and conventional concrete test

Table 4. 8 Average Density of Geopolymer Concrete and Conventional Concrete

| Test No. | Mix- designation | Density at the age of 7 and 28days | |
|---|---|---|---|
| | | 7days(kg/m3) | 28days(kg/m3) |
| 1 | M-0(Control) | 2374.32 | 2306.17 |
| 2 | M-1(BA 0%) | 2239.01 | 2172.84 |
| 3 | M-2 (BA 5%) | 2293.83 | 2239.01 |
| 4 | M-3(BA 10%) | 2223.21 | 2171.85 |
| 5 | M-4(BA 15%) | 2149.63 | 2085.43 |

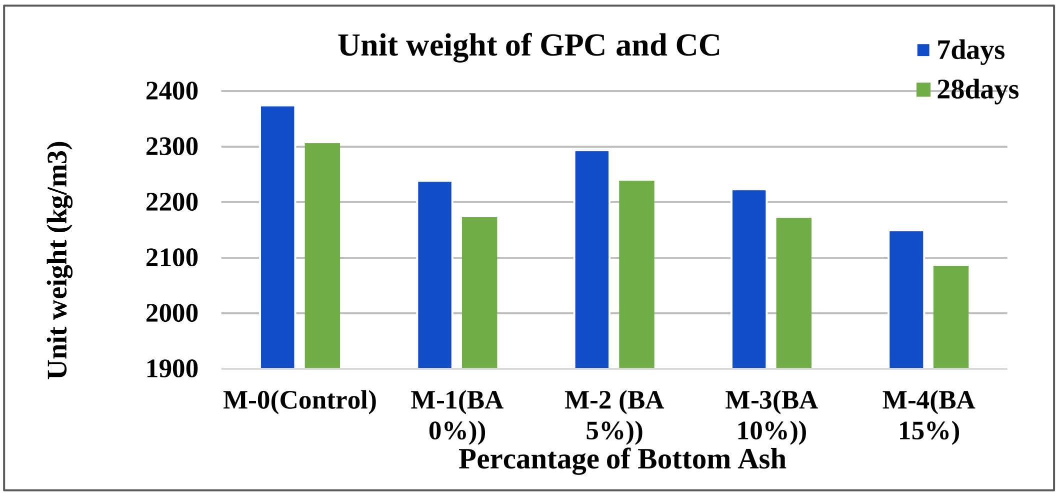



Figure 4. 6 Unit weight of GPC and CC

Before performing the compressive strength test, the unit weight or density of the cured concrete was established for specimens of each mix. According to ASTM C 29, the experimental test results showed that the unit weight of geopolymer concrete was lower than the unit weight of regular Portland cement concrete utilized as the control references. The unit weight of concrete depends on the specific gravity, weight, and unit volume of the specimen. In this study, the volume of a specimen was kept the same, which was (150 *150*150) mm. So, the unit weight of geopolymer concrete was less than the unit weight of OPC concrete because the weight of fly ash was slightly less than cement and the weight of bottom ash was less than that of natural river sand, as indicated in Table 4.9 and Graph 4.6 above. In general, the density of both OPC and Geopolymer concrete which contain 5% of bottom ash was in the range of 2200 Kg/m3- 2500 Kg/$m^3$ which means the density of normal concrete.

### 4.3.2 Compressive Strength of Geopolymer Concrete and Conventional Concrete

The test for compressive strength is evaluated at the age of 7 and 28 days after casting as per ASTM standards. For each parameter, three cubes are considered. The detailed results of the compressive strength test are presented in Appendix A3.2, and the average compressive strength results are summarized in Table 4.10

Table 4. 9 Average Compressive Strength Test Result for GPC And CC

| Test No. | Mix Designation | Average Compressive Strength at the age of 7 And 28 days | | |
|---|---|---|---|---|
| | | 7days(N/mm$^2$) | 28days(N/mm$^2$) | improvement at 28days |
| 1 | M-0 (Control) | 26.05 | 30.08 | 0.00 |
| 2 | M-1 (BA 0%) | 20.59 | 25.53 | -15.12 |
| 3 | M-2 (BA 5%) | 25.56 | 30.39 | +1.03 |
| 4 | M-3(BA 10%) | 22.36 | 26.36 | -12.36 |
| 5 | M-4(BA 15%) | 17.96 | 22.40 | -25.53 |

According to Djwanto et al. (2013), the compressive strength of geopolymer concrete with 10% of BA as fine aggregate at 28 days of curing at 60°C was determined to be 60 MPa. However, according to the data presented in Table 4.10 of the current investigation, at 7 days, the compressive strength of the control (M-0) mix was determined to be the highest value, which is 26.05 N/mm2. Due to the fact that concrete with pozzolanic material does not achieve early strength when compared to normal concrete, this is due to slow hydration and slower setting at lower temperatures, while the compressive strength of the M-2 with 5% BA blended with 3% OPC was 30.39 N/mm$^2$ at an age of 28 days of curing at ambient temperatures. From this research work, it is observed that fly ash-based geopolymer concrete with 5% bottom ash maintains the maximum compressive strength.

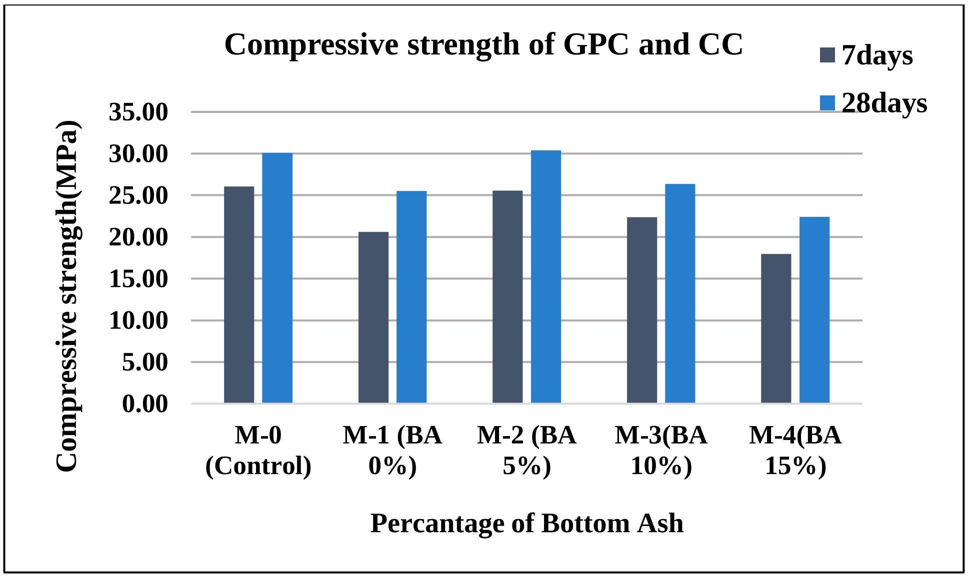



Figure 4. 7 Average compressive strength of GPC and CC

From the figure 4.7 above shows that the compressive strength of fly ash based geopolymer concrete with 5% replacement of sand by coal Bottom ash improves by 1.03% which is very less when compared to conventional concrete almost it is comparable. This improvement is due to pozzolanic properties of bottom ash, CBA contains reactive silica and alumina, which can react with calcium hydroxide (CH) released during the process of geopolymerization, this pozzolanic reaction leads to the formation of additional C-S-H gel in addition to this by reacting with alkaline activator to form A-S-H gel, which is responsible for the strength development. From the current, investigation geopolymer concrete with more than that of 5% bottom ash indicates a reduction in compressive strength. This is most probably due to the angular shape and rough texture causing high inter-particle friction of the bottom ash, the irregular shape, which can result in a lower packing density than natural river sand this may result in lower strength due to insufficient particle interlocking. strength of concrete decreases when the percentage of bottom ash replacement increases due to the bonding between the aggregates in the mixture (Singh and Siddique 2016b).

The compressive strength of the geopolymer concrete decreased as the percentage of replacement increase. Moreover, the compressive strength of geopolymer concrete with BA up to 10% replacement was greater than the characteristics compressive strength of C-25 structural concrete, which has 25 $N/mm^2$.

#### 4.3.2.1 Comparison of Compressive Strength Result of the mixes (M-0, M-1, M-2, M-3 and M-4) using ANOVA with 7 and 28 days of curing

ANOVA (Analysis of Variance) is a statistics tool used to evaluate the difference between means in two or more groups also determine whether they are significant differences among the means of the groups if so, which groups differ significantly from each other.

a) **Hypothesis formulation testing in factorial ANOVA**

   **Null hypothesis(H0): t**here is no significant difference in the mean compressive strength of the 5 mixes

   **Alternative hypothesis (Ha);** there is a significance deference in the mean compressive strength of the five mixes

b) **Normality test**

From Table 4.11, the p-value of the data is below 0.05, which indicates that there is a significant difference in the mean compressive strength of the five mixes. Therefore, the null hypothesis is rejected, and post-hoc tests such as Tukey's Honestly Significant Difference

(HSD) were used to determine exactly which pairs of mixes have significantly different mean compressive strengths.

Table 4. 10 Normality test result of compressive strength

| | DF | Statistic | p-value | Decision at level (5%) |
|---|---|---|---|---|
| Compressive strength | 30 | 0.95678 | 0.25568 | Can't reject normality |

The table 4.12 below indicates the statistical significance of pairwise comparisons between groups or mixes. These letters are used to identify which groups are significantly different from each other based on their mean values, with groups that share the same letter being statistically indistinguishable from each other or not being significantly different from each other. Means that do not share a letter are significantly different.

Table 4. 11 Interactions grouping letters for compressive strength result

| Curing day | Replacement | Mean | Groups | | | |
|---|---|---|---|---|---|---|
| 28 | M-2(5%BA) | 30.39 | A | | | |
| 28 | M-0(control) | 30.08 | A | | | |
| 28 | M-3 (10%BA) | 26.36 | | B | | |
| 7 | M-2(5%BA) | 26.05 | | B | | |
| 7 | M-3(10%BA) | 25.55 | | B | | |
| 28 | M-1(0%BA) | 25.53 | | B | | |
| 28 | M-4(15%BA) | 22.39 | | | C | |
| 7 | M-0(control) | 22.35 | | | C | |
| 7 | M-1(0%BA) | 20.59 | | | C | |
| 7 | M-4(15%BA) | 17.96 | | | | D |

**Note**. Means that do not share a letter are significantly different.

From the table, above the mean compressive strength of M-0 is not significantly different from M-2 at 28 curing days(with P-value of 0.99984 which is >0.05), in addition M-0 at 28days of curing and M-2 at 7days of curing with P-value of 1.24269E-5 which is <0.05 shows that significantly different from all the other mix, this indicates the maximum compressive strength from the rest, moreover M-3 at 7 and 28 curing days, as well as M-2 at 7days and M-1 at 28 days of curing were not significantly different(P-value, 0.87767 and 0.99183) respectively but they have significantly different means from M-4 at curing day of 28 and M-0 and M-2 at 7 days of curing and also the mean compressive strength of M-4 at

7 day of curing  indicates significantly different from other mixes and it is the lower mean compressive  strength than the rest.

### 4.3.3 Flexural Strength for Geopolymer Concrete and Conventional Concrete

Flexural test evaluates the tensile strength of concrete indirectly. It evaluates a concrete beam's resistance to failure due to bending. The results of the flexural test on concrete are represented by the rupture modulus (MR), which is stated in MPa. Flexural stresses are estimated for each sample and averaged across all samples using average rupture loads obtained from the testing machine. The average flexural strength test results for 7 and 28 days are shown in Table 4.13 and figure 4.8 The detail flexural test results are tabulated under appendix Table A3. 3

Table 4. 12 Average flexural strength test result for GPC and CC

| Test No. | Mix Designation | Average Flexural Strength at the age of 7 and 28days | |
|---|---|---|---|
| | | 7days (MPa) | 28days (MPa) |
| 1 | M-0 (Control) | 2.98 | 3.28 |
| 2 | M-1 (BA 0%) | 2.47 | 2.71 |
| 3 | M-2 (BA 5%) | 2.77 | 3.18 |
| 4 | M-3(BA 10%) | 2.62 | 2.9 |
| 5 | M-4(BA 15%) | 2.26 | 2.4 |

According to data presented in the table 4.13, of the current investigation at 7days and 28 days the flexural strength of the conventional concrete (M-0) Mix was determined as the highest value which is 2.98MPa.and 3.12MPa respectively. This is due to concrete with pozzolanic material, does not achieve early strength when compared to normal concrete, due to slow hydration and slower setting at lower temperature, while the flexural strength of the M-2 with 5% BA blended with 3% OPC was 2.77MPa and 3.18MPa, at the age of 7 and 28 days curing at ambient temperatures.

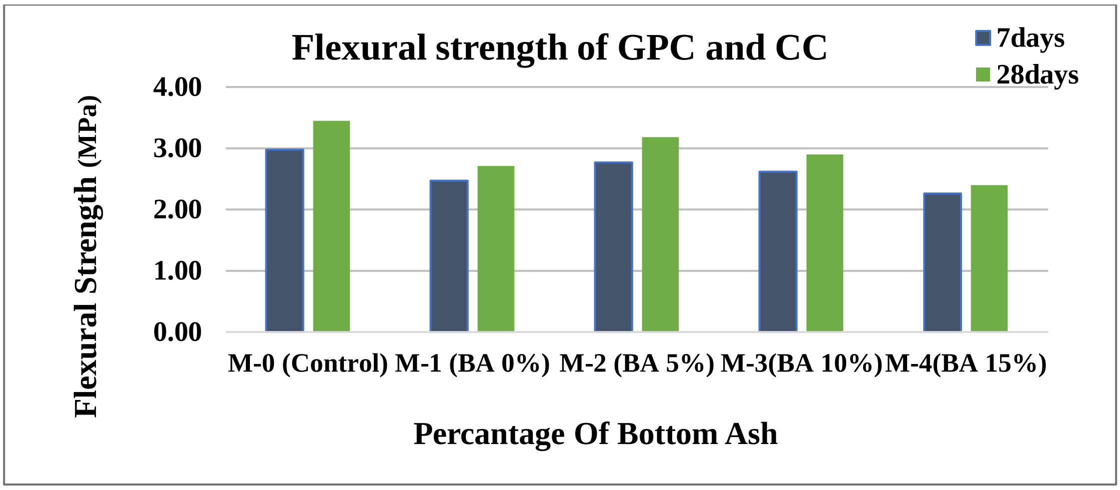



Figure 4. 8 Flexural strength of GPC and CC

From the figure 4.8 above the Flexural strength of fly ash based geopolymer concrete with 5% replacement of sand by coal Bottom ash shows comparable flexural strength with conventional concrete at 28days and also shows better flexural strength than M-1, M-3, and M-4 this is due to the pozzolanic properties of the coal bottom ash, which contribute to the formation of additional bonds within the material, Furthermore, the properties of geopolymer concrete may be affected by the curing temperature, according to (Hassan, et al.2019) the study conducted on fly ash based geopolymer concrete curing at higher temperature (75$^{o}$C) at the age of 28days flexural strength 5MPa were recorded, this is higher than the current study at lower temperature. Addition to this the lower density of geopolymer concrete compared to Conventional concrete is also a contributing factor to the reduction in flexural strength. Due to lower density, geopolymer concrete structures may experience higher levels of deflection and vibration, which can lead to the development of cracks and brittle failure (Abraham 2014). This can further weaken the concrete's flexural strength due to the loss of its structural integrity.

From the figure 4.8 above shows that when percentage of bottom ash increase the flexural strength becoming decrease, and this may due to, the coal bottom ash has lower packing density which results in less interlocking between the particles, leading to reduced strength, and addition to this, the increase in bottom ash may result in lower bonding between the particles and reduced the flexural, strength of concrete.

#### 4.3.3.1 Comparison of flexural Strength Result of the mixes (M-0, M-1, M-2, M-3 and M-4) using ANOVA with 7 and 28 days of curing

ANOVA (Analysis of Variance) is a statistics tool used to determine whether there are any significant differences between the means of two or more groups

**a) Hypothesis formulation testing in factorial ANOVA**

**Null hypothesis(H0): t**here is no significant difference in the mean Flexural strength of the 5 mixes (M-0, M-1, M-2, M-3 and M-5)

**Alternative hypothesis (Ha);** there is a significance deference in the mean Flexural strength of the five mixes

**b) Normality test**

From the Table 4.14 the p-value of the flexural strength data are below 0.05 this indicates that there is a significance difference in the mean flexural strength of the five mixes, therefore the null hypothesis is rejected, then post-hoc tests such as Tukey's Honestly Significant Difference (HSD) used to determine exactly which pairs of mixes have significantly different mean flexural strengths.

Table 4. 13 Normality test for flexural strength

| | DF | Statistic | p-value | Decision at level (5%) |
|---|---|---|---|---|
| flexural strength | 30 | 0.95156 | 0.1861 | Can't reject normality |

Flexural Strength: At the 0.05 level, the data was significantly drawn from a normally distributed population.

The table 4.15 below indicates the statistical significance of pairwise comparisons between groups or mixes. These letters are used to identify which mixes are significantly different from each other based on their mean values, with mix that share the same letter being statistically indistinguishable from each other or not being significantly different from each other. Means that do not share a letter are significantly different

Table 4. 14 Interactions grouping letters for flexural strength result

| Curing days | Percentage replacement | Mean | Groups | | | | | |
|---|---|---|---|---|---|---|---|---|
| 28 | M-0(control) | 3.28 | A | | | | | |
| 28 | M-2(5%BA) | 3.18 | A | B | | | | |
| 7 | M-0(control) | 2.98 | A | B | C | | | |
| 28 | M-3(10%BA) | 2.89 | A | B | C | D | | |
| 7 | M-2(5%BA) | 2.76 | | B | C | D | E | |
| 28 | M-1(0%BA) | 2.71 | | | C | D | E | |
| 7 | M-3(10%BA) | 2.62 | | | C | D | E | F |
| 7 | M-1(0%BA) | 2.47 | | | | D | E | F |
| 28 | M-4(15%BA) | 2.40 | | | | | E | F |
| 7 | M-4(15%BA) | 2.26 | | | | | | F |

Moreover, the mean flexural strength of M-2 at 28days of curing is significantly different from M-1 and M-4 except M-0 and M-2, and also the mean flexural strength of M-4 at 28 days of curing indicates no significance difference with M-1 and M-3 at 7 days of curing but significantly different from other mixes and it is the lower mean flexural strength than the rest.

### 4.3.4 Water absorption of Geopolymer concrete and conventional concrete

Water absorption is used to determine the amount of water absorbed under specified conditions. Water absorption characteristics of the concrete plays an important role for the durability of the structure.

Table 4. 15 Average water absorption test result of GPC and CC at the age of 7 and 28days

| Test No. | Mix-Designation | Water absorption at the age of 7 and 28 days | |
|---|---|---|---|
| | | 7days (%) | 28days (%) |
| 1 | M-0 (Control) | 8.66 | 8.44 |
| 2 | M-1 (BA 0%) | 8.32 | 8.27 |
| 3 | M-2 (BA 5%) | 8.51 | 8.42 |
| 4 | M-3(BA 10%) | 9.44 | 9.33 |
| 5 | M-4(BA 15%) | 10.55 | 10.31 |

A test was conducted to measure the durability of the concrete. As presented in Table 4.16, the average water absorptions of fly ash based geopolymer concrete were 8.32%, 8.52%, 9.44%, and 10.55% for sample with; 0%, 5%, 10%, and 15% of replacement of coal bottom ash as fine aggregate respectively after a 7-day curing period. While; 8.27%, 8.42%, 9.33%, and 10.31% were obtained at 28-day curing days for each respective replacement percentage. The lowest water absorption occurred at Mix-1 which means 0% replacement of coal bottom ash, and the highest value were obtained at 15% replacement for both 7 and 28 days. The detail Water absorption test results are tabulated under appendix Table A2.4

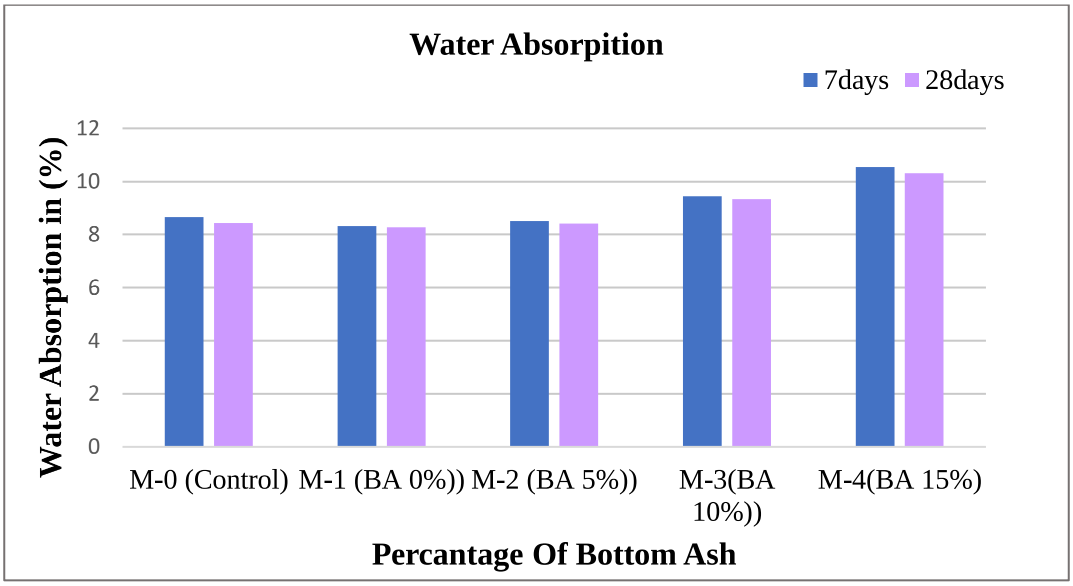



Figure 4. 9 Water absorption of GPC and CC

From the investigation, figure 4.8 above shows that as the percentage of bottom ash increases water absorption of geopolymer concrete at 7 and 28 days also increased, the lower water absorption were observed, on the mix-1 this is due to, the unique chemical composition and reaction mechanism of geopolymer concrete, the reaction of the aluminosilicate source and the alkaline activator, which triggers a chemical reaction to form a binder and harden a mixture, According to Luhar et al. (2015) Test results of water absorption indicates that the water absorption of geopolymer concrete curing at 100 degree Celsius is less compared to control concrete. Although the difference in % of gain in weight is very less which is 0.15% difference, from the current investigation also, indicates that the water absorption of fly ash based geopolymer concrete with 3% OPC as additive, with curing at ambient temperature, the difference in % of gains in weight were 0.17% when compared to conventional concrete.

Moreover, when the percentage of replacement increased, water absorption of geopolymer concrete also increased, this is due to, the rough texture and complicated shape of particles of bottom ash also played significant role in increasing the inter particle friction and also due to the porous surface, which leads to high specific surface area. As the result the surface of bottom ash was, absorb more water. Water absorption of conventional concrete, geopolymer concrete with 0%, 5%, and 10% of BA were less than the maximum water absorption specified by ASTM C642 which is 10% at 28 days. While concrete with 15% of coal bottom ash has water absorption greater than the specified maximum value. From the current investigation finding using concrete with 10%, replacement is acceptable rather than the other replacement percentages in terms of water absorption of the concrete.

The surface water absorption simply reduced the cover concrete's compressive strength. The surface and inner structures of concrete determine the overall strength. As a result, surface water absorption cannot be utilized only to determine concrete strength (Bennet et al. 2013). This could explain why the compressive strength was lower at 0% replacement as compared to the control mix.

**4.3.5 Microstructural property of geopolymer concrete and conventional concrete**

**4.3.5.1 Scanning Electron Microscopy (SEM) Analysis**

Microstructural observation of mixes of conventional concrete and fly ash-based geopolymer concrete with partial replacement of natural river sand by 5% coal bottom ash can be seen through SEM analysis in figure 4.9

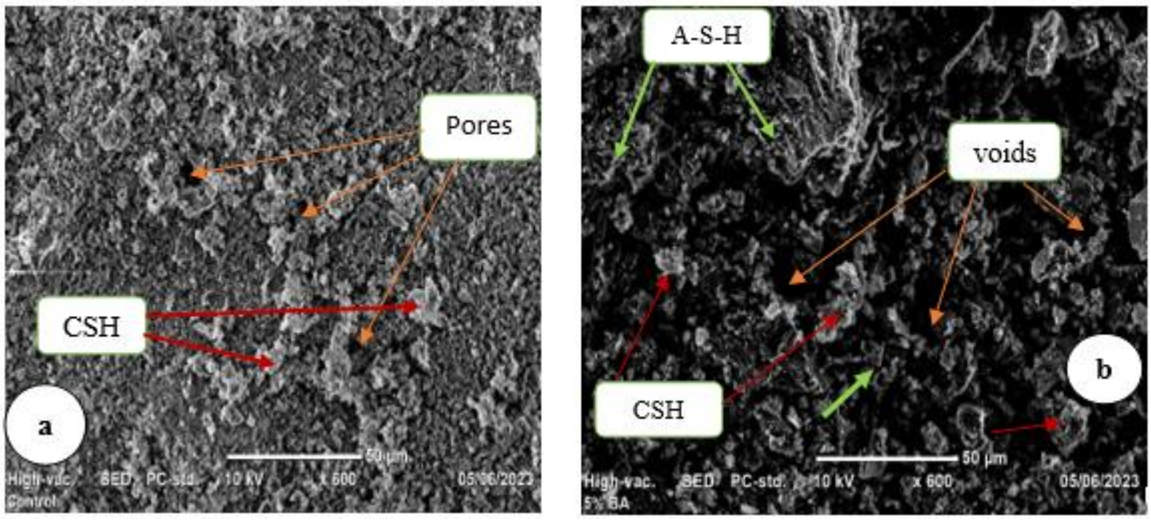



Figure 4. 10 SEM images of concrete. conventional(a), and Geopolymer concrete(b)

Conventional concrete and geopolymer concrete with 5% coal bottom ash mixes were investigated using SEM due to the better physio-mechanical properties observed at 5% replacement of coal bottom ash versus other percentage replacements. The same image was taken After 28 days of curing, a concrete sample Each mix was explored under x600 magnification to investigate the microstructure of the concrete. Considering various scanning electron microscope images, the phases were indicated by studying the literature available (Bennet Jose Mathew and M Sudhakar 2013). It was assumed that the bright matter in the images stands for C-S-H gel or paste.

After having some idea about the presence of C-S-H gel or paste, further referring to the above literature, in geopolymer concrete, the A-S-H gel appears as an amorphous phase in SEM images, which has a heterogeneous and porous structure and very usually exhibits a spongy or fibrous morphology (Davidovits 2008). In conventional concrete, the bright structure with crystalline formation could be CSH, as shown in figure 4.9 (a). while in geopolymer concrete small CSH were appeared this is due to the presence of small quantity of cement in the mix, which provides source of calcium ions that can react with alumina silicate components of the fly ash, which contributes to early strength of the geopolymer concrete at low temperature, moreover the SEM image of geopolymer concrete in figure 4.9(b) shows more pore structure than, the conventional concrete, this is due to the low temperature curing, according to a study by (Kumar et al. 2018), the SEM images of geopolymer concrete cured at high temperature showed a more compact and uniform microstructure with less pores, furthermore the presence of A-S-H gel in geopolymer concrete can provide binding properties and strength to the concrete mix This gel can be formed by the reaction of an alkaline activator with alumina and silica present in fly ash and bottom ash.

#### 4.3.5.2 X-ray diffraction (XRD) Analysis

XRD analysis was done on both conventional and fly ash-based geopolymer concrete, with 5% coal bottom ash as a natural sand replacement that is cured at ambient temperature. XRD was carried out to determine the phase composition and reaction kinetics of fly ash-based geopolymer concrete cured at ambient temperature, which can be used to improve the performance and reliability of the concrete. CuK radiation with a wavelength of 1.5406 A° was utilized to gather the X-ray diffraction pattern in an angle range of $2\theta$ = 10° to 80° using an X-ray diffractometer. Figure 4.9 shows the X-ray diffraction pattern of conventional concrete and fly ash-based geopolymer concrete containing 5% coal bottom ash as a natural sand replacement.

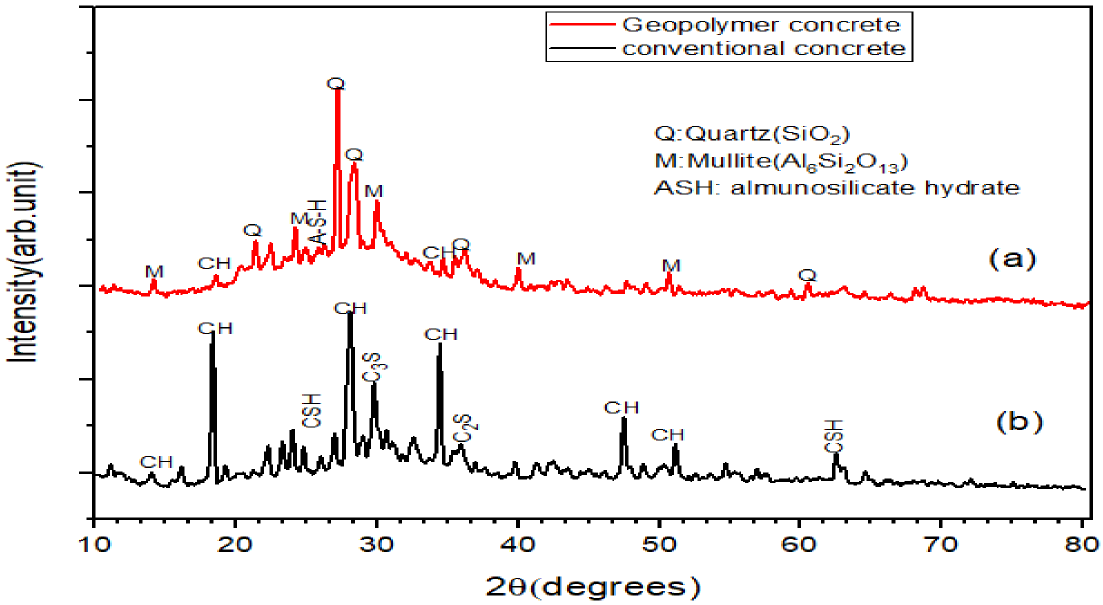



Figure 4. 11 XRD Pattern a) geopolymer concrete, b) conventional concrete

The powder crystal X-ray examination of the samples of conventional concrete and geopolymer concrete (Figure 4.10) shows several peaks in their XRD spectra. Major peaks such as portlandite (C-H), C3S, and C2S are prevalent in conventional and Major peaks, such as quartz and mullite, are prevalent in geopolymer concrete. According to the findings, CH in conventional concrete has high peaks at 2θ values of 28°, whereas quartz (SiO2) in geopolymer concrete has high peaks at 2θ values of 28°. As shown in Figure 4.9, small CH peaks are available at 2θ values of 18° and 35°. This is due to the existence of 3% cement, which acts as an additional source of calcium and can enhance the formation of CH in the early stage of curing. This provides additional strength for fly ash-based geopolymer concrete cured at lower temperatures

Furthermore, Figure 4.10 above shows more crystalline phases, but geopolymer concrete shows more amorphous phases than crystalline structures, which are typically formed through the chemical reaction between source material and an alkaline activator (Hassan, Arif, and Shariq 2020). which creates a geopolymeric gel (A-S-H), which binds the aggregates together and provides the necessary strength to concrete.

## 4.4 Embodied energy and CO2 emission of conventional concrete and fly ash based geopolymer concrete with 5% coal bottom ash scenario

This study used the Mugher cement factory(Ethiopia) embodied energy and CO2 emission coefficients of OPC 3.67 GJ/ton and 0.84 respectively, which is studied by Beressa (2021), in addition this study used Taffeses (2019) studies employed Senegal, embodied energy and

$CO_2$ emission coefficient of coarse aggregate and fine aggregate due to a lack of research in Ethiopia

### 4.4.1 Embodied energy

Embodied energy is the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site. Energy consumption produces $CO_2$, which contributes to greenhouse gas emissions, so embodied energy is considered an indicator of the overall environmental impact of building materials and systems(Venkatarama et al 2016) Calculating the embodied energy of concrete materials is crucial for choosing the optimal choice for decreasing a structure's entire energy consumption and environmental influence. The embodied energy (EE) is computed by summing the product of the quantity of each material (QM) with its embodied energy coefficient (EEC) (Nizam et al., 2018). The energy consumed by ball mill machine is which is found in ASTU chemical laboratory room where and $CO_2$ emission of fly ash is taken as zero as collection of fly ash from flue gas is mandatory except transportation energy from the source to the place where an experiment is conducted,

**a) Energy in transportation of concrete materials**

Transportation of materials is a major factor in the cost and energy of a building. Bulk of the concrete materials in urban and semi-urban centers are transported using trucks in Ethiopia. The transportation distance may vary depending upon the location of construction materials

The Table below shows the material's distance from the source to the place where experiment is conducted (ASTU) with their respective source location used for this study. Natural sand and crushed stone aggregate consume about 1.75 MJ/$m^3$ for every one km of transportation distance. Assuming cement are also transported using trucks, diesel energy of 1MJ/ton/km is spent during transportation (Venkatarama et al 2003). Based on this data the embodied energy of materials utilized in this study was computed as presented in Table 4.17. By summing the embodied energy of concrete materials including transportation energy

The energy consumed during grinding of fly ash by ball mill machine where (0.25kwh/kg) 0.9MJ/kg, the ball mill machine which is found in material department were used for this study

Table 4. 16 Material transportation distance from the source to ASTU

| No | material type | location | distance (km) |
|---|---|---|---|
| 1 | Natural river sand | Metehara | 94 |
| 2 | Coarse aggregate | Kurfa (crushing site) adama | 7 |
| 3 | coal bottom ash | Alemgena (A.A) | 100 |
| 4 | Cement | Muger cement factory | 182 |
| 5 | coal fly ash | lemgena (A.A) | 100 |

Note. The distance is considered for embodied energy calculation

Table 4. 17 Transportation energy of materials per distance

| Material Type | Distance (Km) | Energy (MJ/m$^3$/km) | Total energy (MJ/m$^3$) |
|---|---|---|---|
| Natural river sand | 94 | 1.75 | 164.5 |
| Coarse aggregate | 7 | 1.75 | 12.25 |
| coal bottom ash | 100 | 1.75 | 175 |
| | | Energy (MJ/kg/km) | Energy (MJ/kg) |
| Cement | 182 | 0.001 | 0.182 |
| Coal fly ash | 100 | 0.001 | 0.1 |

Source: (Venkatarama et al 2003)

Table 4. 18 Transportation energy of materials for (MJ/0.405387m$^{3)}$ C-25 conventional concrete

| Material Type | Quantity | Unit | Transport E. (MJ) | Total Transport E (MJ) |
|---|---|---|---|---|
| Natural river sand | 0.01851 | m$^3$ | 164.5 | 3.044 |
| Coarse aggregate | 0.01881 | m$^3$ | 12.25 | 0.230 |
| Cement | 30.55 | kg | 0.182 | 5.560 |

Table 4. 19 Total embodied energy of materials (MJ/0.405387m3) for C-25 conventional concrete

| 1 | Materials | QM (kg) | EEC MJ/kg | EE (MJ) | Transport. E (MJ) |
|---|---|---|---|---|---|
| 1 | Cement | 30.55 | 3.67 | 112.12 | 5.560 |
| 2 | Natural river sand | 68.95 | 0.06 | 4.14 | 3.044 |
| 3 | Coarse Aggregate | 79.097 | 0.16 | 12.66 | 0.230 |
| | total | | | 128.91 | 8.834 |
| | Grand total embodied energy | | | 137.744MJ | |

Table 4. 20 Transportation energy of materials (MJ/0.405387m3 for C-25 fly ash based geopolymer concrete with 5% bottom ash

| Material Type | Quantity | Unit | Energy (MJ/m$^3$) | Total energy (MJ) |
|---|---|---|---|---|
| Natural river sand | 0.0175745 | m3 | 164.5 | 2.891 |
| Coal bottom ash (5%) | 0.0009255 | m3 | 175 | 0.161 |
| Coarse aggregate | 0.01881 | m3 | 12.25 | 0.230 |
| | | | Energy (MJ/kg) | |
| Fly ash | 29.633 | kg | 0.182 | 5.393 |
| Cement (3%) | 0.9165 | kg | 0.182 | 0.166 |

Table 4. 21 Total embodied energy of materials (MJ/0.405387m$^3$) for C-25 fly ash based geopolymer concrete with 5% bottom ash scenario

| Materials | QM (Kg) | EEC (MJ/Kg) | EE (MJ) | Transportation E. (MJ) |
|---|---|---|---|---|
| Cement | 0.916 | 3.67 | 3.36 | 0.166 |
| Fly ash | 29.632 | 0.9 | 26.66 | 5.393 |
| Natural river sand | 65.51 | 0.06 | 3.93 | 2.891 |
| bottom ash | 3.45 | - | - | 0.161 |
| Coarse Aggregate | 79.097 | 0.16 | 12.66 | 0.230 |
| Total | | | 46.61 | 8.841 |
| Grand total embodied energy | | | 55.451MJ | |

From table 4.20 the total imbodied energy consumed by C-25 conventional concrete where 137.744MJ/0.405387m3 or 339.784MJ/m3 and also from table 4.22 the total embodied energy consumed by C-25 fly ash based geopolymer concrete with 5% bottom ash scenario where 55.451MJ/0.405387m3 or 136.7853MJ/m3, this indicates that there is a reduction of 42.59% energy by fly ash based geopolymer concrete, this is due to high energy consumption during cement production process

### 4.4.2 Reduction of CO2 Emissions

One of the challenges is the sustainable development of the cement and construction industries in terms of environmental impact. One ton of Portland cement emits approximately one ton of CO2 into the atmosphere during the manufacturing process (Raijiwala and Patil 2011). The releasing of CO2 leads for the pollution of the atmosphere.

Table 4. 22 Table CO2 emission of materials (kg/0.405387m3) of C-25 conventional

| Materials | QM kg | CO2EC (Kg/Kg) | ECO2 (Kg) |
|---|---|---|---|
| Cement | 30.55 | 0.84 | 25.662 |
| Fine aggregate | 68.95 | 0.004 | 0.2758 |
| Coarse Aggregate | 79.097 | 0.01 | 0.79 |
| Total CO2 emission | | | 26.73kg |

Table 4. 23 CO2 emission of materials (kg/0.405387$m^3$) of C-25 fly ash based geopolymer concrete with 5% bottom ash scenario

| Materials | QM kg | CO2EC (Kg/Kg) | ECO2 (Kg) |
|---|---|---|---|
| Cement | 0.916 | 0.84 | 0.769 |
| Fly ash | 29.632 | 0 | 0 |
| Fine aggregate | 68.95 | 0.004 | 3.16 |
| Bottom ash | 3.45 | 0 | 0 |
| Coarse Aggregate | 79.097 | 0.01 | 0.79 |
| Total CO2 emission | | | 4.72 |

From table 4.23 the total CO2 emissions by C-25 conventional concrete where 26.73kg/0.405387$m^3$ or 65.936kg/$m^3$ and also from table 4.24 the CO2 emission by fly ash based geopolymer concrete with 5% bottom ash scenario where 4.72kg/0.405387$m^3$ or 11.643kg/$m^3$, this indicates that there is reduction of 69.99% of CO2 emission by fly ash based geopolymer concrete when compared to conventional concrete.

Fly ash based Geopolymer concrete, which is an energy- efficient material. As a result, it reduces embodied energy and CO2 emissions while avoiding the overuse of concrete materials. Furthermore, using waste industrial by product such as fly ash and bottom decreases waste deposition in the environment. Additionally, the coal bottom ash used in geopolymer concrete reduces the degradation of the land due to mining of natural river sand. Therefore, in the present circumstances, the geopolymer technology can provide a sustainable solution which can minimize the production of cement there by the CO2 emission can be minimized and increase the utilization of FA in the construction industry. Hence, geopolymer concrete has a great potential for utilization in construction industry as it is environmentally friendly.

# CHAPTER FIVE

# CONCLUSION AND RECOMMANDATION

The findings of various experimental results and the overall outcomes of this study were used to draw conclusions and make recommendations.

## 5.1 Conclusion

- ✓ From the complete silica analysis result, the chemical composition of fly ash can be classified as class F pozzolana as specified by ASTM ($SiO_2 + Al_2O_3 + Fe_2O_3$ is greater than 70%). In addition to this the physical property of the coal bottom ash was fulfilled the requirements for fine aggregate, in accordance with the ASTM standards, the test result demonstrates that, the workability of the geopolymer concrete decreased as the percentage replacement increase, even though 0% and 5% replacement of bottom ash are in the range of (20-100) mm which is the slump value for normal concrete in accordance with the ASTM standard,
- ✓ The compressive strength of the fly ash based geopolymer concrete with 5% bottom ash shows an improvement of 1.03% which is statistically not different from conventional concrete, which is cured at ambient temperature, it is due to the pozzolanic properties of bottom ash. CBA contains reactive silica and alumina, which can react with calcium hydroxide (CH) released during the process of geopolymerization, this pozzolanic reaction leads to the formation of additional C-S-H gel, in addition to this by reacting with alkaline activator to form A-S-H gel, which is responsible for strength development. However, as the percentage of replacement increased to 10% and 15%, the compressive strength of the concrete decreased. This finding shows that 5% of replacement is the percentage that reached maximum compressive strength but was not optimal, which is acceptable for C-25 concrete at 28 days. The flexural strength of geopolymer concrete also shows a comparable result at 28 days of ambient curing to conventional concrete with 5% BA, but as the percentage of bottom ash increases, the flexural strength decreases. Likewise, the water absorption of bottom ash-containing fly ash-based geopolymer concrete increases as bottom ash content increases due to the ash's high water-absorbent property and slow hydration. However, the percentage of water absorption of geopolymer concrete containing 0%, 5%, and 10% was in the range of (0–10) %, which is the maximum water absorption specified by the standard, which is 10% at 28 days. It reduces as the concrete ages because of the late hydration of pozzolanic materials.

- ✓ Furthermore, the microstructure of fly ash-based geopolymer concrete with 5% coal bottom ash as a partial replacement of natural river sand on day 28 shows the formation of A-S-H gel in the concrete due to the higher silica and alumina content of the ash, which reacts with alkaline solutions.
- ✓ Lastly using fly ash-based geopolymer concrete partially replacing fine aggregate by 5% coal bottom ash, which is cured at ambient temperature in C-25 concrete, saves 42.59% energy and minimizes 69.99% of CO2 emissions when compared to conventional concrete

## 5.2 Recommendation

Construction industries, government institutions, and research communities should be made aware of the possibility of using bottom ash as a partial replacement of natural river sand in the production of structural fly ash-based geopolymer concrete, which is cured at ambient temperature and is used for cast-in-situ concrete. In addition to that, the fly ash and bottom ash shall be effectively used, and hence no landfills are required to dump the fly ash and bottom ash, which also reduces the mining of land for natural river sand.

Based on this research and an experimental laboratory study held on it, the researcher forwarded the following recommendations for future study:

- ❖ The water absorption test was only conducted to determine the durability of concrete in this study, whereas permeability, chloride attack, and sulfur acid attack resistance tests will be conducted to determine the long-term durability of concrete.
- ❖ Tensile strength and other engineering properties of geopolymer concrete.
- ❖ Embodied energy and CO2 emission was evaluated in this study, it is economic implication will be studied.

Furthermore, in the future study:

- ❖ A geopolymer concrete mix design standard will be prepared to reduce ambiguity in mix proportioning, or modifications should be made to the ACI mix design of OPC concrete.

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# Appendix 1

# Material Test Result

## A1.1 Physical property of Coal Bottom Ash

### A1.1.1 Sieve Analysis for bottom ash

Procedure for Grading Coal Bottom Ash according to ASTM standard for fine aggregate.

1) The researcher weighted a sample of 2 kg of Coal Bottom ash

2) The sample was quartered.

3) From the quartered sample, weighing 500 g,

4) The empty sieves were weighted, and the data was recorded properly.

5) The pan was placed on the bottom and the other sieves were put on the pan with increasing opening sizes of the sieves.

6) Placed the 500 g of sample on the top of the sieves (having a larger opening size).

7) Smashed the sample for about 10 minutes in a sieve shaker.

8) Each sieve, together with the aggregate retained on it, was measured and the weight retained on each sieve was calculated.

9) The gradation chart was filled in and the fineness modulus was computed.

Table A1. 1 Sieve Analysis for Bottom ash

| Sieve Analysis for Bottom Ash | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Sieve opening (mm)** | Weight of sieve(gm) | Weight of sieve(gm) | Weight of BA retained(gm) | Percent of BA retained | Cumulative percent retained (%) | Percent finer (%) | Range of finer (%) |
| **4.75** | 440 | 440 | 0 | 0.00 | 0 | 100 | 98-100 |
| **2.36** | 405 | 490 | 85 | 16.21 | 16.21 | 83.79 | 80-100 |
| **1.18** | 480 | 605 | 125 | 25.24 | 41.45 | 58.55 | 50-85 |
| **0.6** | 465 | 590 | 125 | 25.24 | 64.67 | 35.33 | 25-60 |
| **0.3** | 300 | 415 | 115 | 23.22 | 87.89 | 12.11 | 5-30 |
| **0.15** | 280 | 330 | 50 | 10.09 | 97.98 | 2.02 | 0-10 |
| **pan** | 255 | 260 | 5 | | 100 | | - |
| | Total | | | | 308.20 | | |

Fineness modules (FM) = $\frac{\sum comulative\ retained}{100}\ \frac{308.20}{100}$ =3.082

### A1.1.2 Unit weight of bottom ash

### A1.1.2.1 Compacted and Loose Unit weight of Coal Bottom Ash

Table A1. 2 Compacted and Loose Unit Weight of Bottom Ash

| **Loose Unit weight of Coal Bottom Ash** | | |
|---|---|---|
| **Descriptions** | **Quantity(gm)** | **Calculation** |
| X= Weight of BA plus the cylinder | 9450 | UWBA= $\frac{X-Y}{V}$ <br> = $\frac{9750-3440}{0.005}$ <br> = 1202 kg/m3 |
| Y= Weight of the empty cylinder | 3440 | |
| V= Volume of the cylinder | 0.005 | |

| **Compacted Unit weight of Coal Bottom Ash** | | |
|---|---|---|
| **Descriptions** | **Quantity(gm)** | **Calculation** |
| X= Weight of BA plus the cylinder | 9550 | UWBA= $\frac{X-Y}{V}$ <br> = $\frac{9550-3440}{0.005}$ <br> = 1222 kg/m$^3$ |
| Y= Weight of the empty cylinder | 3440 | |
| V= Volume of the cylinder | 0.005 | |

### A1.1.3 Specific gravity and water absorption of coal bottom ash

Test procedure according to ASTM standard for fine aggregate

1) 1 kg of the BA was prepared.

2) Sample was dried and then make it saturated.

3) The excess water was decanted with care to avoid loss of fines, spreading the sample on a flat, non-absorbent surface exposed to a gently moving current of warm air.

4) The sample was stirred frequently to get homogeneous drying until achieving the saturated surface dry condition by using the cone test for surface moisture.

5) The mold was held firmly on a smooth, non-absorbent surface with a large diameter. A portion of partially dried cba was loosely placed in the mold by filling it to the brim and heaping additional materials above the top of the mold.

6) The sand was lightly tamped into the mold with 25 light drops of the tamper about 5 mm above the top surface of the sand.

7) The surface was adjusted by removing loose sand from the base and lifting the mold vertically. If surface moisture was still present, the sand retained the molded shape. When the sand slumped slightly, it indicated that it had reached s.s.d. condition.

Procedure:

a) The S.S.D sample was weighed at 500 g.

b) The pycnometer was partially filled with water and 500 g of saturated surface dry CBA was put into the pycnometer.

c) Then, they filled the pycnometer with additional water to fill it to 90% of its capacity.

d) The pycnometer was rolled and inverted to eliminate all air bubbles.

e) The pycnometer was placed in a water bath at 23 °C for an hour.

f) The water level in the pycnometer was brought to its calibrated capacity.

g) Then, the total weight of the pycnometer, specimen, and water was measured.

h) The researcher removed the fine aggregate from the pycnometer, dried it to a constant weight at 105 °C, cooled it in room temperature air for one hour, and measured it.

i) The weight of the pycnometer filled to capacity with water was determined at 23°C.

Table A1. 3 Specific Gravity and Water Absorption of Coal Bottom Ash test result

| **Descriptions** | **Quantity** | **Calculations** |
|---|---|---|
| X: Weight of oven dry specimen | 481(gm) | Bsg = $\frac{Z}{Y+Z-W}$ $\frac{500}{1500+500-1755}$ = 2.04 |
| Y: Weight of pycnometer filled with water | 1500(gm) | |
| Z: Weight of the saturated surface-dry specimen | 500(gm) | Asg = $\frac{X}{Y+X-W}$ $\frac{481}{1500+481-1755}$ = 2.33 |
| W: Weight of pycnometer with specimen and water to calibration mark | 1755(gm) | WA (%) = $\frac{Z-X}{X}$ $\frac{500-481}{481}$ *100 = 3.95 |

**NB.** Bsg: Bulk specific gravity

Asg: Apparent Specific gravity

WA: Water Absorption

## A1.2 Physical property of Natural River sand

### A1.2.1 Silt Content of Natural River Sand

A: Silt deposited above the sand

B**:** Amount of clean sand

Silt content (%) = $\frac{Silt\ deposited\ above\ the\ sand\ (A)}{Amount\ of\ clean\ sand\ (B)} x100$

Table A1. 4 Silt Content of Natural River Sand

| Items | Trial 1 | Trial 2 | Trial 3 | Average |
|---|---|---|---|---|
| **A** | 2.6 | 2.3 | 2.8 | 2.566 |
| **B** | 300 | 300 | 300 | 300 |
| | **0.86** | **0.766** | **0.93** | **0.85%** |

Silt content (%) = $\frac{A}{B}$ x 100 %

**A1.2.2 Sieve Analysis of Natural River sand**

**Procedure for Grading Fine Aggregate according ASTM standard**

1. The researcher weighted a sample of 2 kg of fine aggregates.
2. The sample was quartered.
3. From the quartered sample, weighing 500 g,
4. The empty sieves were weighted, and the data was recorded properly.
5. The pan was placed on the bottom and the other sieves were put on the pan with increasing opening sizes of the sieves.
6. Placed the 500 g of sample on the top of the sieves (having a larger opening size).
7. Smashed the sample for about 10 minutes in a sieve shaker.
8. Each sieve, together with the aggregate retained on it, was measured and the weight retained on each sieve was calculated.

Table A1. 5 Sieve Analysis for Natural River Sand

| Sieve opening (mm) | Weight of sieve(gm) | Weight of sieve +NRS (gm) | Weight of NRS retained (gm) | Percent of NRS retained | Cumulative percent retained (%) | Percent finer (%) | Range of finer (%) |
|---|---|---|---|---|---|---|---|
| 4.75 | 440 | 440 | 100 | 0 | 0 | 100 | 98-100 |
| 2.36 | 405 | 445 | 91.58 | 8.42 | 8.25 | 91.58 | 80-100 |
| 1.18 | 480 | 580 | 71.39 | 20.19 | 28.61 | 71.39 | 50-85 |
| 0.6 | 465 | 620 | 42.31 | 31.28 | 57.69 | 42.31 | 25-60 |
| 0.3 | 300 | 445 | 13.23 | 29.9 | 86.77 | 13.23 | 5-30 |
| 0.15 | 280 | 325 | 4.21 | 9.28 | 95.79 | 4.21 | 0-10 |
| Pan | 255 | 265 | 100 | 2.06 | 100 | - | - |
| | Total cumulative percent retained by mass | | | | 277.27 | | |

Fineness modules (FM) = $\frac{\sum \text{comulative retained}}{100}$ $\frac{277.27}{100}$ $=$2.77

### A1.2.3 Unit weight of natural river sand

Table A1. 6 Compacted and Loose Unit Weight of Natural River Sand

| **Compacted Unity Weight of NRS** | | |
|---|---|---|
| Descriptions | Quantity(gm) | Calculation |
| X= Weight of NRS plus the cylinder | 10335 | UWNRS= $\frac{X-Y}{V}$ |
| Y= Weight of the empty cylinder | 3440 | $\frac{10335-3440}{0.005}$=1379 kg/m$^3$ |
| V= Volume of the cylinder | 0.005 | |
| **Loose Unity Weight of NRS** | | |
| Descriptions | Quantity(gm) | Calculation |
| X= Weight of NRS plus the cylinder | 10265 | UWNRS= $\frac{X-Y}{V}$ |
| Y= Weight of the empty cylinder = | 3440 | $\frac{10265-3440}{0.005}$= 1365 kg/m$^3$ |
| V= Volume of the cylinder | 0.005 | |

### A1.2.4 Specific Gravity and Water Absorption of Natural River Sand

Test procedure according to ASTM standard for fine aggregate

1) 1 kg of the fine aggregate was prepared.

2) At 110°C, the sample was dried to a constant weight in a suitable pan. Allow it to cool for 24 hours and then make it saturated

3) The excess water was decanted with care to avoid loss of fines, spreading the sample on a flat, non-absorbent surface exposed to a gently moving current of warm air.

4) The sample was stirred frequently to get homogeneous drying until achieving the saturated surface dry condition by using the cone test for surface moisture.

5) Hold the mold firmly on a smooth, non-absorbent surface with a large diameter. Placed a portion of partially dried fine aggregate loosely in the mold by filling it to the brim and heaping additional materials above the top of the mold.

6) Lightly tamp the sand into the mold with 25 light drops of the tamper about 5 mm above the top surface of the sand.

7) The surface was adjusted by removing loose sand from the base and lifting the mold vertically. If surface moisture was still present, the sand would retain the molded shape. When the sand slumped slightly, it indicated that it had reached S.S.D. condition.

Procedure:

a) The S.S.D sample was weighed at 500 g.

b) The pycnometer was partially filled with water and 500 g of saturated surface dry CBA was put into the pycnometer.

c) Then, they filled the pycnometer with additional water to fill it to 90% of its capacity.

d) The pycnometer was rolled and inverted to eliminate all air bubbles.

e) The pycnometer was placed in a water bath at 23 °C for an hour.

f) The water level in the pycnometer was brought to its calibrated capacity.

g) Then, the total weight of the pycnometer, specimen, and water was measured.

h) The researcher removed the fine aggregate from the pycnometer, dried it to a constant weight at 105 °C, cooled it in room temperature air for one hour, and measured it.

i) The weight of the pycnometer filled to capacity with water was determined at 23°C.

Table A1. 6 Specific Gravity and Water Absorption of Natural River Sand

| **Descriptions** | **Quantity** | **Calculations** |
|---|---|---|
| X: Weight of oven dry specimen | 490(gm) | |
| Y: Weight of pycnometer filled with water | 1500(gm) | Bsg = $\frac{Z}{Y+Z-W}$ $\frac{500}{1500+500-1815}$ = 2.7 |
| Z: Weight of the saturated surface-dry specimen | 500(gm) | Asg = $\frac{X}{Y+X-W}$ $\frac{490}{1500+490-1815}$ = 2.8 |
| W: Weight of pycnometer with specimen and water to calibration mark | 1815(gm) | WA (%) = $\frac{Z-X}{X}$ $\frac{500-490}{490}$ *100 = 2.04% |

## A1.3 Physical Property Test for Coarse aggregate

### A1.3.1 Sieve Analysis of Coarse Aggregate

Table A1. 7 Sieve Analysis for Coarse Aggregate

| Sieve opening (mm) | Weight of sieve(gm) | Weight of sieve +CA (gm) | Weight of CA retained (gm) | Percent of CA retained | Cumulative percent retained (%) | Percent finer (%) | Range of finer (%) |
|---|---|---|---|---|---|---|---|
| 20 | 1256 | 1256 | 0 | 0 | 0 | 100 | 100 |
| 19 | 435 | 460 | 25 | 1.25 | 1.25 | 98.75 | 95-100 |
| 12.5 | 440 | 1222 | 782 | 39.12 | 40.37 | 59.63 | 40-80 |
| 9 | 446 | 1079 | 633 | 31.67 | 72.04 | 27.96 | 25-55 |
| 4.75 | 444 | 1003 | 559 | 27.96 | 100 | 0 | 0-10 |
| Pan | 265 | 265 | 0 | 0 | 0 | 0 | 0 |
| | | | | Total | 203.66 | | |

FM= 703.66/100 = 7.04

**Note**: the cumulative percentage retained on only sieve size of (37.5 mm, 19 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30mm and 0.150 mm are used incalculation of fineness modulus of coarse aggregate

### A1.3.2-Unit weight of Coarse Aggregate

Table A1. 8 Compacted and Loose Unit Weight of Coarse Aggregate

| **Compacted Unity Weight of CA** | | |
|---|---|---|
| Descriptions | Quantity(gm) | Calculation |
| X= Weight of CA plus the cylinder | 11380 | UWCA= $\frac{X-Y}{V}$ $\frac{11380-3440}{0.005} = 1587$kg/m$^3$ |
| Y= Weight of the empty cylinder | 3440 | |
| V= Volume of the cylinder | 0.005 | |
| **Loose Unity Weight of CA** | | |
| Descriptions | Quantity(gm) | Calculation |
| X= Weight of CA plus the cylinder | 11165 | UWCA= $\frac{X-Y}{V}$ $\frac{11165-3445}{0.005} = 1544$kg/m$^3$ |
| Y= Weight of the empty cylinder | 3445 | |
| V= Volume of the cylinder | 0.005 | |

### A1.3.3 Specific Gravity and Water Absorption of Coarse Aggregate

Test Procedures

1) The researcher took the sample of coarse aggregate by using the sample splitter.

2) The sample was sieved with a 4.75 mm sieve, and the sample passing through the 4.75 mm sieve was ignored.

3) The sample was washed to remove dust.

4) The sample was placed in the oven at 105°C for 24 hours.

5) The sample was taken out of the oven, left to cool, and then the weight was measured.

6) The sample was submerged in water for 24 hours.

7) The researcher removed the sample from the water and rolled it in a large absorbent cloth until all visible films of water were removed.

8) The required weight of the sample in its (S.S.D) condition was taken.

9) The researcher immediately placed the S.S.D sample in the sample container, determined the weight in water at 23 °C, and recorded the data

Table A1. 9 Specific Gravity and Water Absorption of Coarse Aggregate test result

| **Descriptions** | **Quantity** | **Calculations** |
|---|---|---|
| A: Weight of oven dry specimen | 2997(g) | Bsg = $\frac{C}{C-B}$ $\frac{3051}{3051-1900}$ = 2.65 |
| B: Weight of Saturated in the water | 1900(g) | Asg = $\frac{A}{A-B}$ $\frac{2997}{2997-1900}$ = 2.73 |
| C: Weight of the saturated surface-dry specimen | 3051(g) | WA (%) = $\frac{C-A}{A}$ $\frac{3051-2997}{2997}$ *100 = 1.8% |

## A1.4 mix design calculation procedure

Step 1: Calculating the required mean compressive strength based on characteristic strength of 25 MPa which gives; fck = f'ck +8.5 = 25 + 8.5 = 33.5 MPa

Table A1. 10 Average compressive strength conversion

| Characteristics strength (f'ck, MPa) | Mean strength (fck, MPa) |
|---|---|
| < 21 | F'ck +7 |
| 21-35 | F'ck +8.5 |
| >35 | 1.1 x F'ck +5 |

Step 2: Determining the minimum cement content

From a durability point of view, the minimum cement content was taken as 300 kg/m3.

Step 3: Choose a Slump Value

For C-25, a concrete slump of 2–10 cm is recommended.

Step 4: Choose the maximum aggregate size.

For higher compressive strength, a reduced maximum size aggregate was selected. In this case, the maximum size aggregate was 20, and the nominal size aggregate was 19 mm.

Step 5: Mixing water and air content determination the amount of water per unit volume of concrete required for a required slump value is dependent on aggregate grading, amount of entrained air, and maximum size aggregate.

Table A1. 11 Mixing water for different slump and maximum size aggregate

| Slump (cm) | Water ($kg/m^3$) of concrete for indicated maximum size aggregate in mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 12.5 | 20 | 25 | 40 | 50 | 70 | 150 |
| | Non-air entrained concrete | | | | | | | |
| 2-10 | 205 | 200 | 185 | 180 | 160 | 155 | 145 | 125 |
| 8-10 | 225 | 215 | 200 | 195 | 175 | 170 | 160 | 140 |
| 15-18 | 240 | 230 | 210 | 205 | 205 | 185 | 180 | 170 |
| Amount of entrapped air (%) | 3 | 25 | 2 | 15 | 1 | 0.5 | 0.3 | 0.2 |

In Table 3.2 above, with a slump of 2–10 cm and a maximum size aggregate of 20 mm, the water content becomes 185 $kg/m^3$ and 2%, or 20 liters of entrapped air.

Step 6: Determine the water-cement ratio

In a concrete mix, the water-cement ratio is the ratio of the weight of water to the weight of cement.

Table A1. 12 Average compressive strength with water cement ratio

| Compressive strength 28 days (M pa) | Water / cement ratio (by mass) Non-air entrained | Air entrained |
|---|---|---|
| 45 | 0.38 | - |
| 40 | 0.42 | - |
| 35 | 0.47 | 0.39 |
| 30 | 0.54 | 0.45 |
| 25 | 0.61 | 0.52 |
| 20 | 0.69 | 0.6 |
| 15 | 0.79 | 0.71 |

The ACI table above cannot provide the exact value of the water-cement ratio for a 33.5 MPa mean strength. This can be calculated via interpolating the above and below values as follows: 33.5 MPa is found between 30 and 35 MPa.

35 0.47

33.5 X Interpolation $\frac{35-33.5}{0.47-x} = \frac{33.5-30}{x-0.54}$

30 0.54 x = 0.491

The minimum water cement ratio is 0.491

Step 7: Determination of mix cement content

$$\text{Cement content} = \frac{\text{Quantity of water}}{\text{water cement ratio}}$$

$$= \frac{185}{0.491}$$

$$= \underline{376.78}\ \text{kg/m}^3$$

Step 8: Estimating the Bulk Volume Per Unit Volume of Concrete

This depends on the fineness modulus, which is 2.77, and the maximum size aggregate of 20 mm.

Table A1. 13 Volume of coarse aggregate per unit volume of concrete

| Maximum size of aggregate | Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness modulus | | | |
|---|---|---|---|---|
| | 2.4 | 2.6 | 2.8 | 3 |
| 10 | | 0.5 | 0.46 | 0.44 |
| 12.5 | | 0.59 | 0.55 | 0.53 |
| 20 | | 0.66 | 0.62 | 0.6 |
| 25 | | 0.71 | 0.67 | 0.65 |
| 40 | | 0.76 | 0.72 | 0.7 |
| 50 | | 0.78 | 0.74 | 0.72 |
| 70 | | 0.81 | 0.77 | 0.75 |
| 150 | | 0.87 | 0.83 | 0.81 |

The bulk volume of dry rodded aggregate was not found in the above table directly. It can be calculated by interpolation since the fineness modulus of 2.77 is found between 2.6 and 2.8 for a 20 mm maximum size aggregate.

2.6    0.66

2.77    x    (2.6-2.77)/(0.66-x) = (2.77-2.8)/(x-0.62)

2.8    0.62

By solving the equation above, = 0.626

Hence, the dry volume of aggregate per volume of concrete is 0.626.

**Step 9:** Calculate the weight of coarse aggregate (WCA) per $m^3$ of concrete.

WCA= bulk volume x bulk density of coarse aggregate

WCA = 0.626 x 1587

= <u>993.46</u> $kg/m^3$

Step 10: Determining the Solid volume of coarse aggregate.

Solid volume of Coarse aggregate = WCA/ (Specific gravity)

= 993.46 /2.73

= <u>363.9</u> $kg/m^3$

Step 11: Calculating the solid volume of cement, water, and air

Volume of cement (VC) = Weight of cement / Specific gravity of cement

= 376.78/3.155

= 119.42 kg/$m^3$

Volume of water (VW) = 185 kg/$m^3$, Volume of air (VA) = 2% or 20 kg/$m^3$

Step 12: Calculating solid volume of sand

Solid volume of sand = 1000 - (VCA + VC + VW + VA)

= 1000 - (363.9 + 119.42 + 185 + 20)

= 1000 – 690.94

= 311.68 kg/$m^3$

Solid weight of sand = dry volume of sand x specific gravity

= 311.68kg/$m^3$ x 2.7

= 833.47 kg/$m^3$

Step 13: Adjustments for moisture in the aggregate

Fine aggregate adsorption = 2.04% and coarse aggregate absorption = 1.8%

Water absorbed by coarse aggregate = 993.46 kg/m3 x 0.018

= 17.88kg/$m^3$

Water supplied by fine aggregate = 833.47 kg/m3 x 0.0204

= 17 kg/$m^3$

Amount of water needed = 185 kg/m3 + 17.88 kg/m3 – 17 kg/m3

= 185.88 kg/$m^3$

Cement = 376.78 kg/$m^3$

Fine aggregate = 833.47 kg/$m^3$ + 17 kg/$m^3$

= 850.47 kg/$m^3$

Coarse aggregate = 993.46 kg/$m^3$ – 17.88 kg/$m^3$

= 975.58 kg/$m^3$

# Appendix 2

# Hardened Concrete Test Result

## A2.1 Unit Weight of Concrete

Table A2. 1 mass and density of cubes on 7 and 28 days

| Mix-designation | Trial | Mass (Kg) | Mass (Kg) | volume | Unity weight (kg/m3) | |
|---|---|---|---|---|---|---|
| | | 7days | 28days | | 7days | 28days |
| M-0 (Control) | 1 | 7.98 | 7.62 | 0.003375 | 2364.44 | 2257.778 |
| | 2 | 8.2 | 7.6 | 0.003375 | 2429.63 | 2251.85 |
| | 3 | 7.86 | 7.57 | 0.003375 | 2328.89 | 2242.96 |
| | **Average** | **8.01** | **7.60** | | **2374.32** | **2250.86** |
| M-1 (BA 0%) | 1 | 7.62 | 7.15 | 0.003375 | 2257.78 | 2118.52 |
| | 2 | 7.55 | 7.45 | 0.003375 | 2237.04 | 2207.41 |
| | 3 | 7.5 | 7.4 | 0.003375 | 2222.22 | 2192.59 |
| | **Average** | **7.56** | 7.33 | | **2239.01** | **2172.84** |
| M-2 (BA 5%) | 1 | 7.76 | 7.56 | 0.003375 | 2299.26 | 2240.00 |
| | 2 | 7.755 | 7.58 | 0.003375 | 2297.78 | 2245.93 |
| | 3 | 7.71 | 7.53 | 0.003375 | 2284.44 | 2231.11 |
| | **Average** | **7.74** | **7.56** | | **2293.83** | **2239.01** |
| M-3(BA 10%) | 1 | 8 | 7.45 | 0.003375 | 2370.37 | 2207.40 |
| | 2 | 7.51 | 7.24 | 0.003375 | 2225.19 | 2145.19 |
| | 3 | 7 | 7.3 | 0.003375 | 2074.07 | 2162.96 |
| | **Average** | **7.50** | **7.33** | | **2223.21** | **2171.85** |
| M-4(BA 15%) | 1 | 6.95 | 7.305 | 0.003375 | 2059.26 | 2164.44 |
| | 2 | 7.115 | 7.25 | 0.003375 | 2108.15 | 2148.15 |
| | 3 | 7.05 | 7.21 | 0.003375 | 2088.89 | 2136.30 |
| | **Average** | **7.04** | **7.255** | | 2085.43 | **2149.63** |

## A2.2 Compressive Strength Test Result

Table A2. 2 Compressive Strength Test Result on 7th and 28th days

| Mix- designation | Trial | Load (KN) | | Strength (N/mm2) | |
|---|---|---|---|---|---|
| | | 7days | 28days | 7days | 28days |
| M-0 (Control) | 1 | 503 | 660 | 22.33 | 29.32 |
| | 2 | 510 | 675 | 22.64 | 29.98 |
| | 3 | 498 | 696 | 22.1 | 30.94 |
| | **average** | **503.67** | **677** | **22.36** | **30.08** |
| M-1 (BA 0%)) | 1 | 453 | 570 | 20.75 | 25.33 |
| | 2 | 457 | 544 | 20.56 | 24.17 |
| | 3 | 451 | 610 | 20.47 | 27.10 |
| | **average** | **453.67** | **574.67** | **20.59** | **25.53** |
| M-2 (BA 5%)) | 1 | 580 | 700 | 25.77 | 31.09 |
| | 2 | 588 | 694 | 26.13 | 30.83 |
| | 3 | 591 | 706 | 26.25 | 29.25 |
| | **average** | **586.33** | **700** | **26.05** | **30.39** |
| M-3(BA 10%)) | 1 | 570 | 584 | 25.32 | 25.95 |
| | 2 | 575 | 594 | 25.55 | 26.40 |
| | 3 | 581 | 602 | 25.80 | 26.75 |
| | **average** | **575.33** | **593.33** | **25.56** | **26.36** |
| M-4(BA 15%) | 1 | 400 | 510 | 17.77 | 22.66 |
| | 2 | 410 | 495 | 18.22 | 22.00 |
| | 3 | 403 | 507 | 17.90 | 22.53 |
| | **average** | **404.33** | **504** | **17.96** | **22.40** |

## A2.3 Flexural strength test result

Table A2. 3 Flexural Strength Test Result on 7th and 28th days

| Mix-designation | Trial | Load (KN) | Load (KN) | flexural stress (MPa) | |
|---|---|---|---|---|---|
| | | 7days | 28days | 7days | 28days |
| M-0 (Control) | 1 | 10.64 | 10.86 | 3.19 | 3.25 |
| | 2 | 9.51 | 10.95 | 2.85 | 3.27 |
| | 3 | 9.7 | 11.12 | 2.9 | 3.32 |
| | Average | 9.95 | 10.64 | 2.98 | 3.28 |
| M-1 (BA 0%)) | 1 | 8.19 | 9.01 | 2.46 | 2.70 |
| | 2 | 8.32 | 8.82 | 2.50 | 2.64 |
| | 3 | 8.21 | 9.3 | 2.46 | 2.78 |
| | Average | 8.24 | 9.04 | 2.47 | 2.71 |
| M-2 (BA 5%) | 1 | 9.12 | 10.76 | 2.74 | 3.22 |
| | 2 | 9.24 | 10.93 | 2.771 | 3.27 |
| | 3 | 9.301 | 10.23 | 2.79 | 3.06 |
| | Average | 9.22 | 10.64 | 2.77 | 3.18 |
| M-3(BA 10%) | 1 | 8.88 | 9.14 | 2.66 | 2.742 |
| | 2 | 8.93 | 10.32 | 2.68 | 3.10 |
| | 3 | 8.93 | 9.49 | 2.52 | 2.85 |
| | Average | 8.91 | 9.65 | 2.62 | 2.90 |
| M-4(BA 15%) | 1 | 7.61 | 8.84 | 2.28 | 2.51 |
| | 2 | 7.76 | 8.8 | 2.33 | 2.50 |
| | 3 | 7.28 | 7.73 | 2.18 | 2.20 |
| | Average | 7.55 | 8.46 | 2.26 | 2.40 |

## A2.4 Water Absorption Test Result

Table A2. 4 Water Absorption Test Result on 7th and 28th days

| Mix-Designation | Trail | 7days | | | 28days | | |
|---|---|---|---|---|---|---|---|
| | | OD(Kg) | S(Kg) | % | OD(Kg) | S(Kg) | % |
| M-0 (Control) | 1 | 0.741 | 0.812 | 9.58 | 0.726 | 0.788 | 8.54 |
| | 2 | 0.735 | 0.795 | 8.16 | 0.745 | 0.81 | 8.72 |
| | 3 | 0.752 | 0.814 | 8.24 | 0.734 | 0.794 | 8.29 |
| | Average | 0.74 | 0.81 | 8.66 | 0.74 | 0.807 | 8.52 |
| M-1 (BA 0%) | 1 | 0.701 | 0.758 | 8.13 | 0.704 | 0.762 | 8.24 |
| | 2 | 0.715 | 0.776 | 8.53 | 0.705 | 0.765 | 8.51 |
| | 3 | 0.732 | 0.784 | 8.30 | 0.716 | 0.763 | 8.06 |
| | Average | 0.716 | 0.77 | 8.32 | 0.708 | 0.763 | 8.27 |
| M-2 (BA 5%) | 1 | 0.721 | 0.782 | 8.46 | 0.701 | 0.756 | 7.84 |
| | 2 | 0.775 | 0.844 | 8.90 | 0.698 | 0.764 | 9.45 |
| | 3 | 0.748 | 0.809 | 8.17 | 0.701 | 0.757 | 7.97 |
| | Average | 0.759 | 0.781 | 8.51 | 0.700 | 0.759 | 8.42 |
| M-3(BA 10%) | 1 | 0.713 | 0.782 | 9.67 | 0.691 | 0.759 | 9.84 |
| | 2 | 0.742 | 0.8 | 10.25 | 0.687 | 0.753 | 9.60 |
| | 3 | 0.702 | 0.761 | 8.40 | 0.703 | 0.763 | 8.55 |
| | Average | 0.719 | 0.781 | 9.44 | 0.694 | 0.758 | 9.33 |
| M-4(BA 15%) | 1 | 0.69 | 0.771 | 9.85 | 0.661 | 0.731 | 10.59 |
| | 2 | 0.703 | 0.776 | 10.38 | 0.688 | 0.753 | 9.45 |
| | 3 | 0.711 | 0.774 | 8.86 | 0.673 | 0.745 | 10.56 |
| | Average | 0.701 | 0.774 | 10.55 | 0.674 | 0.743 | 10.31 |

# Appendix 3: Oxide composition of coal fly ash

| | GEOLOGICAL INSTITUTE OF ETHIOPIA | Doc. Number: GLD/F5.10.2 | Version No: 1 |
|---|---|---|---|
| | Geochemical Laboratory Desk | | Page 1of 1 |
| Document Title:- | Complete Silicate Analysis Report | Effective date: | Nov. 2022 |

Customer Name:- Kumera Daka and Zewudu Sileshi

Sample type :-Synthetic

Sample Preparation: -200 Mesh

Date Submitted:- 14/03/2023

Issue Date:-24/03/2023

Request No:- GLD/RQ/964/23

Report No:- GLD/RN/1585/23

Number of Sample:- One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

| Collector's code | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | MnO | $P_2O_5$ | $TiO_2$ | $H_2O$ | LOI | Weight of Sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FAD-5 | 49.34 | 30.53 | 3.02 | 0.14 | 0.24 | <0.01 | 0.62 | <0.01 | 0.17 | 0.67 | 1.32 | 11.14 | 250 gm |

Note: - This result represent only for the sample submitted to the laboratory.

| Analysts | Checked By | Approved By | Quality Control |
|---|---|---|---|
| Haimanot Bayeh<br>Gadisa Wakuma<br>Nigist Fikadu | Lidet Endeshaw | Yohannes Getachew | Negash Worku |

Figure A3. 1 oxide composition of coal fly ash