Investigation on the properties of Fly-ash based hybrid geopolymer concrete with Bottom-ash municipal solid waste incineration as a partial replacement of fine aggregates

Natnael Solomon Yifru

A thesis submitted to Department of Construction Engineering and Management, School of Civil engineering and Architecture,

Office of Graduate Studies,

Adama Science and Technology University

October 2024

Adama, Ethiopia

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Advisor: Fikreyesus Demeke (PhD)

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Declaration

I hereby declare that this thesis entitled **"Investigation on the properties of Fly-ash based hybrid geopolymer concrete with Bottom-ash municipal solid waste incineration as a partial replacement of fine aggregates."** is my original work and all sources of material used for organizing this proposal have been duly acknowledged and I approve this by my signature.

Name	**Signature**	**Date**
Natnael Solomon Yifru	…….	…….

Recommendation of Advisor

As the primary advisor for this research project, I attest that I have carefully guided and overseen the student during the development of this thesis and have reviewed the preliminary thesis titled **"Investigation on the properties of Fly-ash based hybrid geopolymer concrete with Bottom-ash municipal solid waste incineration as a partial replacement of fine aggregates."** developed by Natnael Solomon Yifru under my supervision. As a result, I advise sending the thesis to the department for additional examination and assessment.

Name	Signature	Date
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Approval Page of Advisor

I hereby certify that the recommendation and suggestion given by the thesis review committee are appropriately incorporated into the final thesis/dissertation entitled **"Investigation on the properties of Fly-ash based hybrid geopolymer concrete with Bottom-ash municipal solid waste incineration as a partial replacement of fine aggregates."** by Natnael Solomon Yifru.

Fikreyesus Demeke (Ph.D.)	……	……..
Major Advisor/Supervisor	Signature	Date

Approval of Board of Reviewers

We, the undersigned, members of the Board of Reviewers of the thesis defense by Natnael Solomon Yifru have read and evaluated the thesis/dissertation entitled **"Investigation on the properties of Fly-ash based hybrid geopolymer concrete with Bottom-ash municipal solid waste incineration as a partial replacement of fine aggregates."** and assessed the understanding of the candidate about the research. Thisis, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Construction Engineering and Management.

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Finally, approval and acceptance of the thesis are contingent upon the submission of its final Copy to the Office of Postgraduate Studies (OPGS) through the Department of Graduate Council (DGC) and School Graduate Committee (SGC).

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First of all, I wish to express my appreciation to my advisor, Dr. Fikreyesus Demeke, for his tireless support, critics and respect. Meanwhile, I am also very thankful to Construction technology and management laboratory assistant M.r Mesele.

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ABSTRACT

Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules. The most important purpose of this research is concerning about the resource optimization in the production of concrete. Each year, vast amounts of natural resources are consumed to manufacture ordinary Portland cement which itself causes considerable environmental problems. Geopolymer can be considered as the key factor which does not utilize Portland cement, nor releases greenhouse gases. Sufficient data is available about researches on fly ash based geopolymer concrete, but cement hybrid geopolymer concrete using both fly ash and bottom ash has a new era. Fly Ash, a by- product of waste obtained from the burning of municipal solid waste is plenty available worldwide. Bottom ash is another waste from the burning of municipal solid waste and was used as partial replacement of sand in fly ash based geopolymer concrete and the ideal percentage of this replacement was one of the aims of this project. This paper briefly reviews the constituents of geopolymer concrete, its strength and potential applications. To achieve this objective systematic literature review and laboratory investigation was conducted. To find 7 and 28 days compressive strength, three 100×100×100mm specimens with 0, 20, 40 and 60 percent replacement of bottom ash were prepared and cured at ambient condition (28^0C). Same condition of curing was provided and 100×100×500mm prisms were tested to find flexural strength at 7-day and 28-day of the four mixtures. Sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solution 14M with ratio of 2.5 were used as alkaline activator and all other parameters were kept constant to ignore other unknown influences. The optimum rate of cement and bottom ash replacement was 50% and 20% respectively which produced geopolymer concrete with 28-day compressive strength of 26.5MPa, tensile strength of 2.81MPa and flexural strength of 4.30MPa. finally, the study develop a framework that will assist the use of geopolymer concrete in different area of construction. The outcome of the research will provide practical inputs to expand knowledge in this area and will encourage researchers to conduct further studies and highlight the use of geopolymer concrete in construction sector of Ethiopia and other developing countries.

***Keywords**: Geopolymer concrete (GPC), Fly ash, Bottom Ash, Municipal Solid Waste Incineration (MSWI).*

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Lists of Acronyms

FA: Fly Ash

BA: Bottom Ash

MSWI: Municipal solid waste incineration

GPC: Geopolymer Concrete

SEM: Scanning Electron Microscopy

XRD: X-ray Diffraction

CHAPTER ONE

INTRODUCTION

1.1 Background

Nowadays, concrete industry is known to be the major consumer of natural resources, such as water, sand and aggregates, and manufacturing Portland cement also requires large amounts of each of them. Due to its high energy consumption and environmental pollution rates, the Portland cement industry was the subject for many investigations by regulatory agencies and the public. They have believed in adjustment of the concrete industry into sustainable technology because of its role in the infrastructure development and being the main consumer of energy and natural resources. With this increasing request for infrastructural needs, it is a must for us to make a balance between the human need for preserving the environment which is endangered by the limitless use of natural resources and utilization of these natural resources. The concern about environmental issues is becoming more important and ignoring is not the solution any more.

Davidovits (1988; 1994) 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. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on SiAl minerals, that result in a three-dimensional polymeric chain and ring structure consisting of Si-OAl-O bonds (Davidovits, 1994).

One of the industries with the fastest global growth is construction. Based on current global figures, approximately 260,00,00,000 tons of cement are needed annually. In the following ten years, this amount will rise by a quarter. Since limestone is the primary raw material used to make regular Portland cement, a severe scarcity of the material could develop after 25 to 50 years. Furthermore, a ton of carbon dioxide, a serious threat to the environment, is released into the atmosphere during the production of one ton of cement. Cement manufacture also requires a massive amount of energy in addition to the already mentioned. Finding a substitute binder is therefore crucial.

Carbon dioxide, which is produced during the manufacture of cement, pollutes the atmosphere. Fly ash, a waste product of the thermal industry, is just thrown onto the ground and takes up a lot of space. Ground water is contaminated by the chemical industry's waste water that is released into the earth. All of the aforementioned problems can be resolved by creating Geopolymer Concrete and rearranging them (Rangan, B. V, 2008).

1.2 Statement of the problem

Concrete is the most dependable, resilient, and adaptable building material in the world. Among the primary sources of atmospheric pollution, the production of ordinary Portland cement is surpassed only by the production of automobiles. Furthermore, the production of cement required a significant amount of energy. The search for a substitute for the current most costly and resource-intensive material, Portland Cement, is therefore unavoidable. By using inorganic molecules to undergo chemical reactions, geopolymer concrete is created a novel building material. An innovative building material called geopolymer concrete is created by the chemical reaction of inorganic molecules. There is an abundance of fly ash, a by-product of coal from thermal power plants, which can be found all over the world. Fly ash is rich in silica and alumina reacted with alkaline solution produced aluminosilicate gel that acted as the binding material for the concrete. It's a great replacement for the current standard cement concrete in construction projects. In the process of making geopolymer concrete, municipal solid waste incineration bottom ash plays a vital role. Since the amount of bottom ash accumulated keep on increasing, the cost for opening new landfill area, transporting to a disposal site and maintaining the reclamation facilities will increase significantly. In recent years, the utilization of bottom ash in engineering field has received considerable attention due to its potential application including aggregate replacement, concrete products, embankment fill, road construction and reclamation work.

Sufficient data is available about researches on fly ash based geopolymer concrete, but using both fly ash and bottom ash has a new era.

In the short term, there is large potential for geopolymer concrete applications for bridges, such as precast structural elements and decks as well as structural retrofits using geopolymer-fiber composites. Geopolymer technology is most advanced in precast applications due to the relative ease in handling sensitive materials (e.g., high-alkali

activating solutions) and the need for a controlled high-temperature curing environment required for many current geopolymer. Other potential near term applications are precast pavers & slabs for paving, bricks and precast pipes (Rangan, B. V, 2008).

1.3 Objectives

1.3.1 General Objective

The main objective of this study is to investigate the properties of fly ash based hybrid geopolymer concrete that incorporates bottom ash municipal solid waste incineration as a partial replacement of fine aggregates.

1.3.2 Specific Objective

- Characterization of the fly ash, bottom ash, and other materials used in the production of the hybrid geopolymer concrete.
- Investigation of optimum mix proportion, which involves partially replacing a portion of fine aggregate with bottom ash, determine geopolymer alkali additives and cement proportion to achieve the desired molarity for C-25 concrete production within ambient curing condition.
- Investigation of the workability, setting time, and various hardened concrete properties such as tensile strength, flexural strength, and permeability.
- Analyze the microstructure of the hybrid geopolymer concrete through techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD)

1.4 Significance of the study

This study will provide an alternative approach that can be adopted to alleviate the highly prevailing concrete need in Ethiopia, by exploring the driving factors that trigger the government to engage in the use of geopolymer concrete and by assessing the factors that enable the success of using geopolymer concrete. This research will also develop a framework that assists practitioners in the use of geopolymer concrete in different area of construction. Furthermore, the study will be expected to expand knowledge in this area and will encourage researchers to conduct further studies andhighlight the effective use and mix design of geopolymer concrete.

1.5 Scope of the study

The scope of the study on this research encompasses a comprehensive exploration of its

mechanical, durability, and environmental attributes, with a focus on its potential applications in the construction industry. Investigation into the formulation variations, curing techniques, and the influence of constituent materials on the concrete's performance will be pivotal. The study should also delve into the economic aspects, evaluating the cost-effectiveness of geopolymer concrete compared to traditional alternatives. Furthermore, examining its compatibility with established construction materials and adherence to industry standards will be crucial for assessing its viability and integration into mainstream construction practices. Overall, this research aims to provide a holistic understanding of geopolymer concrete, addressing both its technical properties and its practical feasibility for sustainable and efficient construction practices.

1.6 Limitations of the study

The study on geopolymer concrete faces certain limitations that warrant consideration. One significant constraint lies in the relatively limited long-term performance data available, as geopolymer concrete is a relatively recent development compared to traditional concrete. This scarcity of extended durability assessments may hinder a comprehensive understanding of its behavior over extended periods. Additionally, variations in source materials and regional availability of raw ingredients for geopolymer mixtures pose challenges, impacting the generalizability of findings across diverse geographical locations. Moreover, the evolving nature of geopolymer concrete formulations and technologies could introduce uncertainties in the study’s conclusions, given the potential for ongoing advancements in this field. Despite these limitations, a judicious acknowledgment and exploration of these constraints can contribute to a more nuanced interpretation of the study’s outcomes and guide future research directions in geopolymer concrete development.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This Chapter presents a brief review of geopolymers and geopolymer concrete. This review compliments similar reviews given in Research Reports GC1 and GC2 (Hardjito and Rangan 2005, Wallah and Rangan 2006).

Nowadays, concrete industry is known to be the major consumer of natural resources, such as water, sand and aggregates, and manufacturing Portland cement also requires large amounts of each of them. Due to its high energy consumption and environmental pollution rates, the Portland cement industry was the subject for many investigations by regulatory agencies and the public. They have believed in adjustment of the concrete industry into sustainable technology because of its role in the infrastructure development and being the main consumer of energy and natural resources. With this increasing request for infrastructural needs, it is a must for us to make a balance between the human need for preserving the environment which is endangered by the limitless use of natural resources and utilization of these natural resources. The concern about environmental issues is becoming more important and ignoring is not the solution any more.

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2.2 Geopolymer Materials

Davidovits introduced the term ‘geopolymer’ in 1978 to represent the mineral polymers resulting from geochemistry. Geopolymer, an inorganic alumina-silicate polymer, is synthesized from predominantly silicon (Si) and aluminum (Al) material of geological origin or by-product material(Davidovits 1988). The chemical composition of geopolymer

materials is similar to zeolite, but they reveal an amorphous microstructure (Davidovits 1999). During the synthesized process, silicon and aluminum atoms are combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks.

Most of the literature available on this material deals with geopolymer pastes. (Davidovits and Sawyer 1985) used ground blast furnace slag to produce geopolymerbinders. This type of binders patented in the USA under the title Early High-Strength Mineral Polymer was used as a supplementary cementing material in the production of precast concrete products. In addition, a ready-made mortar package that required only the addition of mixing water to produce a durable and very rapid strength- gaining material was produced and utilized in restoration of concrete airport runways, aprons and taxiways, highway and bridge decks, and for several new constructions when high early strength was needed.

Geopolymer has also been used to replace organic polymer as an adhesive in strengthening structural members. Geopolymers were found to be fire resistant and durable under UV light (Balaguru et al 1997)

(van Jaarsveld, van Deventer, and Schwartzman 1999) carried out experiments on geopolymers using two types of fly ash. They found that the compressive strength after 14 days was in the range of 5 – 51 MPa. The factors affecting the compressive strength were the mixing process and the chemical composition of the fly ash. A higher CaO content decreased the microstructure porosity and, in turn, increased the compressive strength. Besides, the water-to-fly ash ratio also influenced the strength. It was found that as the water-to-fly ash ratio decreased the compressive strength of the binder increased.

(Palomo, Grutzeck, and Blanco 1999) studied the influence of curing temperature, curing time and alkaline solution-to-fly ash ratio on the compressive strength. It was reported that both the curing temperature and the curing time influenced the compressive strength. The utilization of sodium hydroxide (NaOH) combined with sodium silicate (Na_2Si_3) solution produced the highest strength. Compressive strength up to 60 MPa was obtained when cured at 85^{o}C for 5 hours.

Xu and van Deventer (2000) investigated the geopolymerization of 15 natural Al-Si minerals. It was found that the minerals with a higher extent of dissolution demonstrated better compressive strength after polymerisation. The percentage of calcium oxide (CaO), potassium oxide (K_2O), the molar ratio of Si-Al in the source material, the type of alkali and the molar ratio of Si/Al in the solution duringdissolution had significant effect on the compressive strength.

Swanepoel and Strydom (2002) conducted a study on geopolymers produced by mixing fly ash, kaolinite, sodium silica solution, NaOH and water. Both the curing time and the curing temperature affected the compressive strength, and the optimum strength occurred when specimens were cured at 60^{o}C for a period of 48 hours.

Van Jaarsveld, van Deventer and Lukey (2002) studied the interrelationship of certain parameters that affected the properties of fly ash-based geopolymer. They reported that the properties of geopolymer were influenced by the incomplete dissolution of the materials involved in geopolymerization. The water content, curing time and curing temperature affected the properties of geopolymer; specifically the curing condition and calcining temperature influenced the compressive strength. When the samples were cured at 70^{o}C for 24 hours a substantial increase in the compressive strength was observed. Curing for a longer period of time reduced the compressive strength.

2.3 Geopolymer concrete and OPC concrete

From a survey of literature and hands on experience, it is now well-established fact that overall procedure that includes batching, mixing and casting processes to make geopolymer concrete are similar to that of OPC concrete. Fly ash and GGBS that are primary materials for geopolymer concrete have also been added to OPC mix in the past few years, which is put in the category of blended cement or hybrid cement. Research has been reported recently on addition of alkaline activators to these hybrid cements. Currently, however the major difference in geopolymer concrete and OPC concrete is the utilization of alkaline activators such as Na2SiO3 and NaOH solutions to activate the source materials in making geopolymer concrete; and elimination of OPC from it. Additionally, mild heat curing is necessary for geopolymer concrete in order to initiate the polymerization reaction, which is not required for OPC concrete. The strength gaining mechanism thus differs. For geopolymer concrete, the strength gaining is through the process of polymerization whereas for OPC concrete, it is through hydration. A brief description of both concretes and their strength gaining mechanisms are described in the following sections.

2.3.1 Geopolymer concrete

In 1978, Davidovits developed a technology for alkali activated binder material by subjecting the mixture to high temperatures. He gave it the name ‘Geo-Polymer’; that came from the word ‘Geosynthesis’ (a science of manufacturing artificial rock at temperatures below 100^{o}C, giving better hardness, durability and heat stability). According to

Davidovits, any material that contains mostly silicon (Si) and aluminium (Al) in amorphous form is a potential source material for the manufacture of geopolymer (Davidovits, 2002). Geopolymer concrete is also popularly known as inorganic polymer, low-temperature aluminosilicate glass, alkali activated cement, alkali activated binders, geocement, inorganic polymer concrete, alkali bonded ceramic, hydroceramic, mineral polymers, alkali ash material, alkali activated aluminosilicate etc. (Rajamane, N.; Nataraja, M.; Lakshmanan, N.; Dattatreya, J.;Sabitha, D., 2012). To understand the process of geopolymerization, a conceptual model as shown in figure 2.1, was developed by Glukhovsky and was adopted as a base for many studies performed later. Strength development mechanism consists of following stages. (Chanh, N.; Trung, B. et al. 2011).

Dissolution/ Destruction/ Coagulation of Si and Al atoms from the source material through the action of alkaline solution- During initial mixing Si and Al ions are separated.

Transportation/orientation/ condensation of dissolved ions. Also understood as coagulation– condensation: - The Si, Al and Aluminosilicate molecules attain equilibrium in the solution.

The whole process is highly dependent on thermodynamics and kinetic parameters. The physical properties depend on the growth of the molecules and formation of crystals.

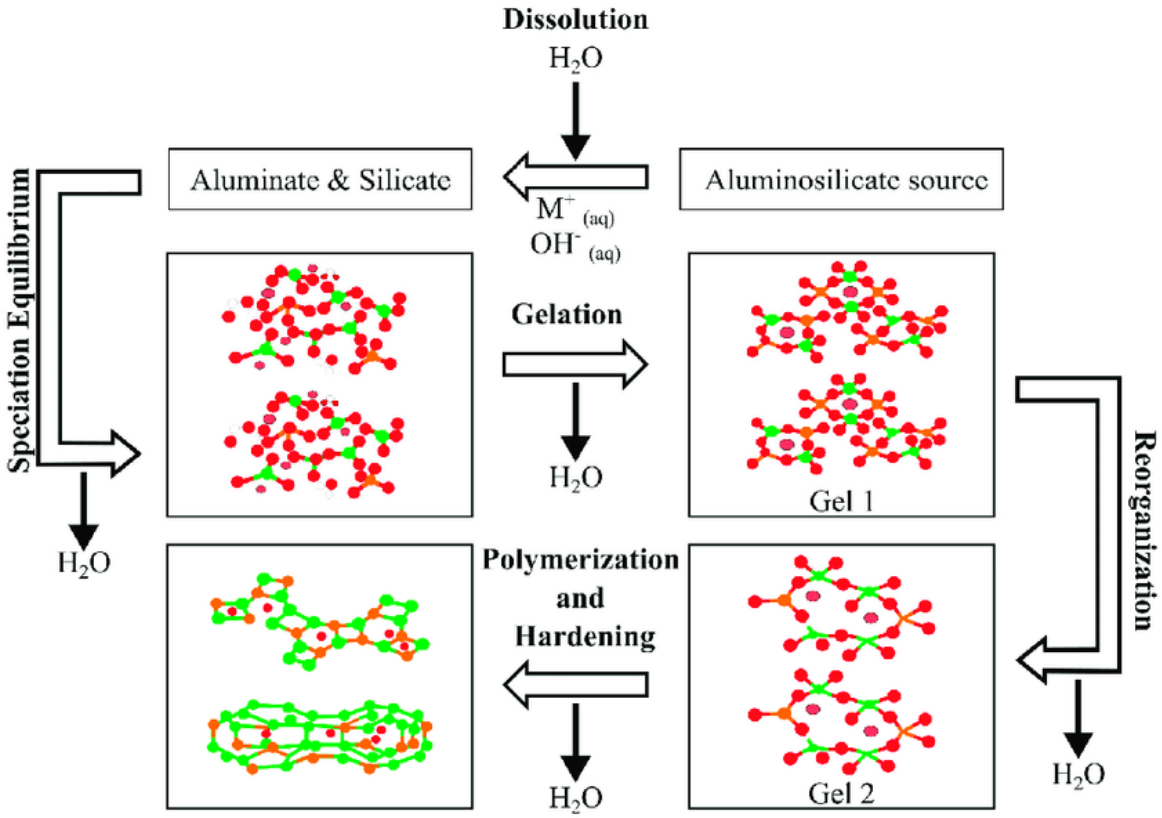


Figure 2. 1 Conceptual model for geopolymerization

Aluminosilicate dissolves rapidly and neighbouring Si or Al molecules then undergo a condensation reaction where adjacent OH ions from these near neighbours condense to form an oxygen bond linking the molecules, and releasing a free molecule of H2O. This released H2O then normally rests inside the gel pores. Biphasic phase: as only Aluminosilicate binder and H2O. After the formation of gel, reorganization or rearrangement continues.

Setting/polycondensation/ polymerization The application of mild heat of up to 90^{o} C causes these "monomers" and other Si and Al hydroxide molecules to polycondense or polymerize, to form rigid chains or 3-D network commonly known as N-A-S-H gel. H2O evaporates on heating. Bonding of undissolved solid particles in the final geopolymeric structure- causes crystallization.

2.3.2 OPC concrete and hydration

OPC is manufactured from calcareous materials such as limestone or chalk and argillaceous material such as shale or clay, containing silica and alumina. These materials are ground, mixed and then burnt in kiln at 1400-1500^{o}C thereby forming clinker. After cooling, clinker is mixed with 3-5% gypsum and ground to fine powder, termed as OPC. The approximate chemical composition of OPC is Calcium Oxide (CaO): 60-67%, SiO2: 17-25%, Al2O3: 3-8% Fe2O3: 0.5-0.6%. When these raw materials are mixed and subjected to high clinkering temperature, four major complex compounds are formed- Tricalcium Silicate (C3S), Dicalcium Silicate (C2S), Tricalcium aluminate (C3A) and Tetracalcium aluminoferrite (C4AF). C3S and C2S are the most important compounds that are responsible for the strength gain. They constitute approximately 70-80% of cement. C3A and C4AF are in proportion of about 5-10% each. The chemical reaction that takes between cement and water is termed as hydration of cement.

Cement hydration can be divided into two phases:

i. Cement constituent compounds dissolve in water to produce a saturated solution from which hydrated products can be precipitated.

ii. Water then present in the matrix reacts with the compounds available, from surface to its interior, thereby converting them into solid hydrated products, with time. The hydration process is not instantaneous and it takes almost one year for completion. The hydrated product of cement adheres firmly to the core that is not hydrated in the cement and forms almost impermeable layer. This can be further explained through following steps.

i. When C3S and C2S react with water. Calcium silicate hydrate (C-S-H) and calcium hydroxide (Ca(OH)2) are formed. Concrete particularly contains 50-60% of C-S-H in its matrix. C3S hydrates rapidly and contributes to early strength (initial 4 weeks) of concrete, also contributing to higher amount of Ca(OH)2. Hydration of C2S is comparatively a slower process and is responsible for later strength of concrete, lower heat of hydration as well as smaller amount of Ca(OH)2. At the age of one year, C3S and C2S contribute almost equally to the strength of cement. Overall Ca(OH)2 formed occupies about 20-25% of the matrix of the hydrated paste. It initiates the problems of durability which can be overcome by using blended cements by adding fly ash, silica fumes etc.

ii. Hydration of C3A, gives a calcium aluminate system of CaO- Al2O3- H2O abbreviated as (C3AH6), which can remain stable at up to 225^{o} C. It does not contribute much to the longterm strength of concrete, but it facilitates the combination of lime and silica.

iii. Hydration of C4AF forms CaO-Fe2O3-H2O; (C3FH6). This step also does not contribute to long term strength but it accelerates the hydration of silicates.

iv. Oxides of Na2O and K2O (commonly known as alkalis) are also present in small quantities in cement and apart from taking part in alkali aggregate reaction, they affect the rate of the gain of strength of cement.

The reaction of cement with water is exothermic and it liberates considerable amount of heat, called heat of hydration. When water is mixed with cement, a rapid initial heat evolution takes place due to instant solubility of aluminates in water. However, this will then cease quickly due to presence of gypsum. Later, due to further formation of ettringite (calcium sulphoaluminate: a reaction of C3A with gypsum) and reaction of C3S, there is evolution of heat of hydration; this evolution is greater during the early stages and continues for a few days albeit at reducing rates. Heat evolution also depends on the fineness of cement, finer the cement, more is the heat of hydration. About 50% of total heat generation occurs during the initial 3 days of casting.

The final product of hydration is referred to as C-S-H gel. Its microstructure consists of thin fibrous small crystals interlocked with each other. The gel has about 28% porosity and the pores are filled with water. After about one month, the matrix contains 85-90% C-S-H gel and 10-15% cement that is not hydrated. The water used for the mixture, partly gets utilized in mixture and partly gets trapped within the gel pores (Shetty, 2009; Neville, A.; Brooks, J., 2006).

2.3.3 Chemical reactions during hydration

When water is added to cement, the following series of reactions occur:

- The tricalcium aluminate reacts with the gypsum in the presence of water to produce ettringite and heat:

  Tricalcium aluminate + gypsum + water = ettringite + heat

  $$C_3A + 3C\underline{S}H_2 + 26H = C_6AS_3H_{32}, \ H = 207 \text{ cal/g}$$

Ettringite consists of long crystals that are only stable in a solution with gypsum. The compound does not contribute to the strength of the cement glue.

- The tricalcium silicate (alite) is hydrated to produce calcium silicate hydrates, lime and heat:

Tricalcium silicate + water = calcium silicate hydrate + lime + heat

$$2C_3S + 6H = C_3\underline{S}_2H_3 + 3CH, + H=120 \text{ cal/g}$$

The CSH has a short-networked fiber structure which contributes greatly to the initial strength of the cement glue.

- Once all the gypsum is used up as per reaction (i), the ettringite becomes unstable and reacts with any remaining tricalcium aluminate to form monosulfate aluminate hydrate crystals:

Tricalcium aluminate + ettringite + water = monosulfate aluminate hydrate

$$2C_3A + 3C_6A\underline{S}_3H_{32} + 22H = 3C_4ASH_{18},$$

The monosulfate crystals are only stable in a sulfate deficient solution. In the presence of sulfates, the crystals resort back into ettringite, whose crystals are two-and-a-half times the size of the monosulfate. It is this increase in size that causes cracking when cement is subjected to sulfate attack.

- The belite (dicalcium silicate) also hydrates to form calcium silicate hydrates and heat:

Dicalcium silicates + water = calcium silicate hydrate + lime

$$C_2S + 4H = C_3\underline{S}_2H_3 + CH, + H = 62 \text{ cal/g}$$

Like in reaction (ii), the calcium silicate hydrates contribute to the strength of the cement paste. This reaction generates less heat and proceeds at a slower rate, meaning that the contribution of C_2S to the strength of the cement paste will be slow initially. This compound is however responsible for the long-term strength of portland cement concrete.

- The ferrite undergoes two progressive reactions with the gypsum:
  - in the first of the reactions, the ettringite reacts with the gypsum and water to form ettringite, lime and alumina hydroxides, i.e.

Ferrite + gypsum + water = ettringite + ferric aluminum hydroxide + lime

$C_4AF + 3C\underline{S}H_2 + 3H = C_6(A,F)\underline{S}_3H_{32} + (A,F)H_3 + CH$

- the ferrite further reacts with the ettringite formed above to produce garnets, i.e.

Ferrite + ettringite + lime + water = garnets

$C_4AF + C_6(A,F)\underline{S}_3H_{32} + 2CH + 23H = 3C_4(A,F)\underline{S}H_{18} + (A,F)H_3$

The garnets only take up space and do not in any way contribute to the strength of the cement paste.

2.4 Chemical composition of geopolymers

Geopolymers are inorganic, typically ceramic, alumino-silicate forming long-range, covalently bonded, non-crystalline (amorphous) networks. Obsidian (volcanic glass) fragments are a component of some geopolymer blends. Commercially produced geopolymers may be used for fire- and heat-resistant coatings and adhesives, medicinal applications, high-temperature ceramics, new binders for fire-resistant fiber composites, toxic and radioactive waste encapsulation and new cements for concrete. The properties and uses of geopolymers are being explored in many scientific and industrial disciplines: modern inorganic chemistry, physical chemistry, colloid chemistry, mineralogy, geology, and in other types of engineering process technologies. The field of geopolymers is a part of polymer science, chemistry and technology that forms one of the major areas of materials science.

Polymers are either organic material, i.e. carbon-based, or inorganic polymer, for example silicon-based. The organic polymers comprise the classes of natural polymers (rubber, cellulose), synthetic organic polymers (textile fibers, plastics, films, elastomers, etc.) and natural biopolymers (biology, medicine, pharmacy). Raw materials used in the synthesis of silicon-based polymers are mainly rock-forming minerals of geological origin, hence the name: *geopolymer*. Joseph Davidovits coined the term in 1978 and created the non profit French scientific institution (Association Loi 1901) *Institut Géopolymère* (Geopolymer Institute).

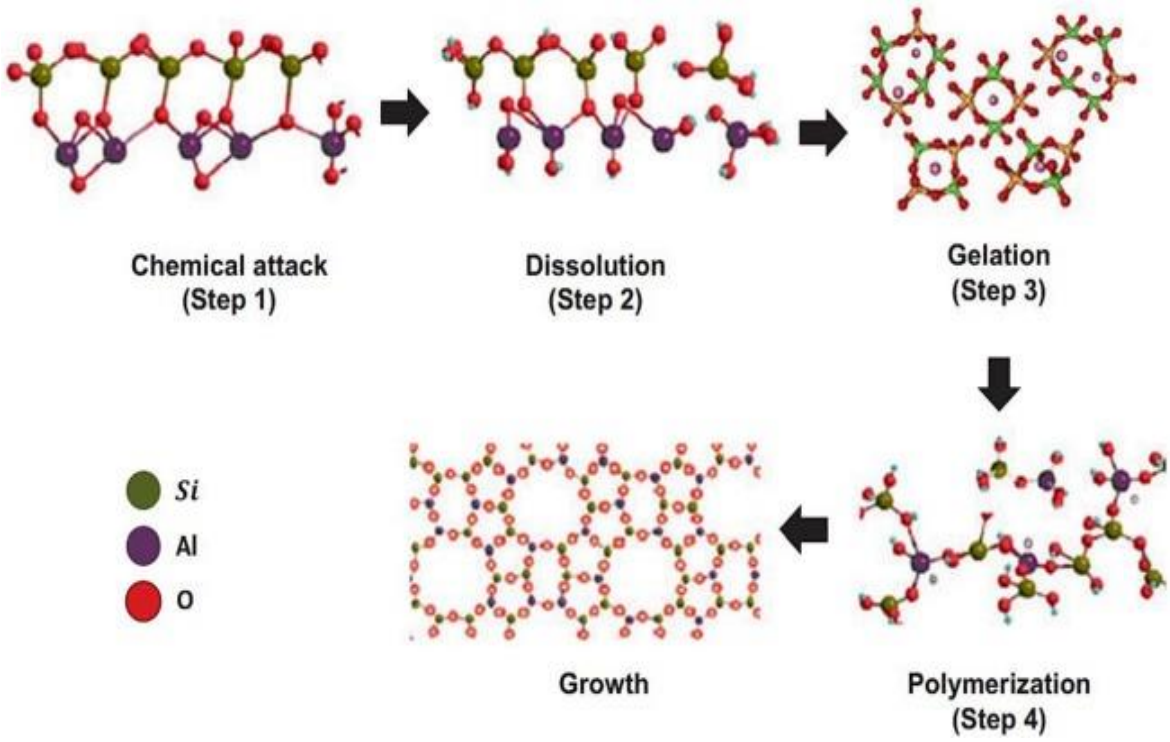


Figure 2. 2 Conceptual model for Chemical composition of geopolymers

According to T.F. Yen geopolymers can be classified into two major groups: pure inorganic geopolymers and organic containing geopolymers, synthetic analogues of naturally occurring macromolecules. In the following presentation, a geopolymer is essentially a mineral chemical compound or mixture of compounds consisting of repeating units, for example silico-oxide (-Si-O-Si-O-), silico-aluminate (-Si-O-Al-O-), ferro-silico-aluminate (-Fe-O-Si-O-Al-O-) or alumino-phosphate (-Al-O-P-O-), created through a process of geopolymerization. This mineral synthesis (geosynthesis) was first presented at an IUPAC symposium in 1976.

2.5 Constituents of Geopolymer Concrete

Geopolymer concrete can be manufactured by using the low-calcium (ASTM Class F) fly ash obtained from coal-burning power stations. Most of the fly ash available globally is low-calcium fly ash formed as a by-product of burning anthracite or bituminous coal. Although coal burning power plants are considered to be environmentally unfriendly, the extent of power generated by these plants is on the increase due to the huge reserves of good quality coal available worldwide and the low cost of power produced from these sources. Therefore, huge quantities of fly ash will be available for many years in the future (Malhotra, 2006). The chemical composition and the particle size distribution of the fly ash must be established prior to use. An X-Ray Fluorescence (XRF) analysis may be used to determine the chemical composition of the fly ash.

Low-calcium fly ash has been successfully used to manufacture geopolymer concrete when the silicon and aluminum oxides constituted about 80% by mass, with the Si-to-Al ratio of about 2. The content of the iron oxide usually ranged from 10 to 20% by mass, whereas the calcium oxide content was less than 5% by mass. The carbon content of the fly ash, as indicated by the loss on ignition by mass, was as low as less than 2%. The particle size distribution tests revealed that 80% of the fly ash particles were smaller than 50 μm (Gourley, 2003; Gourley and Johnson, 2005; Hardjito and Rangan, 2005; Wallah and Rangan, 2006; Sumajouw and Rangan, 2006; Fernandez-Jimenez et al, 2006a; Sofi et al, 2006a; Siddiqui, 2007). The reactivity of low-calcium fly ash in geopolymer matrix has been studied by Fernandez-Jimenez, et al (2006b).

Coarse and fine aggregates used by the concrete industry are suitable to manufacture geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of geopolymer concrete (Hardjito and Rangan, 2005; Wallah and Rangan, 2006; Sumajouw and Rangan, 2006; Gourey, 2003; Gourley and Johnson, 2005; Siddiqui, 2007).

2.6 Fly Ash

2.6.1 Municipal solid waste incineration (MSWI) Fly Ash

Municipal solid waste (MSW) is a waste containing a dayto-day activity of rejects as an unwanted substance from social exercises such as household and commercial solid wastes. MSW consists of a compostable division (such as food waste), a combustible division (such as glass, plastics, paper, and materials), dormant division (such as stones, metals, glass, and ceramics), and moisture content that exists within the compostable division.

The transfer of these wastes, as well as their controlling framework, has got attention. The waste management and utilization approaches are a fundamental issue all over the world including Ethiopia. Incineration is a leading technique not only to treat and decrease wastes by volume less than 90% but also to generate power by recovering energy from municipal solid waste. Incinerated municipal solid waste (IMSW) may handle of burning of strong waste at a temperature of over 900 °C to change over it into fiery remains and this innovation can diminish the volume of municipal solid waste. Incinerated municipal solid waste innovation encompasses the potential to produce waste ingredients to be utilized in the construction industry.

The structure of IMSW is somewhat complicated in the generation of coal ash and petroleum ashes. The Incinerated municipal solid waste ashes can be classified into two:

Bottom ash and fly ash. Fly Ash (FA) and Bottom Ash (BA) are produced as a by-product from municipal solid waste incinerators and coal-fueled power stations. FA is a highly dispersible powder. It contains mainly alumina silicate and ferriferous glassy spherical particles (about 60-80%) and irregularly shaped grains of amorphous clay, mullite quartz, and unburned metamorphic fuel. Bottom ash consists of irregular particles, which can be up to 10-15 mm in size. The chemical compositions of FA and BA ashes from the same power plant are similar.

The disposal management practices of incinerated municipal solid waste fly ash residues at Reppie are based on traditional sanitary landfilling techniques that have been generally applied without any significant regulations. Reppie waste to energy project utilizes as feedstock around 1,400 tons per day of MSW and the incinerator yearly capacity is around 100,000 tons. This amount of books around 50% of municipal solid wastes collected from the city daily (www.eep.gov.et). Hence, collection of municipal solid waste with suitable arrangement plays a great role and IMSW fly ash was collected from Reppie-Waste-to-Energy Plant" which is found in Addis Ababa, Ethiopia. Traditional disposal way of incinerated municipal solid waste fly ash leads a serious environmental, social and economic problems: Transportation of fly ash is difficult since the lightweight particles tend to fly and causing air pollution, long inhalation causes serious respiratory problems, affects horticulture, agriculture and forest fields and requirement of huge land for making ash ponds or dikes, disposal in sea, river or ponds damage the aquatic life and fly ash also causes siltation problems.

2.6.2 Municipal solid waste incineration (MSWI) Fly Ash as cement replacement

Using IMSW fly ash as cement replacing material requires only transportation and grinding since the byproduct of the materials available in bulk at Reppie landfill site. This implies using IMSW fly ash to the minimum reduces the cost of clinker production (the most expensive one) by a certain amount, not mentioning the raw material preparations and other costs associated with cement production.

Because of this and other problems associated with mining and use of cement, different journals and kinds of literature were published to find an alternative material that will partially or fully replace ordinary Portland cement in concrete production. They reached an agreement using Supplementary Cementitious Materials (SCM), such as explosion incinerator slag, volcanic ash, silica fume, IMSW fly ash, and bagasse could have a potential partially replace cement in the construction industry, especially for concrete [Simegn A, Abebe S, Worku A (2021)].

The significance of this study would be a contribution to maximizing incinerated municipal solid waste fly ash to cement mix proportion for M-30 grade of concrete and minimizing the effect of municipal solid waste material on the degradation of the environment due to cement demand. Apart from protecting the environment, the main benefits of using incinerated municipal solid waste fly ash as partial replacement of cement also saving our natural resources and energy as well. Other than, a decrease of the cement fabricating costs of demand, and the fractional substitution of cement would make it possible significantly to reduce the gas emissions to the environment. The study was focused on characterization and optimization of incinerated municipal solid waste fly ash collected from Reppie waste to energy plant and assesses its potential use as an alternative material for partial replacement of cement in concrete.

2.6.3 Physical Properties of Fly ash

The physical properties of fly ash are,

i. Fineness of Fly Ash

As per ASTM, the fineness of the fly ash is to be checked in both dry n wet sieving. The fly ash sample is sieved in 45-micron sieve and the percentage of retained on the 45-micron sieve is calculated. Further fineness is also measured by LeChatelier method and Blaine Specific Surface method.

ii. Specific Gravity of Fly Ash

The specific gravity of fly ash ranges from a low value of 1.90 for a sub-bituminous ash to a high value of 2.96 for an iron-rich bituminous ash.

iii. Size and Shape of Fly Ash

As the fly ash is a very fine material, the particle size ranges in between 10 to 100 microns. The shape of the fly ash is usually spherical glassy shaped.

iv. Color

The color of the fly ash depends upon the chemical and mineral constituents. Lime content in the fly ash gives tan and light colors whereas brownish color is imparted by the presence of iron content. A dark grey to black color is typically attributed to an elevated un-burned content.

2.6.4 Uses of Fly Ash

Fly ash has been used in the past to partially replace Portland cement to produce concretes. An important achievement in this regard is the development of high-volume fly ash (HVFA) concrete that utilizes up to 60 percent of fly ash, and yet possesses excellent mechanical

properties with enhanced durability performance. The test results show that HVFA concrete is more durable than Portland cement concrete (Malhotra 2002).

Recently, a research group at Montana State University in the USA has demonstrated through field trials of using 100% high-calcium (ASTM Class C) fly ash to replace Portland cement to make concrete. Ready mix concrete equipment was used toproduce the fly ash concrete on a large scale. The field trials showed that the fresh concrete can be easily mixed, transported, discharge, placed, and finished (Cross et al 2005). some of the major uses of fly ash are listed below,

It is used in the manufacture of Portland cement. Generally, fly ash benefits fresh concrete by reducing the mixing water requirement and improving the paste flow behavior. The resulting benefits are as follows: Improved workability. The spherical shaped particles of fly ash act as miniature ball bearings within the concrete mix, thus providing a lubricant effect.

Used as a soil stabilization material. Fly ash can be used to stabilize bases or subgrades, to stabilize backfill to reduce lateral earth pressures and to stabilize embankments to improve slope stability. Typical stabilized soil depths are 15 to 46 centimeters (6 to 18 inches).

Figure 2. 3 Showing Fly ash soil stabilization in road construction.

2.6.5 Fly Ash-Based Geopolymer Concrete

Past studies on reinforced fly ash-based geopolymer concrete members are extremely limited (Palomo et.al 2004) investigated the mechanical characteristics of fly ash- based geopolymer concrete. It was found that the characteristics of the material were mostly determined by curing methods especially the curing time and curing temperature. Their

study also reported some limited number of tests carried out on reinforced geopolymer concrete sleeper specimens. Another study related to the application of geopolymer concrete to structural members was conducted by Brooke et al. al (2005). It was reported that the behavior of geopolymer concrete beam- column joints was similar to that of members made of Portland cement concrete.

Curtin research on fly ash-based geopolymer concrete is described in Research Reports GC1 and GC2 (Hardjito and Rangan 2005, Wallah and Rangan 2006), and other publications listed in References at the end of this Report.

2.7 Municipal solid waste incineration Bottom-ash

2.7.1 Physical Properties of municipal solid waste incineration Bottom-ash

According to the economic feasibilities, municipal solid wastes (MSW) are being dumped or treated in different possible manners. Municipal solid waste incinerated ash (MSWIA) is one of the final products of MSW treatment plants after incineration. Due to less sustainable waste management options, MSWIA is produced in tons and dumped into landfills. Researchers in various developmental project suggest using MSWIA as an economical and eco-friendly mode of final disposal. The use of MSW incinerated bottom ash (MIBA) has an exceptional potential of supporting sustainability by conserving natural resources. The paper targets the possible benefits of MIBA in various construction and soil improvement projects by compensating the primary aggregates. The partial replacement of primary aggregates is a durable and cost-effective option for equal or improved strength. The addition of MSWIA is not new, but the studies available are limited in number. The presence of certain chemical compounds in MIBA is leading to advanced industrial-based applications. The residue can be a primary raw material for synthesizing new compounds, in land recovery and Hydrogen gas production. Some studies have favored its utilization in the most natural form, whereas some suggest avoiding the usage due to its various environmental and strength-based limitations. The article investigates significant studies and confirms the possible opportunities from waste residues for more competent raw material (Huber F, Fellner J (2018) Italy).

2.7.2 Engineering Application of Bottom Ash

Generally, the bottom ash particles have dark, angular shapes with porous textures and rough surface. The particle size ranging from gravel of 40 mm to fine sand of 0.075 mm (Kim H, Lee H-K. 2015). Most researchers believed that the properties of bottom ash are similar to natural sand material (Mandal A, Sinha O. 2014). Bottom ash has been utilized

in civil engineering field, agriculture and manufacturing soil products industry (3rd ed: We Energies Publication; 2013. 448 p.). According to (Kim H, Lee H-K. 2015), bottom ash is mainly used in civil engineering field. It is reported that the European Union and United States used about 50% and 35% of the produced bottom ash respectively in this field. Such waste materials are widely used as replacement materials in construction including natural silt, clay, sand and gravel. Hence, bottom ash has the potential application in road construction, concrete, various cement products and reclamation fills.

2.7.3 Road construction with Bottom Ash

Bottom ash is listed as one of waste materials suitable for recycling in road construction (Poulikakos L, Papadaskalopoulou C, et al. 2017) and by far is the most popular outlet for the material. Bottom ash is targeted to substitute sand or fine aggregates in road construction either as partially or full replacement due to its similar properties to natural sand. Coal Combustion Products Utilization Handbook (We Energies Publication; 2013. 448 p.), conducted a study on the performance of bottom ash in subgrade using plate load bearing tests. After one season, the road pavement was found to be in good condition indicating that the subgrade performed satisfactorily. In order to enhance the performance of the pavement, a recommendation has been made to use bottom ash in a 2 to 1 thickness ratio compared to normal base course material.

2.7.4 Aggregate Replacement in concrete

The potential of bottom ash to be used as replacement material in concrete has been explored by numerous researchers. The ash either can use as fine aggregate or coarse aggregate replacement. The replacement will cause some changes on the properties of concrete such as the workability, compressive strength and durability.

found that the workability of concrete reduces with the use of bottom ash as fine aggregate replacement due to physical properties of bottom ash (irregular shape, rough texture and high porosity) increased the inter particles friction and thereby hinders the flow characteristics of fresh concrete. Other than that, the higher water absorption capability of bottom ash itself reduced the workability. This finding has confirmed by which has stated that the increased of bottom ash percentage by weight in concrete has decreased the workability by 4% to 9%. Meanwhile, examined the effect of slump flow values of fresh concrete with bottom ash as the replacement and found the slump value decreases with increasing percentage of bottom ash. This indicate the fact that as water absorbed internally by the porous bottom ash particles increased, huge amount of water was required in order to mix the concrete.

In term of compressive strength, studied the effect of bottom ash as fine and coarse aggregate in concrete mix at 7 days and 28 days curing age. Based on observation, the compressive strengths were found not significantly affected by the replacements of fine bottom ash. However, for the 7-day curing period, the compressive strength of concrete mixes containing 50% and 100% bottom ash decreased about 9% and 15.16% compared to the strength of the control samples, respectively. The lower compressive strength is related to the strength of replacement material in concrete mix. Studies show that bottom ash are more porous and weaker than natural sand. As mentioned before, the higher water absorption by bottom ash has increased amount of mixing water, which contribute to more volume of pores left by water. These pores prevented the strong bonding of cement paste with the aggregate. As a result, the transition zone between the aggregate and cement paste becomes weak and porous which eventually reduces the strength of bottom ash concrete mix.

Nevertheless, found that with long-term duration of curing age, up to 60 days, the compressive strength increased up to 10%. Similar finding was observed by, where 30% sand replacement is used in the concrete mix and the compressive strength recorded the highest value at the curing ages up to 60 days. Therefore, it can be concluded that concrete with bottom ash content will reach its optimum strength beyond 28 days.

2.8 Applications and advantages of geopolymer concrete

With features such as easy availability of raw materials (reducing environment pollution due to stock piles), low CO2 emission, low energy consumption, low production cost, high early strength and fast setting, geopolymers have the potential to be used profitably in fields of civil engineering, automotive and aerospace industries, non-ferrous foundries and metallurgy and plastics industries (Davidovits J., 2002;Rangan B. V., 2014). Rajamane and co-workers concluded that with proper formulation of mixture proportion, 24 hours compressive strength of about 25-30 N/mm2 can be achieved without any special curing regime and hence can be considered as self-curing mixture. The stress-strain relationship depends on the source materials and activators used but overall, the similarity is observed with that of OPC. Bond properties and durability properties were also better those of OPC (Rajamane, N. 2011). For application in the concrete industry, geopolymers possess better abrasion resistance, high temperature resistance, low

shrinkage and thermal conductivity, development of good compressive strength within a day, higher resistance to sulphates and acid, ability to immobilize toxic wastes. These

characteristics enhance the feasibility of utilization in various applications (Duxon, P.; Provis, J. et al. 2017). According to Jaarsveld & Deventer, (Jaarsveld, J.; Deventer, J., 1996) some of the potential applications of geopolymer binders are as listed:

• Surface capping of waste dumps where a high strength matrix is needed, if structures to be constructed above it. Immobilization and encapsulation of toxic wastes such as arsenic, mercury, lead, asbestos and radioactive wastes.

• Low permeability based liners to avoid leakage of contaminants in to ground water or as a lining for fresh water reservoirs to prevent water from seeping in the soil.

• Dam construction as well as the stabilizing of tailings dams.

• Runways for airports.

• Pre-casting of non-structural elements such as fences, light poles, paver blocks, bricks and pipes.

Additional applications can be in chimneys, low cost refractory concrete and fire places, due to its better resistance to high temperatures. Reported good performance under acidic and toxic environment, it can be used in sewer pipes. Its better resistance against sulphate and chloride attacks make it a viable concrete for the structures in coastal area as well as exposed salt water such as under water structure, piers, bridges etc. Due to its quick setting time and high early strength properties, geopolymer concrete can be used in repairs of airport runways and roads (Ramani, 2014).

2.9 Environmental aspects of geopolymer concrete

The advancement of eco-friendly technology in the construction sector has been improving rapidly in the last few years. As a result, multiple building materials were developed, enhanced, and proposed as replacements for some traditional materials. One notable example presents geopolymer as a substitute for ordinary Portland concrete (OPC). The manufacturing process of (OPC) generates CO2 emissions and a high energy demand, both of which contribute to ozone depletion and global warming. The implementation of geopolymer concrete (GPC) technology in the construction sector provides a path to more sustainable growth and a cleaner environment. This is due to geopolymer concrete's ability to reduce environmental pollutants and reduce the construction industry's carbon footprint. This is achieved through its unique composition, which typically involves industrial byproducts like fly ash or slag. These materials, rich in silicon and aluminum, react with alkaline solutions to form a binding gel, bypassing the need for the high-energy clinker production required in OPC. The use of such byproducts not only reduces CO2 emissions

but also contributes to waste minimization. Additionally, geopolymer offers extra advantages compared to OPC, including improved mechanical strength, enhanced durability, and good stability in acidic and alkaline settings. Such properties make GPC particularly suitable for a range of construction environments, from industrial applications to infrastructure projects exposed to harsh conditions. This paper comprehensively reviews the different characteristics of geopolymers, which include their composition, compressive strength, durability, and curing methods. Furthermore, the environmental impacts related to the manufacturing of geopolymer materials were evaluated through the life-cycle assessment method. The result demonstrated that geopolymer concrete maintains positive environmental impacts due to the fact that it produces fewer carbon dioxide CO2 emissions compared to OPC concrete during its manufacturing; however, geopolymer concrete had some minor negative environmental impacts, including abiotic depletion, human toxicity, freshwater ecotoxicity, terrestrial ecotoxicity, and acidification. These are important considerations for ongoing research aimed at further improving the sustainability of geopolymer concrete. Moreover, it was determined that silicate content, curing temperature, and the proportion of alkaline solution to binder are the major factors significantly influencing the compressive strength of geopolymer concrete. The advancement of geopolymer technology represents not just a stride toward more sustainable construction practices but also paves the way for innovative approaches in the field of building materials(Sami Sbahieh , Gordon McKay , Sami G Al-Ghamdi).

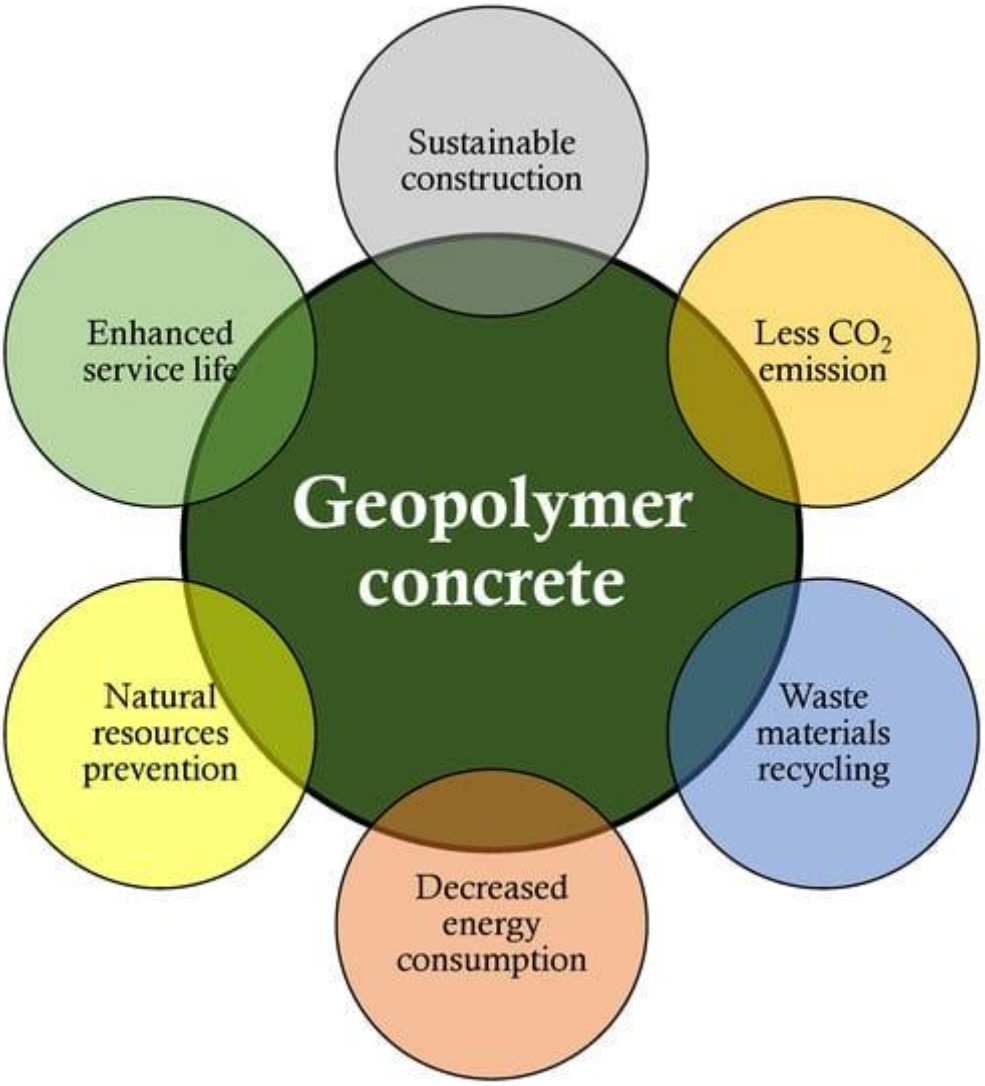


Figure 2. 4 Sustainability aspects of geopolymer concrete

2.10 Study Gap and Summary

The main domains in the area of geopolymer studies that have been researched, and gaps in knowledge are discussed.

As reported in literature review, there have been many studies on the use of fly ash as source materials for geopolymer concrete by eminent academicians and researchers. The current study focuses on establishing the relationships between strength properties of geopolymer concrete. It also focuses on optimizing the utilization of fly ash as source materials. It also focusses on developing the possibility of establishing the relationship between chemical constituents of mixture proportions, temperature of curing and compressive strengths achieved.

Most existing studies have determined the mechanical properties of the mixture of fly ash; whereas in the present study, the strength and durability parameters are considered with

some replacement of cement with fly ash. This extended study would enhance the possibility of its application in regular structures where durability is the main criteria.

This work has also attempted curing the mixtures at specified room temperature. This offers promise for utilization of this concrete for in-situ construction in future.

This research is focused on minimizing usage of materials that add to cost of concrete. The fly ash that is being used can be directly procured from Repi power plant and this is associated with negligible cost. Use of superplasticizer is avoided and instead water is used to further curtail the cost of concrete production. The cost of alkaline activators may be reduced by procuring them in bulk. The study focused on using materials that may prove applicable to the cement concrete industry. Preliminary studies gave good results in terms of strength and durability aspects. This study thus focuses primarily on strength parameters and durability resistance of the mixtures chosen. The study of the chemistry and geopolymerization process is not in the scope of this work.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The literature review in the previous chapter has discussed various past studies and research gaps in relation to geopolymer concrete. Based on the identified research gaps, Chapter 1 outlines the research objectives set for this study. This chapter elucidates the methodology adopted to accomplish the study's objectives.

This chapter elucidates the methodology adopted to accomplish the study's objectives. This chapter consists of three sections structured to achieve the study's objectives using an experimental and analytical research design.

The first section provides an overview of the materials used in the study for manufacturing hybrid geopolymer concrete samples. The sources and collection methods of Coarse Aggregate, Fine Aggregate, Fly-Ash, Bottom-Ash, Cement, Water, and Alkaline solution are presented following the specified guidelines and standards. This section involves characterizing the materials used to create hybrid geopolymer concrete samples, including coarse aggregate, fine aggregate, and water. The results are examined to ensure the collected materials meet the specified standards. Furthermore, the preparation of Fly-Ash and Bottom-Ash is explained, and their characterization and test results are outlined for further discussion in the subsequent chapter.

The second section describes the methods of preparation of test specimens of the study, covering concrete mix design, batching, mixing processes, and the curing of hybrid geopolymer concrete sample.

The third section outlines the experimental and analytical work methods. This section primarily investigates the first objective of determining the mechanical properties of hybrid geopolymer concrete and outlining the methodologies for testing hardened and fresh concrete. And also focusing on the morphological study using microscopic analyses. microscopic techniques like X-ray diffraction (XRD), and Scanning Electron Microscopy (SEM). These methodologies are essential in addressing the study's objectives.

3.2 Materials

3.2.1 Coarse aggregate

Coarse aggregate is a granular material found in nature and obtained from riverbeds (Sand, gravel) or quarries (crushed rock) consisting of finely divided rock and mineral particles

ranging in size from 4.75 mm to 40 mm. This study used crushed gravel coarse aggregate sourced from a nearby quarry site in Adama, Ethiopia. Before use, the aggregate was subjected to a thorough quality assessment as per ASTM C33. This study asses this aggregate to be highly durable and free of any chemicals, clays, silts, or organic matter that could negatively impact its properties.

Figure 3. 1 Coarse Aggregate

3.2.2 Fine aggregate

Fine aggregate is a granular material typically smaller than coarse aggregate, with particle sizes ranging from 0.075mm to 4.75 mm. Find aggregates obtained from natural sources such as riverbeds or manufactured quarries. This study selected locally available river sand from the Metahara region of Ethiopia. The selection was based on the criteria set by the ASTM C 33 standard. Following the standard ensures that the Sand is free of silt, clay, and other organic contaminants. In the present study, the absence of these impurities will be confirmed as an essential condition for using the Sand.

Figure 3. 2 Fine Aggregate

3.2.3 Water

Drinkable Water can generally uses for Concrete. It reacts chemically with cement, which will ultimately set and harden. It also acts as a lubricant and makes the concrete work. To select water for this experiment, ASTM C1602 has followed to determine the pH value of water in the range of 6.5-8.5 and to ensure that salt, oil, industrial waste, and alkaline sulfides do not accumulate in large quantities in the water found in Adama science and technology university.

3.2.4 Cement

Cement is a dense powder made primarily from a calcareous material such as limestone or chalk. Furthermore, Alumina and Silicon are clay or shale from argillaceous material. Despite their excellent mechanical properties and availability, Portland pozzolan cement and ordinary pozzolan cement are the most used types of cement (Elango et al. 2021). During this study, OPC cement was were obtained from the local market for the study in Adama, Ethiopia, and stored in a dry, well-ventilated area, according to ASTM C-150 guidelines, which include protecting cement from moisture and atmospheric agent, storing them in an airtight container to prevent humidity exposure and keeping them off the ground and away from the wall to allow the proper air circulation and to avoid moisture buildup.

3.2.5 Fly Ash

The FA is a fine, spherical shape, heterogeneous glass-like particles - glassy spheres such as: precipitators, cenospheres and plerospheres. They generally have bumpy surfaces. Moreover, the FA contains glassy fragments, carbon blocks as well as small and spongious grains [Belviso C 2018]. The FA has various colour from tan to grey to black. The colour depends mainly on the amount of unburned carbon and presence of iron compounds [Yadav V K and Fulekar M H 2018 Int.]. The size of particle is usually between 0.01 and 200 μm. Generally, 10% to 30% of particles are larger than 45μm [Yadav V K and Fulekar M H 2018 Int.]. Specific gravity is from 1.9 to 3.0 [4, 9] and the bulk density is between: 1 - 2.5 g/cm and specific surface area is between 2,000 to 6,800 cm^2/g [Yadav V K and Fulekar M H 2018 Int.].

The fly ash (FA) used in this study was collected from Addis Ababa municipal solid waste incineration plant (Reppi Waste to Energy plant) in Addis Ababa, Ethiopia. Under the liquid-solid ratio of 6 ml/g, FA was washed twice for 20 min to remove the soluble chloride salts such as NaCl, KCl, CaClOH. The washed fly ash (WFA) was obtained after drying and 400-mesh sieving.

Figure 3. 3 Dry and sieved Fly-Ash

3.2.6 Bottom Ash

The materials used in this study was collected from Addis Ababa municipal solid waste incineration plant (Reppi Waste to Energy plant) located in Addis Ababa, Ethiopia. The wetted BA obtained from Reppi Waste to Energy plant, was oven-dried at 110 ± 5 C (approximately 24 h) to reduce the moisture content such that the BA could be ground easily. Next, the BA was sieved using a No. 4 sieve to eliminate several large fractions which was 17 ± 2% retaining on No. 4 sieve. The BA was then ground until the weight retained on a No. 325 (45-mm opening) sieve of 5 ± 2, 15 ± 2, 25 ± 2, 35 ± 2, 45 ± 2% by weight were obtained, designated as 5BA, 15BA, 25BA, 35BA and 45BA, respectively.

Figure 3. 4 Dry and sieved Bottom-Ash

3.2.7 Alkaline Solutions

Alkaline activator is the basic ingredient of the geopolymers which initiates the potential pozzolanic reaction in aluminosilicate minerals. It also contributes to the rheological characteristics of the geopolymers significantly. It is noted that alkali activation plays a vital role in the kinetics of polymerization. Generally, an alkaline

activator consists of alkali metal hydroxide and alkali metal silicates for the activation of geopolymers. Among these, NaOH and Na_2SiO_3 are widely used due to their low cost and superior rheological performance.

A combination of sodium silicate solution and sodium hydroxide solution was used to react with the aluminum and the silica in the fly ash. The sodium silicate solution comprised Na_2O=14.7%, SiO_2=29.4%, and water=55.9% by mass; it was purchased in bulk from a local supplier. Sodium hydroxide (commercial grade with 97% purity) pellets, bought in bulk from a local supplier, were dissolved in water to make the solution.

Figure 3. 5 Sodium Silicate and Sodium Hydroxide solution

3.3 Methods

3.3.1 Tests for coarse aggregate

3.3.1.1 Gradation test on coarse aggregate

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 (Fig. 3.6).

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.).

ASTM C 33 (“Standard Specifications for Concrete Aggregates”) lists several such size groups using the Simplified practice recommendation (SPR) number designation. The number and size of sieves selected for a sieve analysis depends on the particle sizes present in the sample and the grading Requirements specified.

Figure 3. 6 Nest of sieves

Using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed. The FM is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100.

Note that the total of masses retained may differ slightly from the original sample mass due to loss or gain in the sieving process or due to round-off error. Because the mass of material on each sieve is determined to within 0.1% of the total sample mass, the

maximum difference should not exceed 0.1% times the number of mass determinations.

Table 3. 1 Sieve analysis

Sieve size (mm)	**Weight Retained (g)**	**% of retained**	**Cumulative % retained**	**Cumulative % passing**	**ASTM C33 Range**
20	0	0	0	100	100
19	150	3	3	97	95-100
12.5	1900	38	41	59	40-80
9.5	1705	34.1	75.1	24.9	20-55
4.75	1235	24.7	99.8	0.2	0-10
pan	10	0.2	100	0	0
Total 5000	**Total cumulative percentage retained by mass = 718.9**				

3.3.1.2 Unit weight of coarse aggregate test

This test method determines the bulk density and void content of coarse aggregates. Bulk density is measured both in a loose and compacted state. It is calculated by dividing the mass of coarse aggregate by the volume of the measuring container. Void content is the percentage of space between particles not occupied by aggregate, calculated using the bulk density, specific gravity, and density of water. This test is important for concrete mix design to determine proper coarse aggregate volumes and gradation.

$M=(G-T)/V$

Where:

M = bulk density of aggregate, (kg/m).

G = mass of aggregate plus the container, (kg).

T = mass of the container, (kg).

V = volume of container, (m^3)

G = 36.8 kg

T = 15.1 kg

V = 0.0141 m^3

$M=(36.8 – 15.1)/0.0141=$ 1539 kg/m^3

According to the above calculation, the unit weight of fine aggregate falls within the range of 1120-1600 kg/m3, which complies with the ASTM C29 standard. The study's results, in accordance with ASTM C29, show a range of unit weights for the aggregate, ranging from

1200 to 1750 kg/m.

3.3.1.3 Specific gravity of coarse aggregate test

The specific gravity of an aggregate is the mass of the aggregate in air divided by the mass of an equal volume of water. An aggregate with a specific gravity of 2.50 would thus be two and one-half times as heavy as water. Each aggregate particle is made up of soli matter and voids that may or may not contain water. Because the aggregate mass varies with it moisture content, specific gravity is determined at a fixed moisture content. Four moisture conditions are defined for aggregates depending on the amount of water held in the pores or on the surface of the particles.

The volume of the aggregate particle is usually assumed to be the volume of solid matter and internal pores. Two different values of specific gravity may be calculated depending on whether the mass used is an oven-dry or a saturated surfacedry mass. Bulk specific gravity is the oven-dry mass divided by the mass of a volume of water equal to the SSD aggregate

volume; while SSD bulk specific gravity is the saturated surface-dry mass divided by the mass of a volume of water equal to the SSD aggregate volume. Most normal weight aggregates have a bulk specific gravity SSD between 2.4 and 2.9.

The specific gravity values are calculated as follows.

$$\text{Bulk specific gravity} = \frac{A}{S+B-C}$$

$$\text{Bulk specific gravity SSD} = \frac{S}{S+B-C}$$

where A = the mass of oven-dry sample in air;

S = the mass of saturated surface-dry sample in air;

B = the mass of flask filled with water; and

C = the mass of flask with specimen and water to the calibration mark.

Oven-dry mass in air (A) = 490.7 g

Saturated surface-dry mass in air (S) = 501.4 g

Mass of flask with specimen and water to fill mark (C) = 953.5 g

Mass of flask with water to fill mark (B) = 647.2 g

$$\text{Bulk specific gravity} = \frac{490.7}{501.4+647.2-953.5} = 2.51$$

$$\text{Bulk specific gravity SSD} = \frac{501.4}{501.4+647.2-953.5} = 2.57$$

The specific gravity range specified in ASTM C128-15 For aggregates is 2.5-3. Based on these criteria, the selected material meets the requirements, ensuring suitability.

3.3.1.4 Water absorption of coarse aggregate test

To calculate the mixing water content of concrete, the absorption of the aggregates and their total moisture contents must be known. Absorption is computed as a percentage by subtracting the oven-dry mass from the saturated surface-dry mass, dividing by the oven-dry mass, and multiplying by 100. In concrete technology, aggregate moisture is expressed as a percent of the dry weight of the aggregate.

Absorption is a measure of the total pore volume accessible to water, and is usually calculated using the results from a specific gravity determination (ASTM C 127 and C 128).

$$\text{Absorption \%} = \frac{W_{SSD} - W_{OD}}{W_{OD}} * 100$$

3.3.2 Tests for fine aggregate

3.3.2.1 Gradation test on fine aggregate

Weigh the material retained on each sieve size to the nearest 0.1 g. Ensure that all material entrapped within the openings of the sieve are cleaned out and included in the weight retained. This may be done using brushes to gently dislodge entrapped materials. The 8 in. (203 mm) or 12 in. (304.8 mm) round sieves need to be handled with special care due to the delicate nature of their screen sizes. As a general rule, use coarse wire brushes to clean the sieves down through the No. 50 (300 µm) sieve (Figure 3). Any sieve with an opening size smaller than the No. 50 (300 µm) should be cleaned with a softer cloth hair brush. The final total of the weights retained on each sieve should be within 0.3% of the original weight of the sample prior to grading.

The specified sieves are 75.0, 37.5, 19.0, and 9.5 mm (3,1.5, 3/4, and 3/8 in.) and 4.75 mm, 2.36 mm, 1.18 mm, 600µm, 300 µm, and 150 µm (No. 4, 8, 16, 30, 50, and 100).

Note that the lower limit of the specified series of sieves is the 150 µm (No. 100) sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The coarser the aggregate, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in ASTM C 33, but in some cases, fine sands are used with an FM less than 2.0.

3.3.2.2 Silt content of fine aggregate

A good quality construction sand or fine aggregate has a particle size measuring about 150 microns to 4.75mm. Particles smaller than this are classified as silt. The presence of excess quantity (>8%) of silt in sand reduces the bonding capacity of raw materials and affects the strength and durability of work. It is recommended to conduct silt content test for every $20m^3$ of sand.

Procedure for the Test

Firstly, a 50ml solution of 1% salt and water was prepared in the measuring cylinder. The addition of salt increases the settlement time of silt.

The sample of sand to be tested was then added to the cylinder until the level reaches 100ml.

50ml of the solution of salt and water was again added to the measuring cylinder.

Close the open end of the measuring cylinder and shake it well.

After a period of 1-2 hours, it was noticed that a layer of silt settled over the sand.

Now the researcher note down the volume V1 of the silt layer settled over the sand.

Note down the volume V2 of the settled sand.

Repeat the procedure a couple more times to get the average.

Percentage of Silt Content = (V1/V2) x 100

V1 - Volume of silt layer

V2 - Volume of sand layer

Table 3. 2 Silt content of sample sand

S.no	Description	Sample
1	Volume of sample Sand (V2)	130ml
2	Volume of silt layer (V1)	9ml
3	Percentage of silt	6.9%

The permissible value of silt content in Sand is 8%, hence the sand sample is ok and can be used for construction purposes.

3.3.2.3 Unit weight of fine aggregate test

The unit weight (bulk density) of a fine aggregate is the mass of the fine aggregate divided by the volume of particles and the voids between particles. Methods for determining bulk density are given in ASTM C 29/C 29M. The method most commonly used requires placing three layers of oven-dry fine aggregate in a container of known volume, rodding

each layer 25 times with a tamping rod, leveling off the surface, and determining the mass of the container and its contents. The mass of the container is subtracted to give the mass of the fine aggregate, and the bulk density is the fine aggregate mass divided by the volume of the container. The rodded bulk density of fine aggregates used for normal weight concrete generally ranges from 1200 to 1760 kg/m^3.

3.3.2.4 Specific gravity of fine aggregate test

The fine aggregate specific gravity test is used to calculate the specific gravity of a fine aggregate sample by determining the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. It is similar in nature to the **coarse aggregate specific gravity** test.

The fine aggregate specific gravity test measures fine aggregate weight under three different sample conditions:

Oven-dry (no water in sample).

Saturated surface dry (water fills the aggregate pores).

Submerged in water (underwater).

Using these three weights and their relationships, a sample's apparent specific gravity, bulk specific gravity and bulk SSD specific gravity as well as absorption can be calculated. Aggregate specific gravity is needed to determine weight-to-volume relationships and to calculate various volume-related quantities such as voids in mineral aggregate (VMA), and voids filled by asphalt (VFA). Absorption can be used as an indicator of aggregate durability as well as the volume of asphalt binder it is likely to absorb. The standard fine aggregate specific gravity and absorption test is AASHTO T 84 and ASTM C 128 Specific Gravity and Absorption of Fine Aggregate

3.3.2.5 Water absorption of fine aggregate test

The water absorption of fine aggregate used for concrete has a significant effect on the required water content of the mix in order to produce concrete which is sufficiently workable in its fresh state and sufficiently strong in its hardened state. The water absorption of fine aggregates goes hand in hand with the moisture content of the fine aggregate to determine water demand.

The water absorption value for fine aggregates describes the percentage increase in weight between the dry aggregate and the saturated aggregate. Therefore the absorption value is the amount of water which the fine aggregates are able to hold. It can be difficult to control the moisture content of high absorption aggregates in practice, leading to variations in the

quality of the produced concrete. As stated above fine aggregates with a high water absorption value (greater than around 2%) can create problems controlling the moisture content of the aggregates in practice. This leads to variability in aggregate moisture content which can make it difficult for the correct water content of the concrete mix to be determined.

3.3.3 Tests for municipal solid waste incineration (MSWI) fly ash

3.3.3.1 Preparation of MSWI fly ash

Municipal solid waste incineration (MSWI) fly ash is a hazardous waste containing high chlorine and harmful substances generated during the waste incineration disposal, and its resource utilization has a positive effect on reducing environmental pollution. The raw materials used in this research were MSWI fly ash. The MSWI fly ash had a fine particle size and a gray and black appearance, and it was collected from an MSWI power plant (Repi Waste to power plant) in Addis Ababa, Ethiopia.

3.3.3.2 Sieve analysis of MSWI fly ash

Sieve analysis has been carried out for the three samples with sieve shaker (sieve size: 4.75, 2.36, 1.18, 0.425, 0.3, 0.15 and 0.075 mm). Thise analysis was performed to categorize the fine particles present in the samples. The results of sieve analysis have been used to prepare gradation curve of fly ash samples. In the present study, ash samples were classified as per Unified Soil Classification System (USCS).

3.3.3.3 Specific gravity MSWI fly ash

Specific gravity tests were performed for fly ash samples as per IS 2720 (Part-3)-1980. Considering the particle size, specific gravity of fly ash samples were determined using density bottles. Specific gravity is an important physical property to study the applicability of fly ash in the field of construction engineering.

3.3.3.4 Chemical composition of MSWI fly ash

The chemical composition of MSWI fly ash or Silica analysis (Si, Al, Fe, Mg, Ca, K, Na, and S) was characterized at the laboratory of Geological Survey of Ethiopia using Atomic Absorption Spectrometer and UV- visible Spector photometer as per BGS standard (BGS, 1993). The Milling, specific gravity, sieving, Loss on Ignition, and moisture content of MSWI fly ash were carried out in the mechanical unit operation laboratory of the Geological Survey of Ethiopia as well.

3.3.3.5 Microstructural analysis of MSWI fly ash

The microstructural morphology of fly ash is obtained from SEM. Compared with the bottom ash, the fly ash particles exhibit irregular and angular morphology and smoother surface texture. In addition, fly ash particles have higher internal porosity than the bottom ash. It has been reported that the surface morphology and particle texture can provide essential information on leaching behavior and mechanical properties. The high porosity of the fly ash provides not only a higher potential for a leaching due to a highly reactive surface but also higher absorption rate. Moreover, porosity is closely related to the specific gravity and unit weight. Therefore, the higher porosity of the fly ash may explain the lower specific gravity and unit weight measured from the physical tests. The irregular and angular shape of the fly ash will cause low workability when incorporated with cement or asphalt.

3.3.4 Tests for municipal solid waste incineration (MSWI) bottom ash

3.3.4.1 Preparation of MSWI bottom ash

The bottom ash was collected from an MSWI power plant (Reppi Waste to power plant) in Addis Ababa, Ethiopia. Samples have been tested in the laboratory to investigate their physical, chemical and geotechnical properties. Specific gravity test has been performed to determine the physical properties of the collected samples. X-ray diffraction (XRD) test has been performed to determine the atomic structure of crystalline substance present in bottom ash samples. To study the morphological characteristics of bottom ash samples, scanning electron microscope (SEM) test was performed.

3.3.4.2 Sieve analysis of MSWI bottom ash

The particle size distribution of the fine aggregate was determined using a sieve test method. A fine aggregate sample was weighed and passed through a series of sieves with gradually smaller openings ranging from 4.75 mm to 0.075 mm in diameter. The arrangement of the sieves followed the guidelines of ASTM C33, and the fines modulus of the fine aggregate fell within the range of 2.3-3.1.

3.3.4.3 Specific gravity MSWI bottom ash

Specific gravity of bottom ash was found to be lower than fly ash. This may be due to the presence of cenospheres and poor gradation of bottom ash. Specific gravity is influenced by following factors; chemical composition and presence of hollow fly ash particle or particles of bottom ash with porous vesicular textures. Specific gravity of MSW was found

to be in agreement with past research. In case of MSW, specific gravity was attributed due to the presence of decomposed organic matter.

3.3.4.4 Chemical composition of MSWI bottom ash

Studies on bottom ash mineralogy (Clozel-Leloup et al., 1999) revealed that, as expected, incineration bottom ash is predominantly composed of high-temperature solids (primary phases). Most of these phases are metastable under natural conditions and can be chemically transformed into thermodynamically stable assemblages or minerals, often called secondary phases (Zevenbergen and Comans, 1994).

In addition to unburned material, fresh incinerator bottom ash may contain a low-density, impurity-bearing slag phase and a vitreous phase with variable quantities of crystals and glassy material. The most common phases include silicates (quartz), alumino-silicates of Ca and Na (plagioclase, ghelenite, piroxene, olivine, alite, belite), metal oxides, hydroxides (portlandite), sulphates (anhydrite), carbonates (calcite, siderite), as well as metals and alloys (Clozel-Leloup et al., 1999; Zevenbergen and Comans, 1994).

Due to the high bottom ash reactivity, aging of primary phases results in formation of secondary phases, including both new phases such as gypsum and ettringite, and neoformed carbonates, sulphates, oxalates, hydroxides and zeolites, as well as amorphous species.

3.3.4.5 Microstructural analysis of MSWI bottom ash

The microstructural composition of the bottom ashes was investigated by means of powder X-ray diffraction analysis (XRD). The XRD technique used Cu Ka radiation (copper tube operated at 30kV and 40mA) on a Scintag mod. X1 diffractrometer operated at 0.05 2W (count time=3 s).

Bottom ashes were characterised for their physical (including bulk density, water content, loss on ignition) as well as chemical properties (including phase oxide composition, elemental composition, anion content). The laboratory testing programme followed a wider protocol adopted by the NNAPICS consortium (Stegemann et al., 1999), making use of standard methods (either international or national), as well as internal procedures.

3.4 Preparation of test specimens

3.4.1 Mix Design

Hybrid geopolymer concrete specimens were prepared for different mixture variables, including the percentage of fly ash, Bottom Ash, Cement and alkaline solution. The mixture GC1, GC2 and GC3 consist of 40,50 and 60% of Cement replacement of fly ash

and 10% of Bottom ash replacement of fine aggregate respectively. Similarly, GC4, GC5 and GC6 consist of 40,50 and 60% of Cement replacement of fly ash and 20% of Bottom ash replacement of fine aggregate respectively, and GC7, GC8 and GC9 consist of 40,50 and 60% of Cement replacement of fly ash and 30% of Bottom ash replacement of fine aggregate respectively prepared with constant alkaline solution. The OPC (GC0) mix was also prepared by following ACI code. specifications to compare the experimental data.

Ten mixes were prepared, including a control mix, to investigate the properties of fly ash based geopolymer concrete with cement and bottom ash replacement for concrete mixes, as Hardjito and Rangan (2006) previously studied. As per the findings of the Hardjito and Rangan study, sand can be replaced with 10%, 200%, and 30% of bottom ash as a fine aggregate in a concrete mix. In the case of mix design incorporating cement in the concrete mix, replacing fly ash with OPC was carried out at 40%, 50%, and 60%, according to prior research by Hardjito and Rangan (2006). All these mix proportions of GC and OPC concrete shown in Table 3.2and 3.3.

Table 3. 3 Summary of Concrete Mix for cube Mould

Summary of Concrete Mix for six (6) cube Mould (3 specimens for 7 days & 3 for 28 day)							
No	**Mix ID**	**Cement(Kg)**	**Fine Aggregate(Kg)**	**Coarse Aggregate(Kg)**	**Fly Ash(Kg)**	**Bottom Ash(Kg)**	**Alkaline solution(Kg)**
0	GC0(0,0)	8.8389	15.1389	22.2264	**0**	**0**	0
1	GC1(40,10)	2.8917	4.909086	22.2264	4.33755	1.636362	2.8917
2	GC2(50,10)	3.614625	4.909086	22.2264	3.614625	1.636362	2.8917
3	GC3(60,10)	4.33755	4.909086	22.2264	2.8917	1.636362	2.8917
4	GC4(40,20)	2.8917	13.090896	22.2264	4.33755	3.272724	2.8917
5	GC5(50,20)	3.614625	13.090896	22.2264	3.614625	3.272724	2.8917
6	GC6(60,20)	4.33755	13.090896	22.2264	2.8917	3.272724	2.8917
7	GC7(40,30)	2.8917	11.454534	22.2264	4.33755	4.909086	2.8917
8	GC8(50,30)	3.614625	11.454534	22.2264	3.614625	4.909086	2.8917
9	GC9(60,30)	4.33755	11.454534	22.2264	2.8917	4.909086	2.8917

Table 3. 4 Summary of Concrete Mix for beam Mould

Summary of Concrete Mix for six (6) beam Mould (3 specimens for 7 days & 3 for 28 days curing)							
No	**Mix ID**	**Cement(Kg)**	**Fine Aggregate(Kg)**	**Coarse Aggregate(Kg)**	**Fly Ash(Kg)**	**Bottom Ash(Kg)**	**NaOH(Kg)**
0	GC0(0,0)	13.091	22.4343	32.9301	**0**	**0**	0
1	GC1(40,10)	4.284	21.81816	32.9301	6.426	2.42424	4.284
2	GC2(50,10)	5.355	21.81816	32.9301	5.355	2.42424	4.284
3	GC3(60,10)	2.142	21.81816	32.9301	4.284	2.42424	4.284
4	GC4(40,20)	4.284	19.39392	32.9301	6.426	4.84848	4.284
5	GC5(50,20)	5.355	19.39392	32.9301	5.355	4.84848	4.284
6	GC6(60,20)	2.142	19.39392	32.9301	4.284	4.84848	4.284
7	GC7(40,30)	4.284	16.96968	32.9301	6.426	7.27272	4.284
8	GC8(50,30)	5.355	16.96968	32.9301	5.355	7.27272	4.284
9	GC9(60,30)	2.142	16.96968	32.9301	4.284	7.27272	4.284

Designing a mix for fly ash based geopolymer concrete containing bottom ash involves determining the appropriate proportions of key ingredients. Here's a general guide for mix design:

Material Properties: Understand the properties of fly ash and bottom ash, including chemical composition and particle size distribution. Determine the specific surface area of the ashes.

Alkaline Activator: Select an alkaline activator, commonly a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Determine the molarity of NaOH and the modulus of sodium silicate.

Mix Proportions: Establish the ratio of fly ash to bottom ash based on the desired properties. Consider the alkali content and ash composition in the mix.

Water-to-Binder Ratio: Determine the water-to-binder ratio, taking into account the water content in the ashes. Aim for a balance between workability and strength.

Mixing Procedure: Mix the dry components thoroughly. Gradually add the alkaline activator solution while continuing mixing until a homogeneous paste is obtained.

Curing Conditions: Decide on the curing temperature and duration based on the desired strength and durability. Common curing options include ambient curing or elevated temperature curing.

Testing and Optimization: Cast samples for testing, including compressive strength,

flexural strength, and other relevant properties. Evaluate the results and adjust mix proportions if necessary for optimal performance.

Quality Control: Implement quality control measures to ensure consistency in raw materials and mix preparation.

3.3.2 Sample preparation

Sample preparation for the research typically involves the following steps, the first step was Gather fly ash and bottom ash samples from the power plant by Ensuring representative samples to capture variations in composition. Dry the collected ash samples to remove moisture content. Typically, this involves air-drying or oven-drying at a controlled temperature. Then Sieve the dried ash to achieve a consistent particle size distribution. This step helps in obtaining uniform properties and improves reactivity. Mix the sieved ash with an alkaline activator solution. Common activators include sodium hydroxide (NaOH) and sodium silicate. Thoroughly mix the ash and activator to ensure homogeneity by using appropriate mixing equipment to achieve a uniform paste. Place the prepared mixture into molds for shaping the geopolymer specimens. Ensure proper compaction to eliminate air voids. Cure the cast specimens under controlled conditions. Common curing methods include ambient curing or elevated temperature curing. Finally perform various tests to evaluate the properties of geopolymer concrete.

3.4.2.1 Methods of mixing, casting and compacting

Fly ash and Bottom ash along with cement and aggregates, were mixed as one in a 100-liter capacity concrete pan mixer for about 2–3 min. The alkaline liquid was then added to the dry material mixture. The fresh GC was cast into the cubical molds instantly after mixing in 3 equal layers. Each layer was compacted by given 20 to 30 manual strokes using a tamping rod, and then vibrated for 15 to 20s on a vibrating table to avoid air voids. After 24 h specimens were removed.

Figure 3. 7 mixing and casting

3.4.2.2 Methods of curing

Hardened GPC specimens were demolded after 24 h after casting. Any GPC specimens those were not fully hardened after these 24 h periods were allowed extra time to cure in their molds. The demolded specimens were then emersed in a water pond and they were left to cure at ambient temperatures until testing for 7 and 28 days.

Figure 3. 8 Curing of concrete in water pod

3.5 Methods of experimentation

3.5.1 Fresh concrete test

Slump tests were conducted for the hybrid OPC-geopolymer concrete mixes and the results are presented. It can be observed that OPC content had a significant effect on the workability of the one-part mixes. The geopolymer concrete mix (GC0) that contains no OPC exhibited the highest workability as indicated by the slump value.

3.5.2 Hardened Concrete Test

3.5.2.1 Compressive Strength

The specimens used for this test were cubes of standard size 150mm x150mm x150mm.for each time period of each molarity, 3 specimens were casted i.e., (A total of 6 specimens for all time periods ie.,7 days,28 days). Alkaline Solution Ratio of 1:2.5 and 1:3 were considered for testing.

3.5.2.2 Flexural Strength

The specimens used for this test were beams of standard size 100 mm x 100 mm x 500 mm. for each period of time of each molarity, 3 specimens were taken i.e., a total of 6 specimens for all time periods ie.,7 days,28 days. Alkaline Solution Ratio of 1:2.5 and 1:3 were considered for testing. {T =2P/bd2}is the formula for calculation of flexural strength for 7 and 28 days and the outcomes were tabled and represented beneath.

3.5.2.3 Durability properties

Durability of concrete structures is largely influenced by various physical and chemical processes that results to concrete deterioration. However, the corrosion of reinforcement steel through chlorides or carbonation continues to be the most common cause of concrete deterioration. Additionally, other causes such as thermal variations, alkali-silica reaction, and chemical attacks are also crucial factors of distress and cracking in concrete structures. The permeability, porosity, and chloride penetration of FAs were also studied.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

The previous chapter provided an overview of the research methodology employed in this study. The present chapter presents the results and discusses the potential utilization of Fly-Ash and Bottom-Ash as a constitute of hybrid geopolymer concrete.

The first section of this chapter delves into the discussion of sub-objective one. It begins by examining the material characterization properties of Fly-Ash and Bottom-Ash. Additionally, it investigates the effects of fine aggregate replacement ratio with Bottom-Ash and curing time on concrete's compressive strength and density. By the end of this investigation, it transitions to the study's second section. The second section is dedicated to addressing sub-objectives two and three. In this section, the chapter presents the results in relation to the combined effect of Bottom ash replacement and cement replacement on the compressive strength of hybrid geopolymer Concrete. Furthermore, it discusses the morphological tests conducted.

4.2 Material test result and discussion

4.2.1 Fine Aggregate characterization

This section presents the results of physical tests performed on the fine aggregate, which included assessing its silt content, conducting sieve analysis, and measuring unit weight, specific gravity, and water absorption. These specific tests were chosen within the scope of this study because they provide crucial insights into the fine aggregate's quality, suitability, and behavior when incorporated into concrete mixtures. By analyzing these parameters, the researcher can make informed decisions regarding properly utilizing and proportioning the fine aggregate, thereby ensuring optimal performance and desired outcomes regarding the concrete's strength, workability, and durability.

4.2.1.1 Silt Content Of A Sand

Sand is a common natural resource found in glaciers, rivers, lakes, seas, and windblown deposits. However, these sources often contain impurities like dust, loam, or clay, which are finer than sand. These finer particles can weaken the bond between materials, reducing concrete strength and quality. The silt content was determined according to ASTM C117 to ensure the study's sand met the required standards. The results confirmed that the sand used met ASTM standards, which recommend rejecting sand if the silt content exceeds 6%,

as indicated in Table 4.1

Table 4. 1Silt content of sand

Items	Trial 1	Trial 2	Trial 3	Average
A = Volume of separated layer (ml)	6	6.5	6	6.1667
B = amount of fine aggregate (ml)	300	300	300	300
Silt content (%) == $\frac{A}{B}$ * 100%	2%	2.17%	2%	2.05%

4.2.1.2 Unit Weight Of Fine Aggregate Test

The unit weight of fine aggregate measures how much space it will occupy in concrete. To determine this, the ASTM C29 standard was followed. According to Table 4.2, the unit weight of fine aggregate falls within the range of 1120-1600 kg/m3, which complies with the ASTM C29 standard.

Table 4. 2 Unit weight of fine aggregate calculation and result

Indications	Quantity	Calculation
I= Volume of the container	0.01 m^3	UWFA= $\frac{S-N}{I}$
S= Aggregate plus container weight	20.760 Kg	UWFA= $\frac{20.760-5.605}{0.01}$
N= Weight of the empty container	5.605 Kg	UWFA= 1515.5 kg/m^3

4.2.1.3 Specific Gravity And Water Absorption Test For Fine Aggregate

As per ASTM C128-15, the specific gravity of an aggregate is calculated by dividing its mass by the volume of water. On the other hand, absorption refers to the increase in mass of an aggregate due to water present in its pores. The specific gravity range specified in ASTM C128- 15 for aggregates is 2.5-3. Based on these criteria, the selected material meets the requirements, ensuring suitability.

4.2.1.4 Fine Aggregate Gradation Test

The particle size distribution of the fine aggregate was determined using a sieve test method. A fine aggregate sample was weighed and passed through a series of sieves with gradually smaller openings ranging from 4.75 mm to 0.075 mm in diameter. The arrangement of the sieves followed the guidelines of ASTM C33, and the fines modulus of the fine aggregate fell within the range of 2.3-3.1. The results are presented in tabulated

form in Table 4.3, where the fines modulus of 2.985 is within the specified range. Additionally, the gradation of the aggregate is graphically represented in Figure 3.3, showing that it falls between the upper and lower limits set by ASTM C33.

Table 4. 3 Sieve analysis of fine aggregate

Sieve Size (mm)	Weight Retained (g)	Percentage of Retained	Cumulative Percentage Retained	Cumulative Percentage Passing	ASTM C33 Range
4.75	45	4.5	4.5	95.5	95-100
2.36	110	11	15.5	84.5	80-100
1.18	190	19	34.5	65.5	50-85
0.6	270	27	61.5	38.5	25-60
0.3	250	25	86.5	13.5	10-30
0.15	95	9.5	96	4	0-10
Pan	40	4	100	0	0
Total	5000				
Total cumulative percentage retained by mass = 298.5					

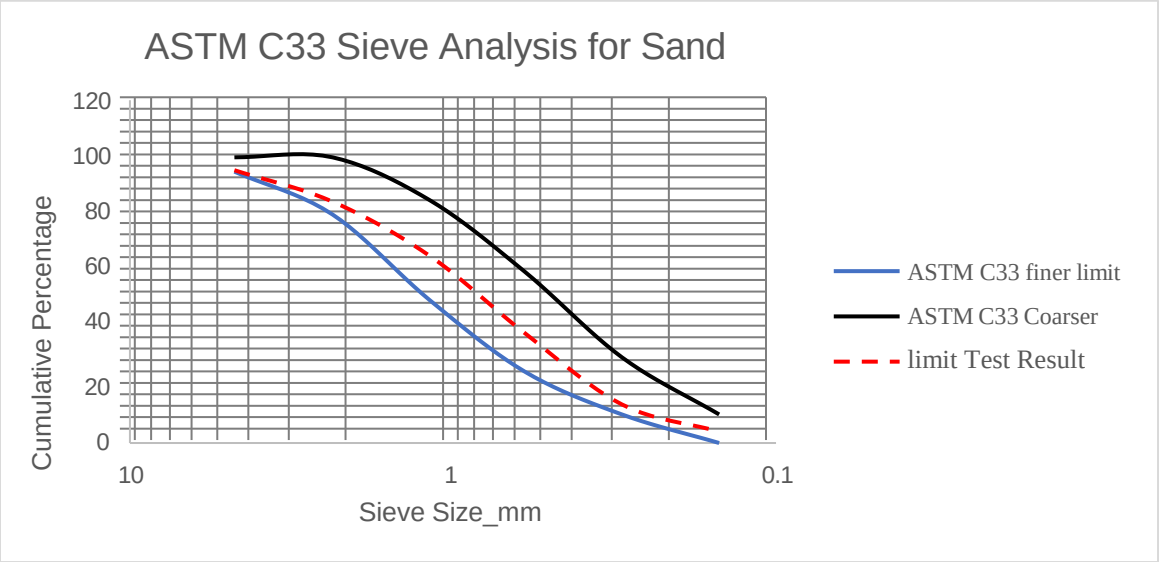


Figure 4. 1 Gradation Curve for Fine Aggregate According to ASTM C33

$$\sum_{sive\ size\ 4.75}^{sive\ size\ 0.15} (\text{cumulative percentage retained by mass})/100$$

= 298.5/100 = **2.985**

Figure 4. 2 Sieving of fine aggregate

4.2.2 Tests On Coarse Aggregate

In this section, physical tests were conducted on the coarse aggregate. These tests included determining the unit weight, specific gravity, and sieve analysis of the aggregate. No additional tests were performed since the study utilized non-toxic and pure aggregate obtained from a local crushed stone provider.

4.2.2.1 Unit Weight Of Coarse Aggregate Test

The grading, shape, and texture of the aggregate determine the unit weights of coarse aggregate. For this reason, unit weight tests are necessary to ensure that concrete mix designs are optimized for the coarse aggregate used. The study's results, in accordance with ASTM C29, show a range of unit weights for the aggregate, ranging from 1200 to 1750 kg/m^3. Table 3.1 confirms that the selected coarse aggregate met the ASTM criteria.

Table 4. 4 Unit weight of coarse aggregate

Indications	Quantity	Calculation
I= Volume of the container	0.01 m^3	UWCA= $\frac{S-N}{I}$
S= Aggregate plus container weight	22.41 Kg	UWCA= $\frac{22.415-5.605}{0.01}$
N= Weight of the empty container	5.605 Kg	UWCA= 1681 kg/m^3

4.2.2.2 Specific Gravity And Water Absorption Test For Coarse Aggregate

The experiment utilized ASTM C127, a standard test method for measuring coarse aggregate specific gravity and absorption. Based on the results obtained and presented in Table 4.5, the bulk specific gravity and saturated-surface-dry bulk specific gravity (SSD) meets the requirements of ASTM C127 water absorption 0.6-6% and SSD with 2.4-2.9 range.

Table 4. 5 Specific gravity and water absorption for coarse aggregate results

Description	Amount	Formulas	Calculations
A: weight of oven-dried test sample in air	5 Kg	Bulk specific gravity = $\frac{A}{B-C}$	Bsg= $\frac{5}{5.08-3.3}$ = 2.80
B: Weight of SSD sample in air	5.08 Kg	Bulk Specific gravity (SSD) = $\frac{B}{B-C}$	B_{SSD}= $\frac{5.08}{5.08-3.3}$= 2.85
C: Weight of saturated sample in Water	3.3 Kg	Absorption % = $\frac{B}{B-A}$ X 100	Abn. % $\frac{5.08}{5.08-5}$x 100 = 1.6%

4.2.2.3 Coarse Aggregate Gradation Test

As part of the ASTM C33 procedure, the experiment utilized apparatus such as a balance, a series of sieves, a shovel, and a sieve brush. A round opening sieve was used to measure the aggregates' particle size distribution to investigate the coarse aggregate's gradation. Table 4.6 illustrates the grading of aggregates and fines modulus, which indicates aggregates' fineness, coarseness, and uniformity. And as per ASTM, fineness modulus lies in the range of 5.5-8

Table 4. 6 Sieve analysis calculation for coarse aggregate (astm c33)

Sieve Size (mm)	Weight Retained (g)	Percentage of Retained	Cumulative Percentage Retained	Cumulative Percentage Passing	ASTM C33 Range

20	0	0	0	100	100
19	150	3	3	97	95-100
12.5	1900	38	41	59	4.-80
9.5	1705	34.1	75.1	24.9	20-55
4.75	1235	24.7	99.8	0.2	0-10
Pan	10	0.2	100	0	0
Total	5000				
Total cumulative percentage retained by mass = 718.9					

The gradation curve of the coarse aggregate used was within the ASTM lower and higher-grade requirements, as shown in Figure 4.2.

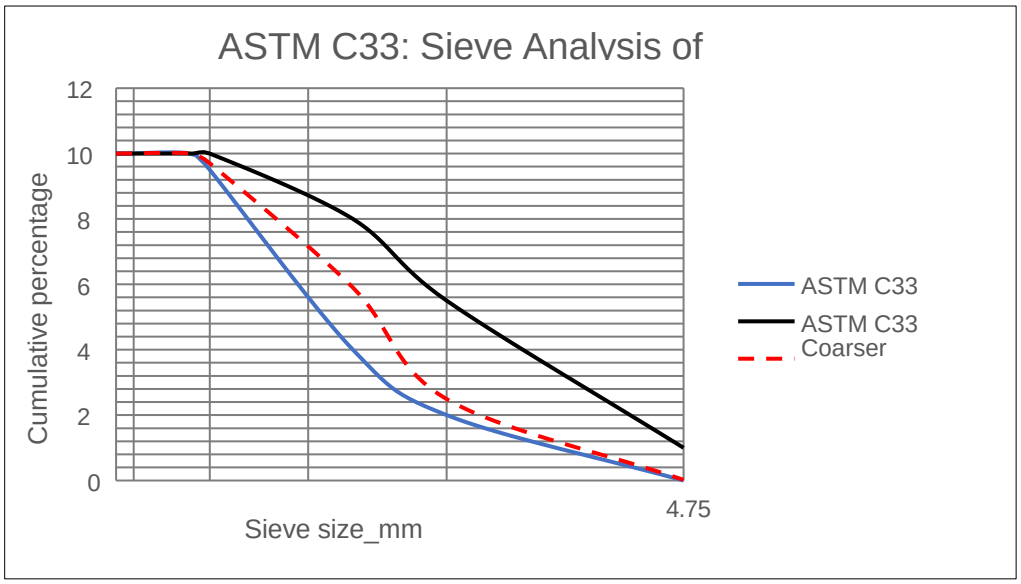


Figure 4. 2 Gradation Curve for Coarse Aggregate According to ASTM C33 Range

4.2.1 Fly-Ash Characterization

The FA typically contains 90 - 99% inorganic material, 1-9% organic material, and up to 0.5% fluid components [Vassilev S V, Vassileva C G 2005].The inorganic material is composed of 34 - 80% amorphous materials and 17% - 63% crystalline phases. The crystalline phases are usually: quartz, mullite, and various iron rich phases such as: hematite, goethite and calcite. The FA organic component is characterized by unburned carbon [Rickard W D A, Temuujin J and van Riessen A 2012].

The following tests have been conducted to characterize this sample of fly ash which has been collected from Addis Ababa municipal solid waste incineration plant (Reppi Waste to

Energy plant) in Addis Ababa, Ethiopia.

4.3.1.1 Chemical composition

The combined chemical composition of Reppie fly ash ($SiO_2 + Al_2O_3 + Fe_2O_3 = 50.0\%$) testified the pozzolanic nature of fly ash as per ASTM C- 618 specifications (2013). According to this specification, the Reppie incinerated municipal solid waste fly ash qualifies to be a Class C artificial Pozzolan. The more content of pozzolanic properties of materials in concrete used, it increases mechanical strength and durability, lowering the heat of hydration and thermal shrinkage, increase in water tightness, reduction in the alkali-aggregate reaction, resistance to sulfate attack, and better workability. Cost efficiency are also some of the improvements achieved by using pozzolans blended with Portland cement and pozzolans improve lime properties.

The chemical compositions or silicate analysis of incinerated municipal solid waste fly ashes were determined (Table 4.7).

The CaO content of incinerated municipal solid waste fly ash resulted in nearly one-third of ordinary Portland cement and this implies fully replacement of cement impossible. Because, CaO content of the ash has impact on concrete soundness and strength. Excessive presence of lime makes cement unsound, causes the cement to expand, and disintegrate, while lime deficiency decreases the strength of the cement's property and allows cement to quickly set. Increasing the quantity of the cemented binder cycle and, to a lesser extent, calcium-aluminate hydrates, enhancing the long-term stability and reducing the system's permeability. The test result indicates that the calcium content of IMSW fly ash shows 22.54% which gratifies others experiment that makes it possible to concrete ingredients on behalf of cement.

On the other hand, the SiO_2 content of incinerated municipal solid waste fly ash test result was 30.72% which is higher than OPC (Table 4.7**).** The presence of such content of silicon plays a vital role to increase the pozzolanic property as well as strength of cement. Reppie incinerated municipal solid waste fly ash of Al_2O_3 content were 14.96% which is greater than OPC as a result alumina adds a quick-setting property to cement that means reduce setting time by the increasing rate of hydration. Therefore increasing the percentage replacement of MSWI fly ash will increase alumina content. This needs more water demand to reduce the setting time of producing concrete. The concentration of MgO and Fe_2O_3 in municipal solid waste incinerated fly ash samples slightly increased from Portland cement. Iron oxide provides the color, strength, and hardness of cement. It acts as

a flux and forms tri calcium alumino ferrite with calcium and aluminum to impart toughness and strength to cement in the chemical reaction at high temperatures. Magnesium oxide is a very small amount in cement that provides color and hardness. Magnesia should not be present in cement more than 2%, however, the test result indicated that 2.82% of MgO present in the sample and due to excess content of magnesia (0.28%) makes to decrease cement strength.

The chemical composition of the sample has been obtained with the help of Ethiopian geological survey is shown in Table 4.7.

Table 4. 7 Chemical composition of the Fly ash used

Compound	Reppie MSWI Fly Ash by mass , %	OPC Cement as per ES,2005
SiO_2	30.72	18 - 24
Al_2O_3	14.96	2.6 - 8.0
Fe_2O_3	3.90	1.5 - 7.0
CaO	22.54	6.1 - 6.9
MgO	2.82	0.5 - 4.0
Na_2O	3.62	--
K_2O	8.16	0.2 - 1.0
MnO	0.26	--
P_2O_5	2.11	--
SO_3	--	0.2 - 4.0
TiO_2	0.04	--

The MSWI fly ash was found to have high alkali content (Na2O and K2O) comparable to OPC and it can cause a quick setting, reduce the ultimate strength of concrete, increase expansion underwater, shrinkage under drying conditions and this implies that adding more percentage of incinerated municipal solid waste fly ash to concrete may not be advisable due to its alkali concentration(Simegn A, Abebe S, Worku A 2021).

High amount of sulfates and chloride content in ashes were dangerous because sulfates and chloride content make more hydration and reduce the setting time of concrete. However, the test result from the silicate analysis of incinerated municipal solid waste fly ash was

completely free from sulfate and chloride content. This is to means that concrete produced by blending incinerated municipal solid waste fly ash with OPC may not be exposed to sulfate attack from its source.

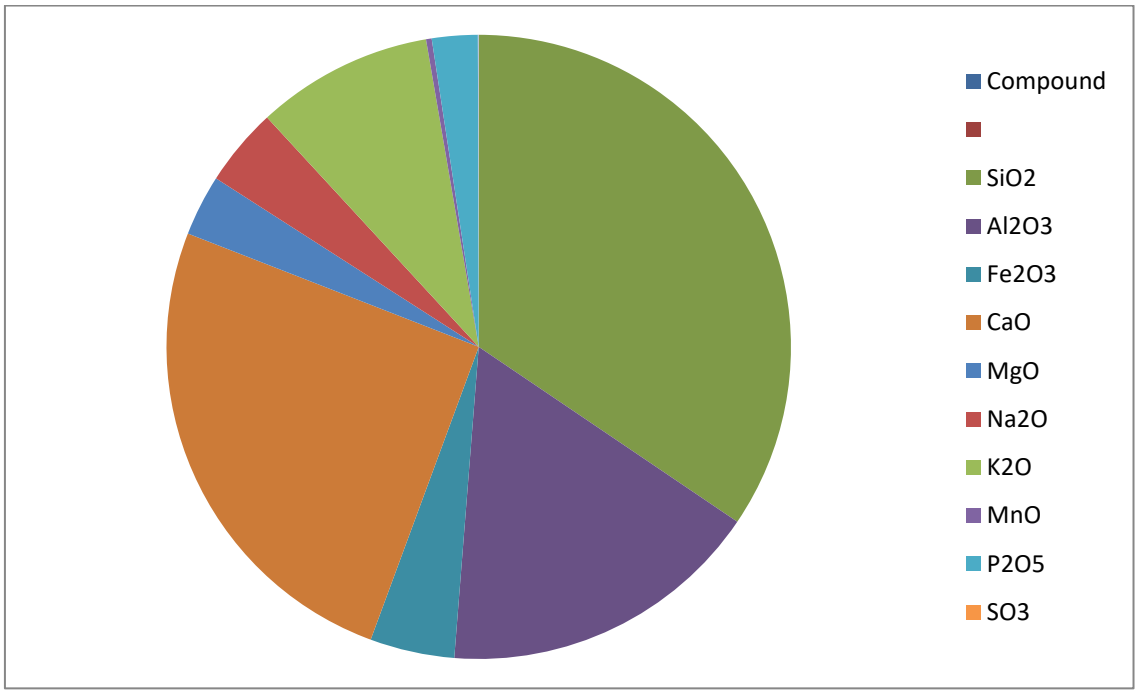


Figure 4. 3 showing the % contents of chemicals compounds by mass

4.3.1.2 Scanning Electron Microscope (SEM)

The JCM-6000Plus, operating at an acceleration voltage of 15.00, with magnifications of 1500.0, 600.0, and 300.0. was used to study the morphology of the fly ash particles. Examination under the scanning electron microscope showed that the samples had the usual fly ash morphology and were composed of mostly small, spherical particles. Fig. 2 shows SEM micrograph of the cenospheses particle. It can be noticed that the fly ash sample consists of almost regular spherical (cenospheres) particles ranging 2 um to 14 um in diameter. Fig. 4.1 shows micrograph of cenospheres particle. Usually, fly ash composed of mostly small and spherical particles.

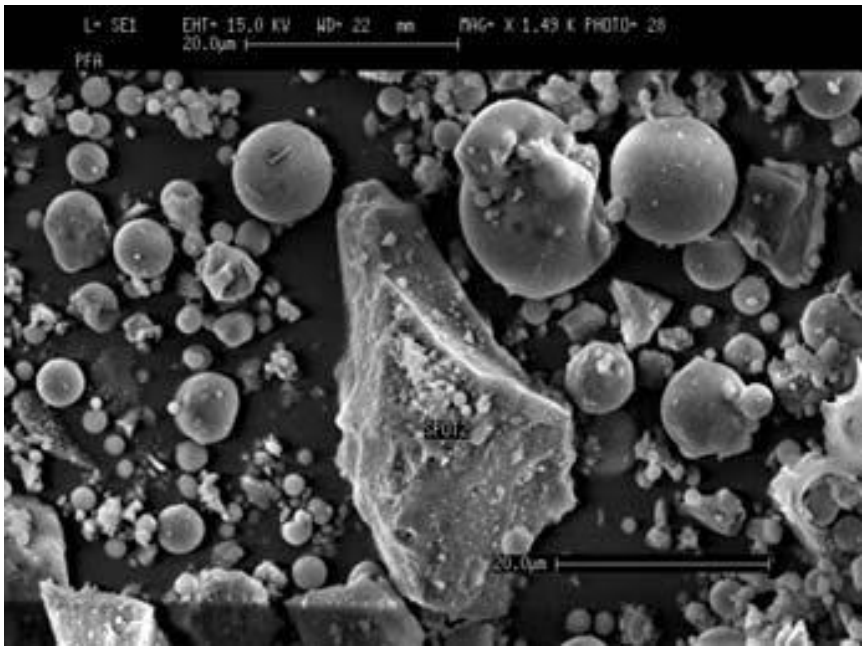


Figure 4. 4 SEM micrograph for the cenospheres particle

4.3.1.3 Mineralogical Composition of MSWI Fly Ash

The sample has been evaluated for its mineralogical composition by X-ray diffraction (XRD) spectrometer. The sample is scanned from 2q of 0±80°. The search match JCPDS data files have been used for identification of the minerals present in the sample (Fig. 4.2). Fly ash were subjected to X-ray diffraction test (XRD) to identify the minerals present in those materials. Around 10 g of each sample passing through 75 μm IS sieve was taken in a glass beaker with 5 ml of deaired water added to it. Prepared solution was then mounted on a glass slide and placed in desiccator for a day. XRD analysis was performed on this prepared sample at a scanning speed of 10°/min and step size of 0.02° with 2θ ranging from 5° to 75°. Diffractometer used in this analysis has potential difference of 40 kV and 15 mA current. The obtained XRD pattern of fly ash has been analyzed and matched with the standard data using X'Pert High score program to conclude their mineralogy. Figures 4.5, represent the presence of inert material in fly ash. From Fig. 4.5, it is observed that quartz (SiO_2) and mullite ($Al_{1.69}O_{4.85}Si_{1.22}$) are predominant in fly ash. Strongest peaks of quartz are noticed at 26.52°, 20.76°, 36.44°, 42.39°, 50.04°, 59.76° and 67.87°. Similarly, the peaks of mullite are matched at 16.52°, 33.13°, 35.21°, 39.27°, 40.78°, 42.39° and 50.04°.. Strongest peaks of quartz were noticed at 28.89°, 26.65°, 36.52°, 39.46°, 40.26°, 42.39°, 50.15°, 59.92° and 68.11°. Similarly, peaks of corundum were noticed at 25.49°, 43.2° and 68.11°.

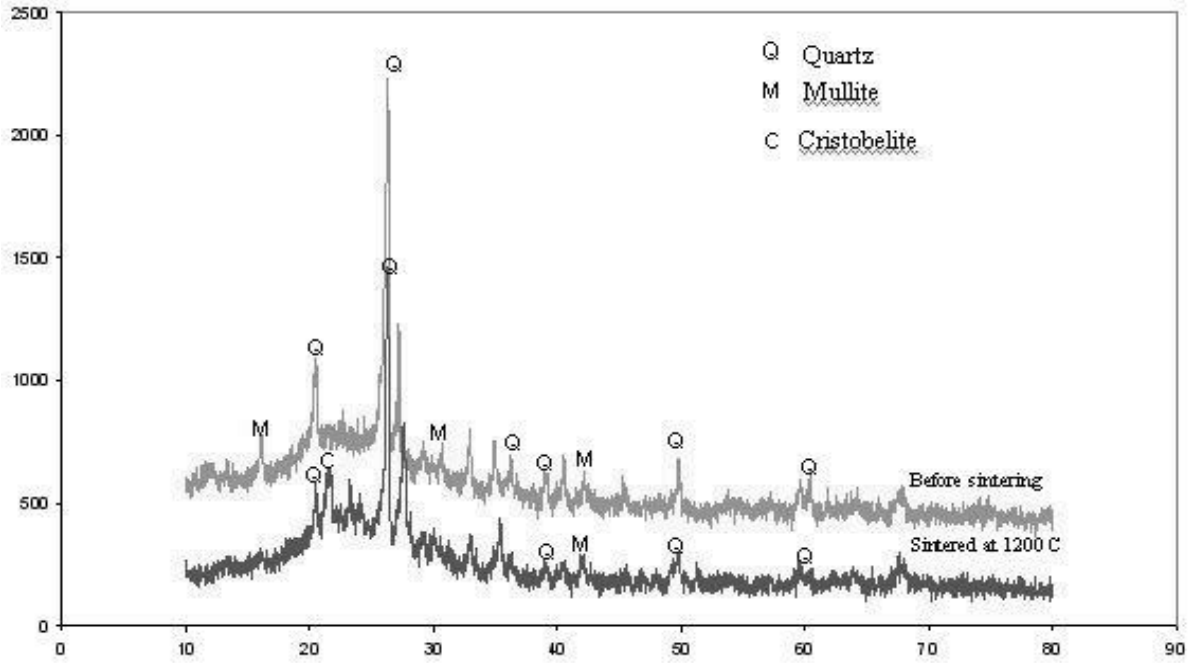


Figure 4. 5 X-Ray diffraction pattern for fly ash sample

4.3.1.4 Fineness of Fly Ash

As per ASTM, the fineness of the fly ash is to be checked in both dry and wet sieving. The fly ash sample is sieved in 45-micron sieve and the percentage of retained on the 45-micron sieve is calculated. Further fineness is also measured by LeChatelier method and Blaine Specific Surface method.

4.3.1.5 Specific Gravity of Fly Ash

The specific gravity of fly ash ranges from a low value of 1.90 for a sub-bituminous ash to a high value of 2.96 for an iron-rich bituminous ash.

4.3.1.6 Size and Shape of Fly Ash

As the fly ash is a very fine material, the particle size ranges in between 10 to 100 microns. The shape of the fly ash is usually spherical glassy shaped.

4.3.1.7 Color

The color of the fly ash depends upon the chemical and mineral constituents. Lime content in the fly ash gives tan and light colors whereas brownish color is imparted by the presence of iron content. A dark grey to black color is typically attributed to an elevated un-burned content.

4.2.2 Bottom-Ash Characterization

Studies on bottom ash mineralogy (Clozel-Leloup, B., Bodenan, F., Piantone, P.) revealed

that, as expected, incineration bottom ash is predominantly composed of high-temperature solids (primary phases). Most of these phases are metastable under natural conditions and can be chemically transformed into thermodynamically stable assemblages or minerals, often called secondary phases (Zevenbergen, C., Comans, R.N.J., 1994).

In addition to unburned material, fresh incinerator bottom ash may contain a low-density, impurity-bearing slag phase and a vitreous phase with variable quantities of crystals and glassy material. The most common phases include silicates (quartz), alumino-silicates of Ca and Na (plagioclase, ghelenite, piroxene, olivine, alite, belite), metal oxides, hydroxides (portlandite), sulphates (anhydrite), carbonates (calcite, siderite), as well as metals and alloys (Zevenbergen, C., Comans, R.N.J., 1994).

Due to the high bottom ash reactivity, aging of primary phases results in formation of secondary phases, including both new phases such as gypsum and ettringite, and new formed carbonates, sulphates, oxalates, hydroxides and zeolites, as well as amorphous species.

4.2.2.1 Chemical Composition of MSWI Bottom-Ash

Table 4.2 presents the chemical compositions of BA. The main chemical composition of BA was SiO2, Al2O3,Fe2O3, and CaO, which were 35.6, 19.6, 14.9, and 18.7% by weight, respectively. The values of SO3 and LOI were 1.7 and 3.6% by weight, respectively. The chemical composition of BA met the requirements for fly ash class F as specified by ASTM C618, which requires a minimum of SiO2 +Al2O3 +Fe2O3 values of 70% by weight and the maximum requirements for the SO3 and LOI values of 5 and 6% by weight, respectively.

The CaO composition in BA was 18.7% by weight, which was notably high. The study of McCarthy et al. [Zevenbergen, C., Comans, R.N.J., 1994] found that BA of this study could be classified as an intermediate-calcium oxide content (between 10% and 20% of the CaO).

In addition, the chemical composition of BA was similar to fly ash from the same source since BA had SiO2 +Al2O3 +Fe2O3 values of 70.1% by weight while 83.7% by weight of the three oxides was obtained in the case of fly ash [Kim H-K, Lee H-K. 2011]. This finding indicated that the chemical composition of BA was consistent with a pozzolanic material; therefore, it is possible to develop BA for use as a pozzolanic material, such as fly ash.

Table 4. 8 Chemical composition of MSWI Bottom Ash.

Compound	Content, % wt
SiO_2	35.6
Al_2O_3	19.6
Fe_2O_3	14.9
CaO	18.7
MgO	2.4
SO_3	1.7
Na_2O	1.2
K_2O	2.3
LOI	3.6

4.2.2.2 Scanning Electron Microscope (SEM) Analysis of MSWI Bottom Ash

A variety of particle shapes and compositions of the MSWI bottom ash observed by SEM are presented in Fig. 4.5**.** Most bottom ash particles were polycrystalline with large grains set in a very fine-grained matrix. This may result from the different nature of MSWI burn in the incineration system. The majority of the ash particles are obviously angularly shaped, porous aggregates of 5–100 lm in diameter with a flaky texture. The angular and/or porous fragments in the bottom ash may represent inorganic components that were partially or completely melted and then become porous due to the release of trapped gases.

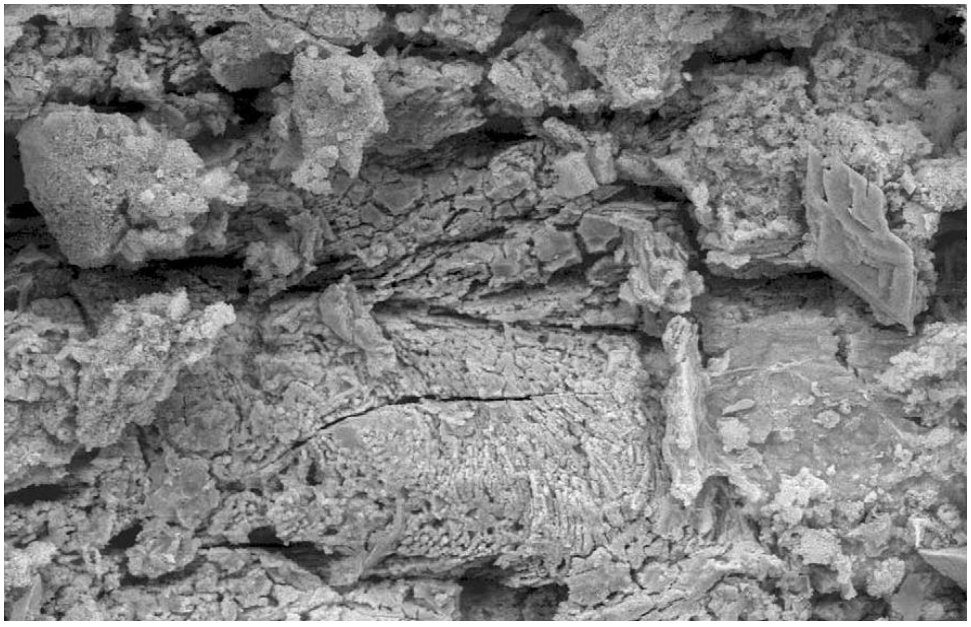


Figure 4. 6 SEM micrographs showing morphologies of MSWI bottom ash particles.

4.2.2.3 Mineralogical Composition of MSWI Bottom Ash

MSWI Bottom ash were subjected to X-ray diffraction test (XRD) to identify the minerals present in those materials. Around 10 g of each sample passing through 75 μm IS sieve was taken in a glass beaker with 5 ml of deaired water added to it. Prepared solution was then mounted on a glass slide and placed in desiccator for a day. XRD analysis was performed on this prepared sample at a scanning speed of 10°/min and step size of 0.02° with 2θ ranging from 5° to 75°. Diffractometer used in this analysis has potential difference of 40 kV and 15 mA current. The obtained XRD pattern of bottom ash has been analyzed and matched with the standard data using X'Pert High score program to conclude their mineralogy. Figures 5 represent the presence of inert material in bottom ash. From Fig. 5, it is observed that quartz (SiO_2), mullite ($Al_{1.69}O_{4.85}Si_{1.22}$) and calcium carbonate ($CaCO_3$) are predominant here. Strongest peaks of quartz are noticed at 26.63°, 20.77°, 49.94°, 59.85°, 67.97°, 36.44° and 45.69°. Similarly, the peaks of mullite are noticed at 16.43°, 33.13°, 35.21°, 60.78° and 60.61°. Peaks of calcium carbonate are found at 39.47° and 60.61°.

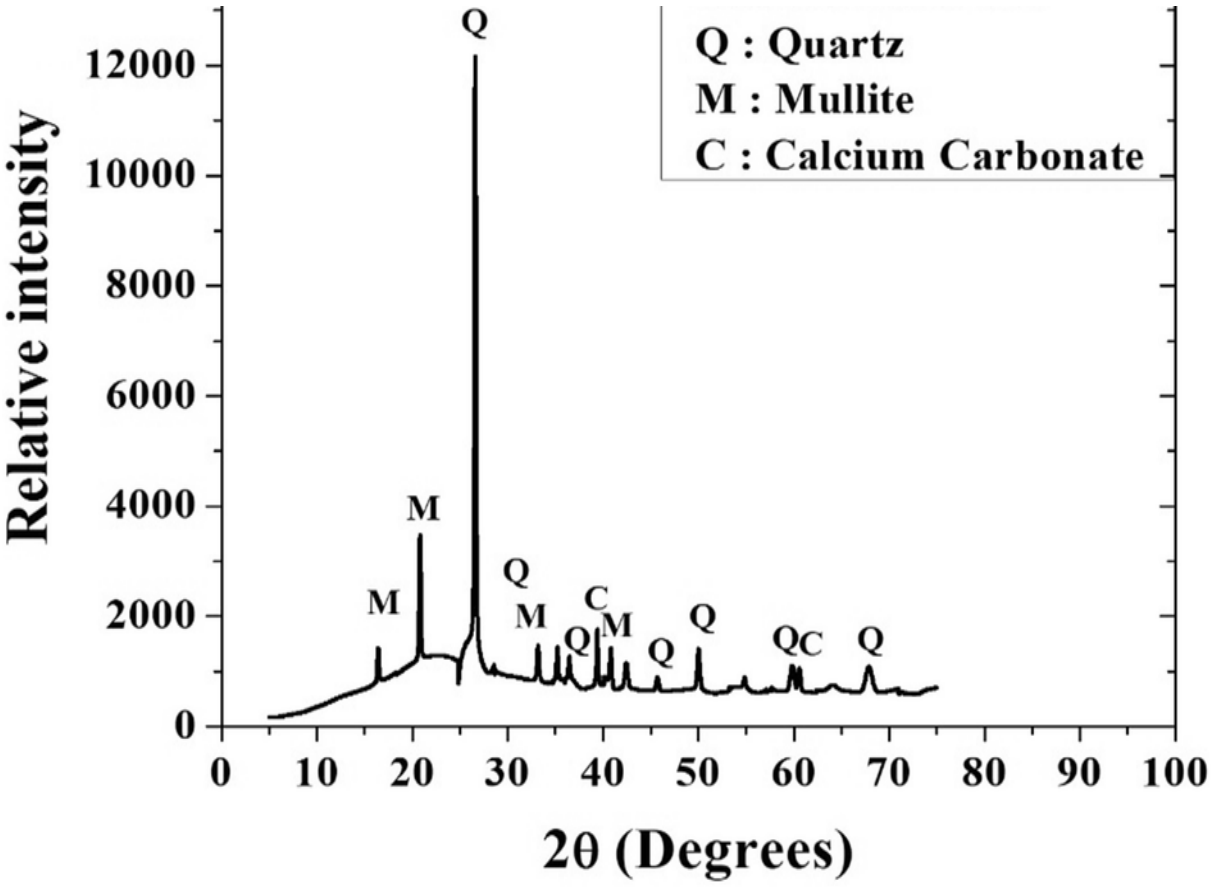


Figure 4. 7 X-ray diffraction pattern for KTPS Bottom ash sample

4.3 Experimental results and discussion

4.3.1 Fresh Concrete test

To assess the workability of selected concrete mix by conducting slump test. Vertical settlement of a standard cone of fresh concrete (actually frustum of a cone) under its own weight is called slump. For highly workable mixes, slump is of the order of a few inches, which can be measured accurately. Hence slump test is to be preferred in such cases.

The experimental work shows that the workability of fresh concrete slightly decreases as the percentage replacement of incinerated municipal solid waste fly ash increases. The decrease in the workability of the concrete is supposed to be due to the relatively high rate of hydration and this makes increasing water demand of fly ash as compared to ordinary Portland cement.

Figure 4.7 Performing slump test

In general, some reduction in the slump by pozzolan was due to the fact that the cement was partially substituted by artificial pozzolan by weight and therefore the number of solids in the paste was higher than that of the control mixture due to the lower specific gravity of artificial pozzolan compared to that of Portland cement as a result of this more water is needed to lubricate particles.

Table 4. 9 Slump test result

No	Mix ID	Slump value in mm
0	GC0 0,0	26
1	GC1 40.10	34
2	GC2 50,10	46
3	GC3 60,10	54
4	GC4 40,20	32
5	GC5 50,20	37
6	GC6 60,20	35
7	GC7 40,30	27
8	GC8 50,30	32
9	GC9 60,30	34

In general, some reduction in the slump by pozzolan was due to the fact that the cement was partially substituted by artificial pozzolan by weight and therefore the number of solids in the paste was higher than that of the control mixture due to the lower specific gravity of artificial pozzolan compared to that of Portland cement as a result of this more water is needed to lubricate particles.

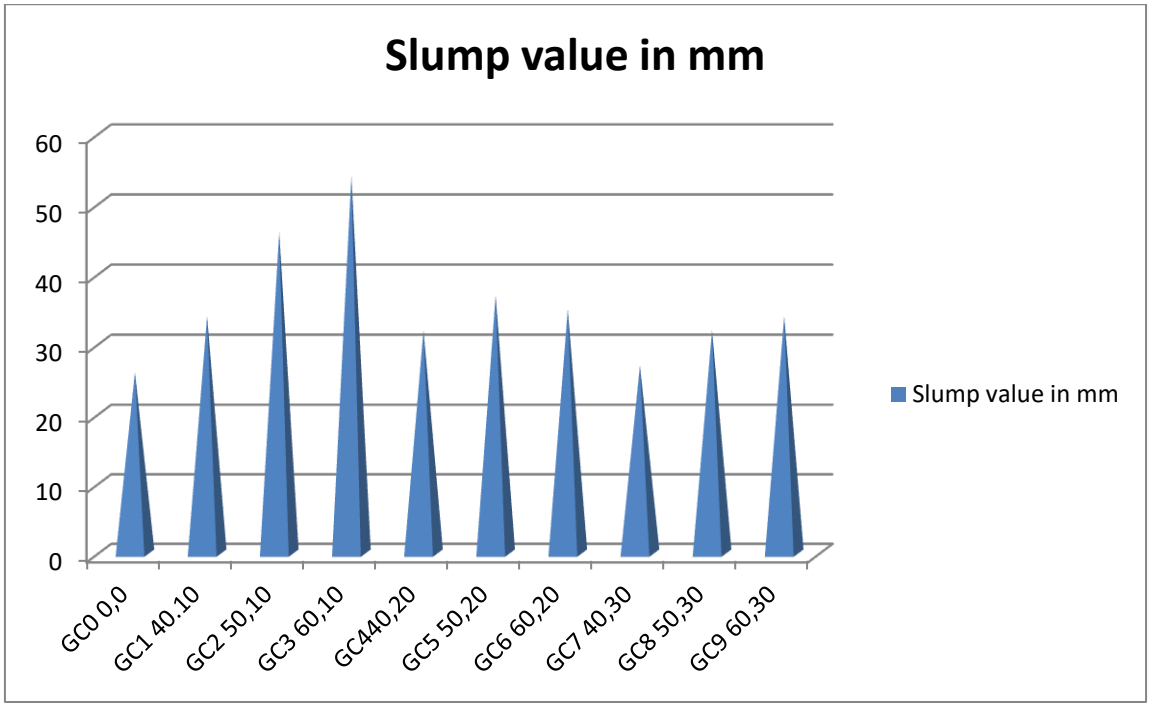


Figure 4. 8 Chart shows the slump value of concrete at different % of replacement

4.3.2 Hardened Concrete Test

4.3.2.1 Compressive strength

Fig. 4.8 presents the effect of bottom ash on the compressive strength of hybrid geopolymer concrete. It shows that the compressive strength of the specimens increased with the increased of bottom ash in the concrete up to 20% of level replacement. At the age of 7 days, GC5 gained its strength about 26% lower than control specimens. This may due to the pore refinery effect by pozzolanic reaction of bottom ash. Despite of the increase in porosity due to the replacement of bottom ash, the silica content in bottom ash particles enhance the formation of C-SH, a gel responsible for strength development [Mandal A, Sinha O. 2014]. The compressive strength of the bottom ash concrete starts to decrease when the replacement level increased to 30%. The excessive amount of bottom ash has produced porous concrete and reduces its compressive strength.

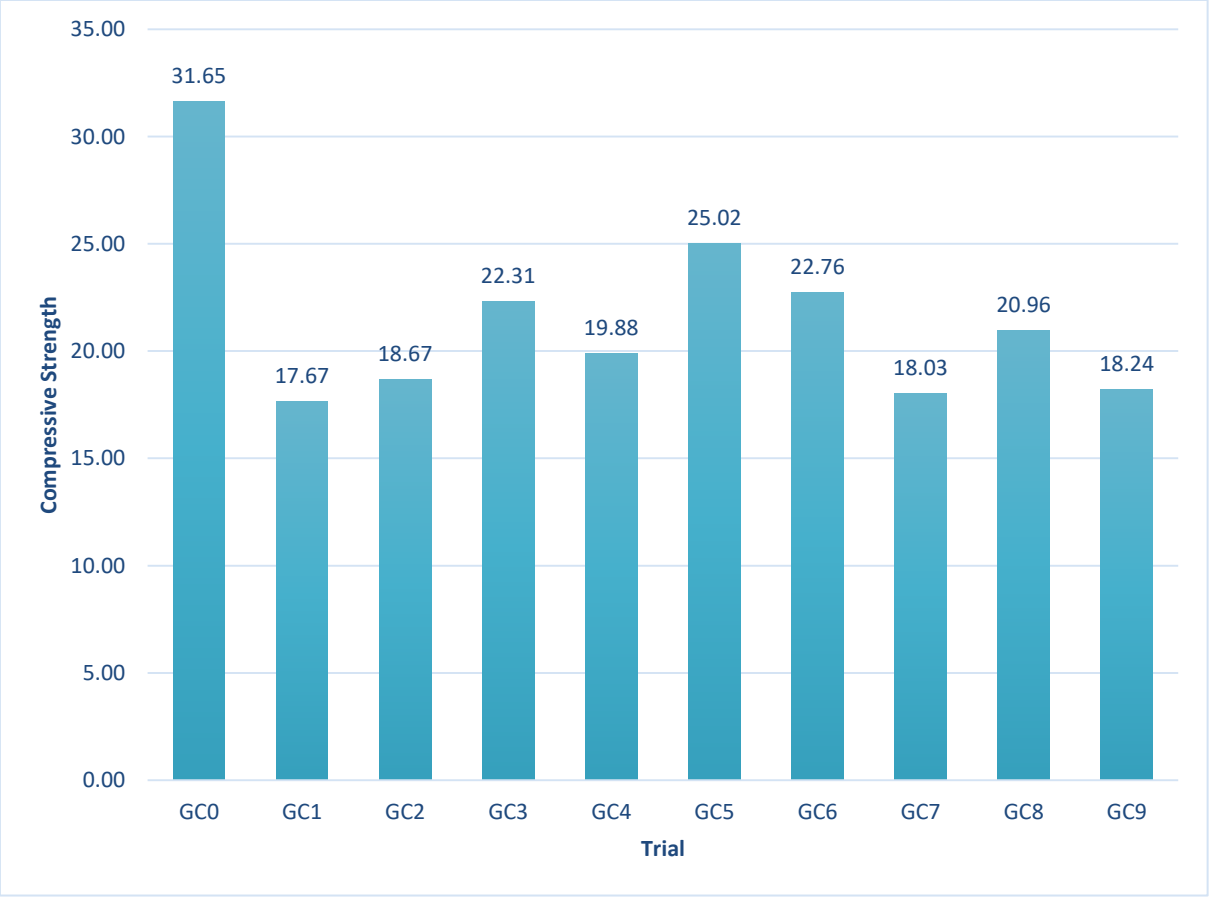


Figure 4. 9 Day 7 Compressive strength of specimens compared with the replacement amount

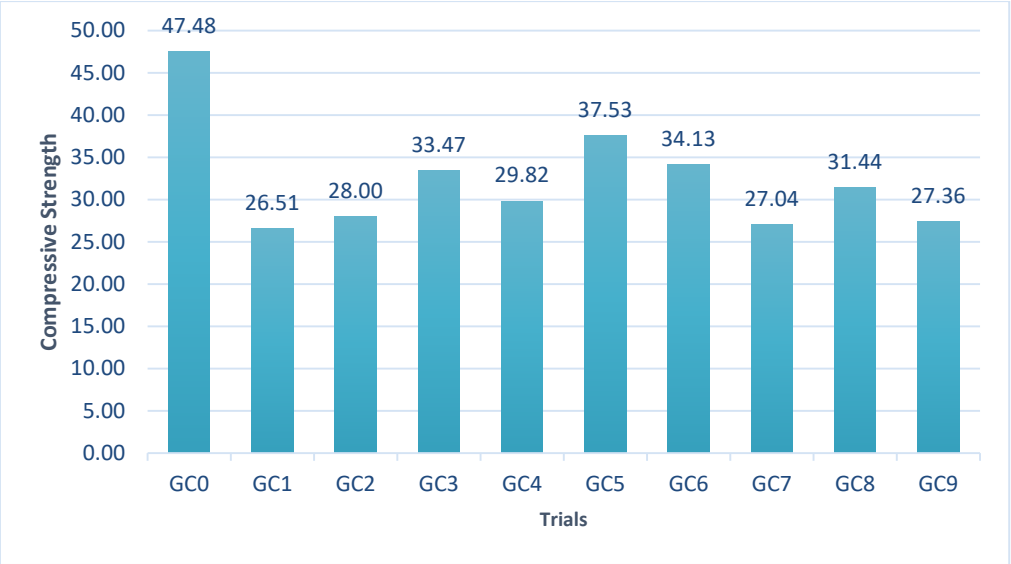


Figure 4. 10 Day 28 Compressive strength of specimens compared with the replacement amount

The average compressive strength of blended concrete increases with increasing the percentage replacement of incinerated municipal solid waste fly ash content at both the curing period. The probable reason for this is due to the high replacement of MSWI fly ash which has low calcium content by cement, thus reducing cement content of the mixture which in turn causes a reduction in the hydration reaction. In addition to this high content of MSWI fly ash resulted in a higher water requirement, making the water unavailable for the hydration of cement for further reaction. As a curing period increases, the compressive strength also increases at a constant mix proportion. The reason behind this, the pozzolanic effects of compressive strength enhancement is typically more pronounced in late age curing days than at an early age.

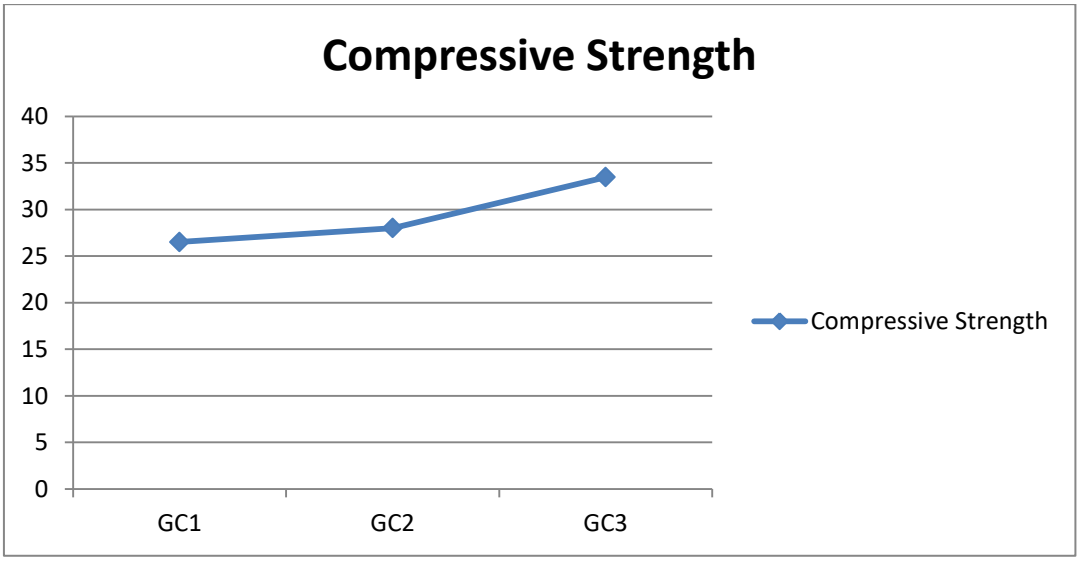


Figure 4. 11 Day 28 Compressive strength compared with Fly Ash replacement

4.3.2.2 Flexural strength

The flexural strength of all specimens was observed to exhibit the same behavior as compressive strength. The results of flexural strength of the specimens are shown in Fig. 4.10 From the figure, it is evident that flexural strength of hybrid geopolymer concrete with 20% replacement of bottom ash are higher compared to the other. At 7 days, an increase of 2.82% and 7.85% were observed for mixes GC5 and GC9, respectively comparison to the control mixture GC0. The same development was observed at the age of 28 days with mixes GC5 and GC9 showing increase of 3.74% and 11.09% respectively. However, the flexural strength of the specimen decreased when 10% and 30% replacement of bottom ash to sand were used in the concrete. it is evident that when the bottom ash mixing ratio increased, the degree of flexural strength reduction decreased. The decreased in flexural strength of the specimen as the replacement level of bottom ash increased is believed due to the poor interlocking between the aggregate, as bottom ash particles are spherical in nature [Marto A, Hasan M, Hyodo M, Makhtar AM.].

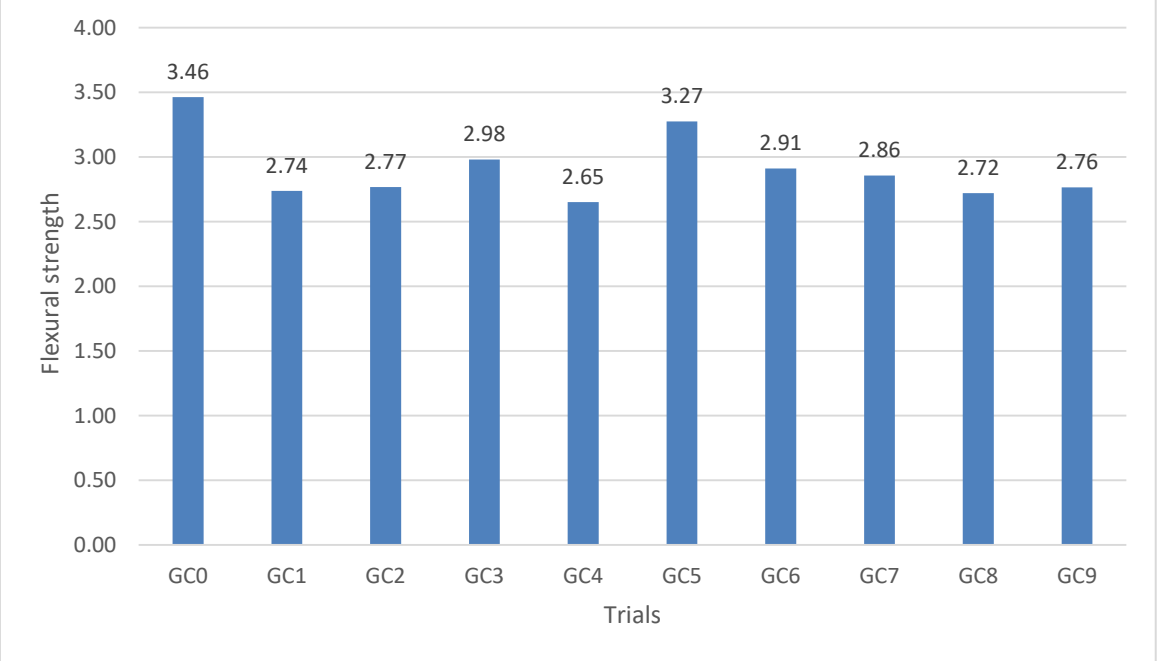


Figure 4. 12 Day 7 Flexural strength of specimens compared with the replacement amount

Concrete develops cracks when tensile forces exceed its tensile strength. That is why we use steel reinforcement in reinforced concrete because of reinforcement bar strong in tension but not in compression and therefore, it is necessary to determine the tensile strength of concrete to regulate the load at which the concrete members may crack. The tensile strength of concrete is one of the basic and important properties which greatly affect

the extent and size of cracking in structures.

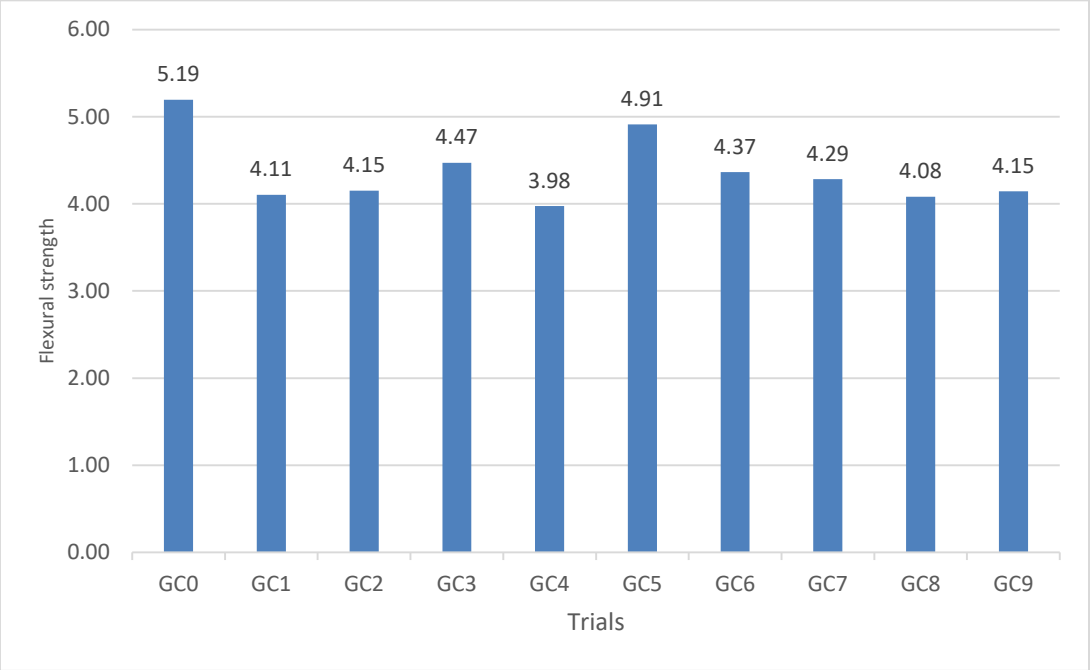


Figure 4. 13 Day 28 Flexural strength of specimens compared with the replacement amount

4.3.2.3 Permeability Test

Permeability indicates the penetration extent of water and other aggressive elements in concrete structures that could lead to corrosion, chloride-ion attack, and carbonation. The reduction in permeability could help to reduce the ingress of acidic ions in the GPC matrix, and consequently, enhance the resistance of concrete to the acid attacks. The control of concrete porousness is crucial as the entrance and diffusion of ions from the surroundings via construction materials are essentially responsible for the weakening of structures. Generally, the use of FA has been seen to lower the permeability and porosity of concrete; thus, enhancing its long-term performance. It also improves the workability of the concrete due to the lubricating effect provided by the spherical FA particles. But FA has a slow reactivity due to its a relatively lower surface area, and hence, retardation in the strength development. The inclusion of FA increases the heat of hydration as more water is available for the initial hydrolysis, thus, reducing the Ca2+ concentration in the pore solution. As a result, FA particles acts like a Ca2+ sink and depresses the calcium concentration, delaying the CH and C-S-H nucleation and crystallization. This in turn retards the hydration process; however, higher ultimate strength and better durability of the concrete is achieved at longer curing periods. Moreover, the addition of FA lowers the risk of cracking in structures and thus improves their life. The reduced permeability of FA-GPC

concretes also reportedly enhances its chloride ion penetrability and sulfate resistance. The water permeability of FA-GPC is largely dependent on the solution-to-ash (S/A) ratio with lower S/A ratio showing lower permeability and high compressive strength values. The pasteto-aggregate (P/A) ratio also affects the water permeability of FAGPC, but with a lesser influence. Higher the P/A ratio, higher will be the water permeability and lower the compressive strength. Both these parameters largely depend on the pore volume and the development of cracks inside the FA-GPC matrix. To be more accurate, shrinkage has been accounted the main reason for the occurrence of the cracks from the consumption of the pore solution during the polymerization process to the induced cracks appearing on the surface of the hardened FA-GPC.

Subsequently, it leads to a lower compressive strength and water permeability characteristics of the FA-GPC. The amount of macro-pores greater than 1 mm also governs the water and air permeability of FA-GPC. This mainly depends on the quantity of coarse FA particles: higher its concentration, more uneven the material distribution, leading to higher macro-porosity, subsequently, higher permeability of the FA-GCP. However, the addition of 10% of OPC in the FA-GPC has been proven to exhibit ‘‘low” to ‘‘very low” permeability values.

4.3.2.4 Water absorption test

The water absorption of FA-GPC is typically lower than that of OPC concrete, irrespective of any curing ages. This is mainly due to the formation of aluminosilicate gels in higher concentration which provides a very good inter-particle bond in the FA-GPC. Moreover, the addition of foam agent was also found to further lower the water absorption of the FA-GPC by about 6.8%. The water absorption of an alkali-activated FA geopolymer mortars was also observed to be lower than the OPC mortars when Na2O was utilized in proportion of 4%. Contrarily, FAGPC could also exhibit higher water absorption than the OPC concrete, mainly due to the incomplete geopolymerization process, resulting in higher voids within the GPC matrix. The use of recycled aggregates like RCA could also increase the water absorption of the FA-GPC in both immersion and capillary suction. For instance, the incorporation of 30% of RCA could increase the water absorption of the FA-GPC by about 16.8%; whereas, a drastic increase of 46% was noticed when 100% of RCA was utilized. In fact, the water permeability of GPC containing RCA was found to be about 2 to 5 times higher than of the OPC concrete at w/c ratios of 0.5 and 0.7, respectively. Nevertheless, it has been well documented in the literature that the water absorption of FA-

GPC is lower than the limit of 3% specified for good concretes.

4.3.2.5 Density

The density of the test sample at the age of the 7th and 28th day for the different levels or proportions of replacement was determined. The experimental test results show that the density of the hardened concrete decreases with increasing the amounts of incinerated municipal solid waste fly ash percentage replacement and this is due to the lower unit weight or specific gravity of incinerated municipal solid waste fly ash comparable to ordinary Portland cement. The reduction in the density of concrete helps to decrease the self-weight of the concrete in the determination of the design dead load of the concrete structural member to have reduced concrete cross-sectional dimension supporting the structural member and thus saves the amount of concrete volume relatively.

Table 4. 10 Weight of the Geopolymer concrete sample

Mix ID	Weight of beam(Kg)	Weight of cube(Kg)
GC0 0,0	**11.295**	**8.22**
GC1 40.10	**10.16**	**7.13**
GC2 50,10	**10.72**	**6.86**
GC3 60,10	**10.73**	**6.94**
GC440,20	**10.66**	**6.78**
GC5 50,20	**10.13**	**6.83**
GC6 60,20	**10.62**	**7.08**
GC7 40,30	**10.55**	**6.78**
GC8 50,30	**10.83**	**7.17**
GC9 60,30	**10.64**	**7.21**

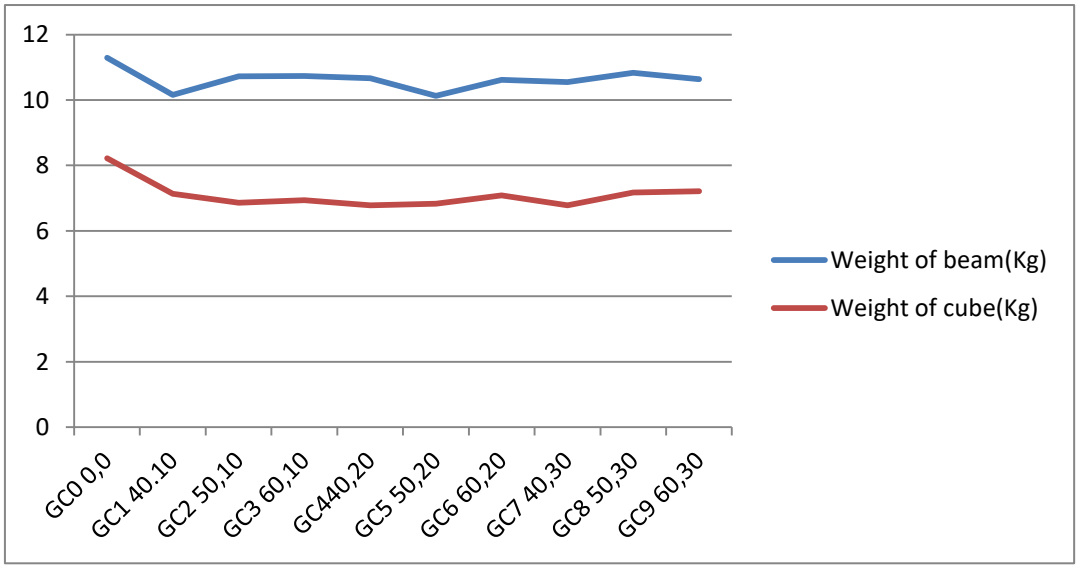


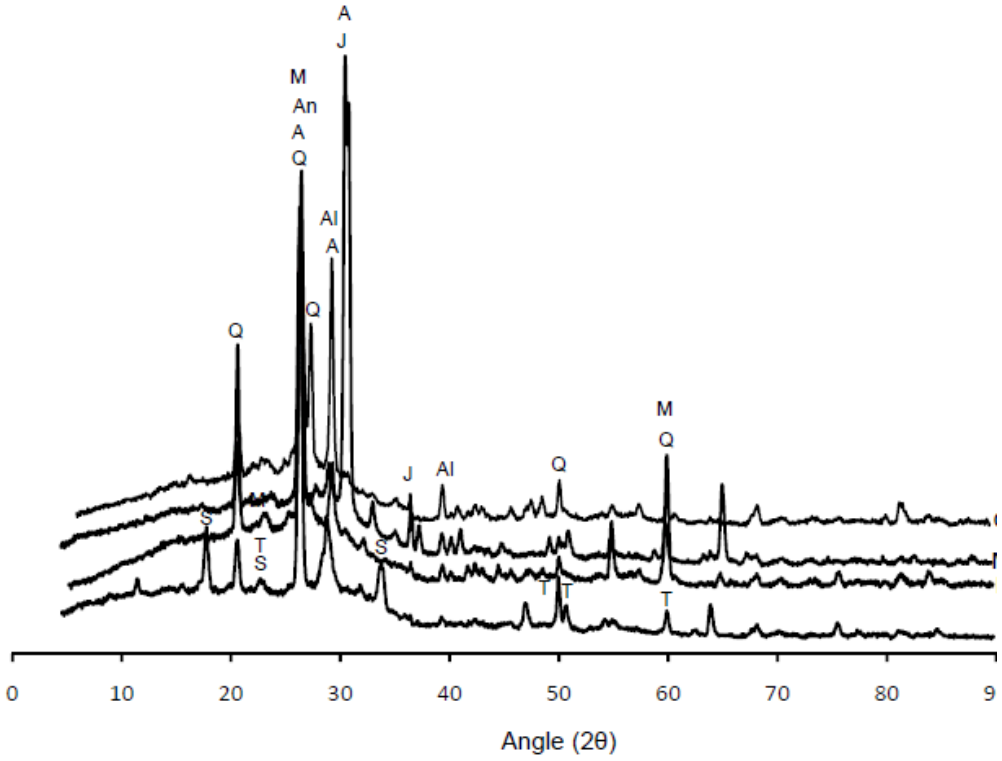
Figure 4. 14 weight of sample beam and cube

4.3.2.6 Microstructure of the concrete

The effect of OPC content on the microstructure of the one-part mixes was studied. Fig. 4.15 presents the microstructural images of the samples at 28 days of age using backscattered electron (BSE). As can be seen in the SEM micrographs, increasing the OPC content in the mix leads to a more compact and less porous structure. Meanwhile, there are less unreacted spherical fly ash particles in the matrix. Because of the inclusion of a large amount of OPC, mix GP60 shown in Fig. 4.15 also comprises both unreacted and partially reacted OPC particles as confirmed by the EDS results. Komnitsas also reported that, when the OPC concentration is high, microstructure porosity decreases for the formation of amorphous Ca-Al-Si gels, leading to increased strength. It can also be seen in Fig. 4.15 that unreacted or partially reacted OPC particles are rarely seen in the paste having 30% (GP30) or lower amount of OPC, which shows their participation in the formation of either geopolymer gel or a new gel. The microstructure of ambient cured GP0 contains both unreacted fly ash particles and geopolymeric matrix, demonstrating a loose and amorphous structure. The large amount of unreacted fly ash particles explain the very low compressive strength as confirmed by the compression tests. GP30 has a more compact microstructure with less unreacted fly ash particles with respect to GP0, GP10 and GP20, although it has a more porous microstructure than GP60 and GP40. For GP30, the major product of this low calcium content structure is geopolymeric gel surrounded by partial CSH gel in the entire network as was also observed previously.

Overall, the SEM images depict the coexistence of geopolymeric gel and CSH gel phases, showing a hybrid product like calcium alumino-silicate hydrate (CASH) as suggested by Garcia-Lodeiro et al. This will be further confirmed from the C/S ratios measured as follows.

GP30 has a more compact microstructure with less unreacted fly ash particles with respect to GP0, GP10 and GP20, although it has a more porous microstructure than GP60 and GP40. For GP30, the major product of this low calcium content structure is geopolymeric gel surrounded by partial CSH gel in the entire network as was also observed previously. This will be further confirmed from the C/S ratios measured as follows.



S - Syngenite, T – Thenardite, Q – Quartz, A-Analcime, An-Anorthite, M-Mullite, J-Jadeit

Figure 4. 15 XRD Analysis of geopolymer concrete

CHAPTER FIVE

CONCLUSION AND RECCOMENDATION

5.1 Conclusion

The research reported herein comprised experimental and analytical studies on the behavior and strength of fly ash-based hybrid geopolymer concrete. Low-calcium (ASTM Class F) dry fly ash obtained from a local power station(Repi west to power plant) was used as the source material to make geopolymer concrete. Sodium silicate solution and sodium hydroxide solution were mixed together to form the alkaline liquid. The silicon and the aluminum in fly ash reacted with the alkaline liquid to form the geopolymer paste that bound the loose aggregates and other unreacted materials to produce the geopolymer concrete. The aggregates consisted of 10mm and 7mm granite-type coarse aggregates, and fine sand. The mixture proportions and the manufacturing process used to make the geopolymer concrete were based on earlier research at Curtin (Hardjito and Rangan 2005).

Six hybrid geopolymer concrete beams and Six hybrid geopolymer concrete cubs were made and tested. The test results were compared with the predictions of methods of calculations available for cement concrete and the design provisions given in the Australian Standard for Concrete Structures AS3600 and the American Concrete Institute Building Code ACI318-02. The major conclusions drawn from this research are presented in the following Sections.

Beams were manufactured and tested. The beams were simply supported and loaded with two concentrated loads placed symmetrically over the span.

Cubs were manufactured and tested. The test cubs were subjected to eccentric compression in single curvature bending.

From the experimental and analytical studies, the following conclusions are made:

- The crack patterns observed for Hybrid geopolymer concrete beams were similar to those reported in the literature for Portland cement concrete beams. All beams failed in flexure in a ductile manner accompanied by crushing of the concrete in the compression zone.
- As expected, the cracking moment increased as the concrete compressive strength increased.
- The flexural capacity of test beams was calculated using the flexural design provisions contained in the draft AS3600 (2005). Good correlation is found

between the test and calculated ultimate bending moments.

- The measured service load deflections of test beams were compared with the values calculated using the serviceability provisions of draft AS3600 (2005). For the purpose of these calculations, the service load was taken as the failure load/1.5. Good correlation between test and calculated values is found.
- The study demonstrated that the design provisions contained in the draft Australian Standard for Concrete Structures AS3600 (2005) are applicable to hybrid geopolymer concrete beams.
- The crack patterns and failure modes observed for geopolymer concrete cubs were similar to those reported in the literature for Portland cement concrete columns. Flexural cracks initiated at column mid-height, followed by cracks along the length of the column. The mode of failure was flexural, as indicated by opening of the cracks and the crushing of the concrete in the compression zone in the mid-height region.
- The load capacity of test cubs were calculated using a simplified stability analysis proposed by Rangan (1990) for Portland cement concrete cubs, and the design provisions contained in Section 10.4 of AS3600 and Rule 10.12 of ACI318-02. Good correlation between test and calculated failure.

5.2 Recommendation

This study presents the properties of hybrid geopolymer concrete containing fly ash as geopolymer binder and bottom ash as aggregates replacement. The results show that bottom ash can be used as fine and coarse aggregates for making geopolymer concrete with 26.51–37.53 MPa compressive strengths. These hybrid geopolymer concretes had the densities of 1661–1688 kg/m^3, which were lower than geopolymer concrete containing natural aggregates (crushed limestone and river sand). The increase of NS/NH ratio decreased the slump of fresh concrete, compressive strengths, whereas the increase in L/A ratio increased the slump of fresh concrete.

This study recommends these two natural materials for their ability to substitute Portland concrete. Implementing the findings of this study can contribute to a greener environment worldwide by promoting using environmentally friendly materials. However, it should be noted that the scope of the current study is limited, as it does not include all durability tests for concrete.

For future investigation, this study recommends the following points

- Further research should investigate the water desorption capacity of fine aggregate Bottom ash.
- The test subject should be analyzed under natural curing conditions for more realistic results.
- The life cycle cost of the investigated concrete should be assessed in comparison with conventional concrete to evaluate its economic feasibility.

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APPENDIX

Appendix A: oxide composition of 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:-

Sample type :- SCBA/ASh

Sample Preparation: -200 Mesh

Date Submitted:- 24/03/2023

Issue Date:-03/04/2023

Request No:- GLD/RQ/1038/23

Report No:- GLD/RN/1620/23

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
HBD-11	52.44	14.13	2.96	1.96	0.78	1.36	2.28	0.06	0.66	0.45	2.31	10.68	500 gm

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

Analysts	Checked By	Approved By	Quality Control
Haimanot Bayeh Gadisa Wakuma Nigist Fikadu	Lidet Endeshaw	Yohannes Getachew	Negash Worku

Appendix B: Pictures taken during experimental works.

Appendix B1: Picture taken during Slump test

Appendix B2: Picture taken during Preparation of Alkaline Solution

Appendix B3: Picture taken during beam flexural test

Appendix B4: Picture taken during beam flexural test

Appendix B5: Picture taken during sieve analysis