Investigation of Physio-Mechanical and Micro-Structural Properties of Hybrid Geopolymer Concrete as Partial Replacement of Bagasse Ash with Cement

Heran Bogale Degefa

A Thesis Submitted to Department of Civil Engineering

School of Civil Engineering and Architecture

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

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

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Declaration and Recommendation

I hereby declare that this Master Thesis entitled "**Investigation of Physio-Mechanical and Micro- Structural Properties of Hybrid Geopolymer Concrete as Partial Replacement of Bagasse Ash with Cement"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation. It is being submitted for the partial fulfillment for the award of the degree of Master of Science in Civil Engineering (Specialization in Construction Engineering and Management) at Adama Science and Technology University School of Civil Engineering and Architecture.

Heran Bogale	______________________	_______________
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I/we hereby certify that I/we have read and evaluated this thesis entitled "**Investigation of Physio-Mechanical and Micro- Structural Properties of Hybrid Geopolymer Concrete as Partial Replacement of Bagasse Ash with Cement"** prepared under my guidance by Heran Bogale submitted in partial fulfillment of the requirements for the degree of Mater's of Science in in Civil Engineering (Specialization in Construction Engineering and Management). Therefore, I/we recommend that the candidate has fulfilled the requirements and hence he/she can submit the thesis to the department.

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I/we hereby certify that all the correction and recommendation suggested by the board of examiners are incorporated into the final thesis entitled "**Investigation of Physio-Mechanical and Micro- Structural Properties of Hybrid Geopolymer Concrete as Partial Replacement of Bagasse Ash with Cement**'' by Heran Bogale.

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ABSTRACT

The utilization of waste products made of aluminosilicate materials in the production of geopolymer concrete at heat curing is a solution that reduces the economic impact of cement production, since cement is considered one of the most expensive components of concrete production. Various researchers have investigated the applicability of Ordinary Portland Cement (OPC) in producing hybrid geopolymer concrete to overcome the problem of getting improved hardened concrete properties using pure geopolymer concrete at ambient curing temperature. However, the impact of replacing sugarcane bagasse ash (SCBA) with OPC in hybrid geopolymer concrete under immersion curing has not been studied yet. In this regard this study aims to investigate the effects of incorporating OPC as a partial substitute for SCBA in geopolymer concrete production. Factors such as workability, compressive strength, water absorption, sulfate attack, and microstructure, along with economic implications, were analyzed. In addition, the chemical composition of sugarcane bagasse ash was examined through complete silica analysis. To develop the concrete mix for C-25 concrete grade, the American Concrete Institute's mix design method was employed. The study consisted of producing two mixes: a control mix made up of cement, water, fine and coarse aggregate, and a replacement mix with varying weight percentages of OPC (5%, 10%, 15%, 20%, and 25%) substituted for sugarcane bagasse ash. The alkaline activator solution of sodium silicate and sodium hydroxide was utilized to activate the bagasse ash as a binder. Additionally, sugarcane bagasse is classified as a material with high silicon dioxide content and pozzolanic properties. As the OPC content increased in the concrete mix, the workability of the concrete decreased due to extra water demand. However, the compressive strength at 28 days of curing saw a 23.31% improvement for the 15% replacement mix compared to the control mix (100% OPC). The cause of the increase in the compressive strength of the concrete was due to the creation of semi hydrate gel and geopolymer gel. Therefore, a 15% replacement mix showed the best results in terms of compressive strength. Moreover, the pores inside the concrete matrix were filled due to CSH and geopolymer gel formation, leading to lower water absorption in the concrete with a 15% replacement mix. Furthermore, adding OPC to SCBA based geopolymer concrete was improve the sulfate attack resistance of the hybrid geopolymer concrete. The hybrid geopolymer concrete was analyzed microstructurally and compared to the control mix. The study found that the mix with a 15% replacement had calcium silicate hydrate gels and geopolymer gel. The study concluded that by utilizing OPC up to 15% as a partial replacement for sugarcane bagasse ash, the compressive strength of hybrid geopolymer concrete can be improved while also lowering the cost of cement manufacturing.

Keywords: *Concrete mix; sugarcane bagasse ash; geopolymer gel; cement; compressive strength.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURES PAGE NO.

LIST OF ACRONYMS

Acronyms	Full Name
FA	Fly Ash
RHA	Rice Husk Ash
MP	Mega Pascal
ACI	American Concrete Institute
SEM	Scanning Electron Microscope
IS	Indian Standard
CA	Coarse Aggregate
XRD	X-Ray Diffraction
OPC	Ordinary Portland Cement
CA	Coarse Aggregate
ASTM	American Society for Testing Materials
FA	Fine Aggregate
GGBF	Ground granulated Blast Furnace Slag
FM	Fineness Modulus
UWFA	Unit Weight of Fine Aggregate
UWCA	Unit Weight of Coarse Aggregate
SSD	Saturated Surface Dry
Bsg	Bulk specific gravity
Asg	Apparent specific gravity
EE	Embodied Energy
EEC	Embodied Energy Coefficient
SCBA	Sugar Cane Bagasse Ash
MJ	Mega jule
GPC	Geopolymer Concrete

LIST OF CHEMICAL FORMULAS

Formulas	Name of Chemical Compound
H_2O	Water
$2CaO.SiO_2$	Dicalcium Silicate
$3CaO.SiO_2$	Tricalcium Silicate
$3CaO.Al_2O_3$	Tricalcium Aluminate
$4CaO.Al_2O_3.Fe_2O_3$	Tetracalcium Aluminoferrite
$CaSO_4.2H_2O$	Calcium Sulphate hydrate
C-S-H	Calcium Silicate Hydrate
A-S-H	Aluminium Silicate Hydrate
CaO	Calcium Oxide
Na_2O	Sodium Oxide
Na_2SiO_3	Sodium Silicate
SiO_2	Silicone Oxide
Fe_2O_3	Iron Oxide
Al_2O_3	Aluminum Oxide
C-A-S-H	Calcium Aluminum Silicate Hydrate
MgO	Magnesium oxide
NaOH	Sodium Hydroxide
$Ca(OH)_2$	Calcium Hydroxide

1. INTRODUCTION

1.1 Background of the Study

Concrete is a highly versatile and frequently used material in the construction industry, playing a crucial role in the construction of various structures such as bridges, storage tanks, dams, seaports, tunnels, roads, and subways (Kiran & Kishore, 2017). Concrete usage across the world is second after water, due to its essential features, which include high compressive strength, durability, adaptability, availability, affordability, fire resistance, excellent thermal resistance, compatibility with steel reinforcement bars, and the ability to be cast in desired shapes (Thakur et al., 2018). Aggregate and paste make up the majority of its components. Sand, gravel, or crushed stone make up the aggregate, while cement, water, and other chemical or cementitious admixtures may make up the paste. The aggregates are bound together by the paste, which make up 70% to 80% of the concrete, and expected to affect the concrete's qualities because they make up most of the material (Trivedi & Shrivastava, 2020). Ordinary Portland Cement (OPC), one of the most often used building materials to make a paste in concrete, is expensive and requires a lot of energy to be produced. As a result, many efforts have been made to develop affordable materials. One of these methods is to use aluminosilicate (pozzolanic) wastes to create the cementitious binder without OPC, such as Geopolymer concrete (Singh et al., 2015).

Geopolymer concrete binders are a type of inorganic polymer that can be formed using industrial waste or by-products as source materials to form a binder that looks like and performs a similar function to conventional concrete. Geopolymer concrete can be used in applications to fully replace OPC with environmental and economic benefits. It is made from alumina and silicon, that usually produced by mixing pozzolanic materials with alkaline activators, such as sodium hydroxide and sodium silicate ($NaOH$ and Na_2SiO_3). Alkaline activators, $NaOH$ and Na_2SiO_3, activate the reaction in geopolymer concrete by breaking down the silica and alumina in the industrial byproducts used as substitutes for traditional Portland cement (Raijiwala & Patil, 2010). This results in the formation of aluminosilicate compounds that can bind together to create a strong and durable concrete material. Aluminosilicate source materials commonly used for this purpose are fly ash, bottom ash, cement kiln dust, silica fume, rice husk ash, ground granulated blast-furnace slag, and metakaolin (Niveditha &

Koniki, 2020). The temperature during curing is very important and depending upon the source materials and activating solution; heat often must be applied to facilitate polymerization.

Geopolymer binders differ from Portland cement in their setting mechanism which depends on polymerization rather than hydration. As a result, geopolymer can achieve their significant maximum strength within 3 to 5 days, depending on the curing effort applied (Niveditha & Koniki, 2020). Heat curing in an oven at above ambient temperature (40 to 90°C for 6 to 48 hours) is then applied to accelerate a polymeric reaction and gives strength to the final products. The characteristics of geopolymer concrete have been improved by the use of hybrid geopolymer concrete. There are several research on slag/fly ash and slag/metakaolin blends used in alkali-activated systems that have been published in the literature (Vinícius N. Castaldelli et al., 2013).The use of hybrid geopolymer concrete can enhance the mechanical and durability properties of the concrete (Khater, 2012).

It was reported that the amount of SiO_2, Al_2O_3, and Na_2O in any form of ratio affects the final properties of hardened geopolymer concrete. Therefore, the study of the optimum oxide ratio can be extendedly adjusted to maximize the benefit of hybrid geopolymer concrete in ambient curing conditions (Nath & Sarker, 2012). The amount of calcium in geopolymer mixes has a crucial role in regulating the setting time. According to reports, a calcium source that has been partially added, like calcium oxide (CaO), can increase the mechanical strength of low-calcium geopolymer concrete. Calcium mineral could lead to the formation of C-S-H or (C, N)-A-S-H gels within a polymeric binder and improve the overall properties significantly and be able to develop for control the setting time of geopolymer concrete at ambient curing temperature (Suwan & Fan, 2014). Several studies have been conducted recently to determine how to reuse industrial and/or agricultural wastes that are produced in large quantities in society; this strategy is in line with the concepts of sustainable development. Bagasse ash from sugar cane is the most significant volume of waste produced.

The drawback of the polymerization process when utilizing sugarcane bagasse ash is that it may acquire high compressive strength under the condition of high curing temperature for a period of one to two days. This is now thought to be wasteful and challenging to apply for construction work, and the ambient curing process and achieving a suitable compressive strength should be the main goals in the development of SCBA hybrid geopolymer concrete (Trivedi & Shrivastava, 2020).

In the current study, the SCBA based hybrid geopolymer concrete mixture was mixed different percentage of OPC. An experimental investigation was carried out to examine the impact of adding OPC to the mechanical and physical properties of SCBA based hybrid geopolymer concretes such as consistency, workability, compressive strength, and durability under immersion curing. In addition, micro-structural tests were performed. Moreover, the economic feasibility of SCBA based hybrid geopolymer concrete was evaluated.

1.2 Statement of the Problem

Concrete is typically costly due to the presence of an expensive component, which is cement, and the energy-intensive and expensive processes involved in its production. Extensive research has been carried out to explore cost-effective alternatives to replace OPC, mainly or entirely, with pozzolanic wastes such as fly ash, bottom ash, kiln dust, and GBFS (Suwan et al., 2016). Numerous studies have examined OPC-free cementitious materials, like geopolymer concrete, due to their use of pozzolanic waste materials with alkaline activators.

Geopolymer concrete (GPC) is currently manufactured as precast reinforced-concrete products, but heat curing is necessary for effective mechanical properties. Incorporating calcium source materials in geopolymer concrete (GPC) has been receiving significant attention in developing geopolymer under moist curing conditions to overcome the limitations associated with using curing units and to improve convenience in practical applications. Calcium source materials like $Ca(OH)_2$, CaO, steel slag, and high calcium fly ash can enhance calcium content in GPC (Singh et al., 2015; Suwan et al., 2016). However, the mechanical properties of these systems cannot match those of fully hydrated Portland cement or fully heat-cured geopolymer cement. OPC has been selected as a calcium source material for these GPC production for its wide commercial availability, potential energy compounds, and dependable uniformity and quality, adhering to established standards.

Adding OPC in geopolymer concrete is often categorized as geopolymer-Portland concrete (GeoPC) or hybrid geopolymer concrete when used as an additional material in GPC. It has been found that the alkaline activator and the calcium mineral in OPC can interact, resulting in a rise to good strength and reducing the paste's setting time. Various researchers have undertaken several investigations on the applicability of OPC in the production of hybrid geopolymer concrete (Hongen Zhang et al., 2019; Khater, 2012; Nath & Sarker, 2012). However, the impact of replacing sugarcane bagasse ash (SCBA) with OPC in hybrid geopolymer concrete under immersion curing has not been studied yet. This study aims to fill this gap by looking at how OPC affects concrete when used as a partial replacement for SCBA. The study examined the characteristics of both fresh and hardened concrete with varying percentages of OPC used as a replacement for SCBA.

1.3 Objectives of the Study

1.3.1 General Objective

The main objective of this research is to investigate the physio-mechanical, durability and microstructural properties of C-25 sugar cane bagasse ash (SCBA) hybrid geopolymer concrete.

1.3.2 Specific Objectives

- To characterize material in SCBA Hybrid geopolymer concrete.
- To investigate the fresh properties of SCBA based hybrid Geopolymer concrete in comparison to conventional concrete.
- To investigate the mechanical properties, durability properties, and microstructure of SCBA Hybrid geopolymer concrete.
- To determine the economic aspects of SCBA Hybrid geopolymer concrete.

1.4 Significance of the Study

This study suggests that using bagasse-ash hybrid geopolymer concrete can effectively reduce waste while also reducing construction expenses and promoting environmental sustainability. Hybrid geopolymer concrete has the potential to increase strength and durability of concrete while decreasing the amount of cement needed, which helps prevent waste accumulation of bagasse ash. Furthermore, this study can serve as a valuable resource for other researchers in the field.

1.5 Scope of the Study

In summary, this study aimed to examine the physical, mechanical, and microstructural properties of bagasse ash hybrid geopolymer concrete of strength class C-25. The research involved analyzing the chemical properties of SCBA and the physical characteristics of the materials used in making concrete. The effect of OPC on the SCBA based geopolymer concrete's workability was also assessed. Additionally, the study involved casting, curing, and conducting compressive strength and durability tests on the concrete sample on the 7th, 14th, and 28th days using specific combinations of bagasse ash, OPC, and an alkaline solution of 2.5:1 ratio of sodium silicate to sodium hydroxide with a concentration of 12M of sodium hydroxide. The results were then compared to a control concrete specimen.

1.6 Organization of the Thesis

Essentially, there were five chapters in the study. Background information, the problem statement, the objectives, the Significant of the study, and the study's scope are all introduced in the first chapter. The second chapter was mainly a literature review that stated the study's focus. This section covers reviews on concrete ingredients; the meaning of geopolymer concrete; factors affecting the SCBA based hybrid geopolymer concrete; mechanical and microstructural properties of SCBA geopolymer concrete; economic feasibility; and research gaps were covered. The third chapter discusses the materials utilized and the experimental methodologies used to conduct various experiments. The fourth chapter contains the results of various tests as well as their discussion. Finally, the final chapter presents the study's conclusion and a researcher's recommendation.

1.7 Summary

In this chapter, the background and statement of the problem have been presented. Further, the study aim, associated objectives, scope of the study, significance of the study, and the organization of the thesis to achieve these objectives have been briefly presented. The literature review and the areas of previous research that need to be filled have been described in the following chapter.

2. LITERATURE REVIEW

2.1 Introduction

To develop a better understanding of the research objective, a comprehensive literature review has been conducted to identify the different approaches that researchers have taken to address geopolymer concrete and hybrid geopolymer concrete as part of the current study process. The general purpose of this chapter is to provide an extensive review of recent papers on geopolymer concrete. In addition, the study gap was identified. Besides this, factors affecting geopolymer concrete and different micro and macro-level tests are extensively covered.

2.2 Concrete and its Ingredient

Concrete is one of the most important building materials among all the materials used in construction, and it is the material that is most easily accessible worldwide. The production of concrete has expanded to meet the rising demand for construction activities (Kiran & Kishore, 2017). Concrete is composed of cement, fine and coarse aggregates, water, chemical additives, and extra cementitious materials as required (Lloyd & Rangan, 2010). Types of concrete, strength, and density, as well as the end products' chemical and thermal resistance, are all directly influenced by the composition of the binders and the type of aggregates utilized.

2.2.1 Cement

Binder (Cement) is the material that is used most frequently worldwide next to the water. It is a crucial part of building infrastructure and the most significant input for the construction sector, especially in infrastructure and housing programs, which are essential for socioeconomic development (Lamba et al., 2021). Cement plays a central role in concrete by providing an inert medium (the cement paste) in the plastic state and by ensuring proper bonding between the different ingredients, and also with the reinforcement, after hardening (Srinivas et al., 2017). It is primarily prepared by combining predetermined proportions of calcareous material such as limestone or chalk and silica and alumina commonly found as clay or shale.

There are different types of Cement depending on their composition, method of manufacturing (grinding, burning, etc.), and also the relative proportion of the different compounds, such as Ordinary Portland Cement (OPC) which is used for all types of construction, such as foundation, walls, and slab. Rapid-Hardening cement which maximum strength obtained in 3 Days. This cement is more fine-grained and contains a higher proportion of 3 $CaSiO_2$. RHC is used in special Constructions where an early strength is required. Low-Heat cement has lower line content and higher silica and iron Content than ordinary Portland cement. The heat of hydration is generated much more slowly and is about one-third less than that of OPC. LHC is used in Massive structures like dams. Pozzolana Portland (PPC) – is made by mixing pozzolanic material with OPC Clinker and grinding them together in the cement mill. It is used in seashore construction, as it is more resistant to sulfates and the corrosive action of seawater. Quick setting cement (QSC) – doesn't contain gypsum and consequently sets and hardens within 30 minutes. It is used for underwater construction.

One of these types and the most commonly used one is Portland cement. It is a controlled blend of aluminates, ferrates, and calcium silicates that are ground to a fine powder with gypsum and other materials.

2.2.1.1 Ordinary Portland cement (OPC)

Modern Portland cement is made using substances that must have the appropriate proportions of lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron (Fe_20_3), with just trace amounts of magnesia and sulfur trioxide. Because they make up over 90% of Portland cement, these four principal compounds govern the hydraulic properties of cement (Prabhath et al., 2022). Portland cement is one of the most widely used cement and is the most important hydraulic cement.

Cement is primarily composed of alite (C_3S), belite (C_2S), aluminate (C_3A), and alumino ferrite (C_4AF). Despite such low percentages, minor additives can still significantly affect the characteristics of both freshly made and cured cement paste. Since then, there have been advancements made to the cement-making process, but the fundamental steps have stayed the same. The typical composition of Ordinary Portland Cement (OPC) is listed in Table 2.1.

Table 2. 1 Composition of Ordinary Portland cement

Chemical Compound	Abbreviation	Oxide composition
	Major compounds	
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF
	Minor compounds	
Gypsum	$CaSO_4.2H_2O$	CSH_2
Magnesium	MgO	M
Alkali Oxides	Na_2O and K_2O	N, K

2.2.1.2 Cement Hydration

The term "hydration" refers to the physical and chemical reactions that take place when cement and water are combined. Because it is responsible for the setting and hardening of concrete, cement hydration is crucial. A chemical process changes the cement from a powder to a cohesive matrix with substantial strength that binds the aggregate particles. Portland cement and water undergo an exothermic chemical reaction (Richardson, 2000). Both C_3S and C_2S react with water to produce an amorphous calcium silicate hydrate known as C–S–H gel which is the main 'glue' which binds the sand and coarse aggregate particles together in concrete. When water and Portland cement are mixed, the constituent compounds of the cement and the water undergo a chemical reaction resulting in the hardening of the concrete (Bogale, 2007). Each of the compounds found in the cement reacts with water, but the rate at which they react is different. C_2S and C_3A are the most reactive compounds, whereas C_2S reacts much more slowly.

2.2.1.3 Normal Consistency Test of Cement

The quantity of water required to achieve a normal consistency as defined by the penetration of 10 ± 1 mm of the Vicat plunger (ASTM C 187) is expressed as a percentage by weight of the dry cement, the usual range being about 26% to 33%. The test is highly dependent on the environmental factors that are present, particularly the temperature and how tightly the cement is packed inside the molds. The test simply assesses the plasticity of cement paste and does not assess the quality of the cement.

2.2.2 Coarse and Fine Aggregate

Aggregates are the most fundamental components of concrete, occupying around 60 to 80 % of the total volume of concrete. The properties of fresh and hardened concrete are directly affected by the quality of the fine and coarse aggregates. Better quality aggregates should consist of particles with adequate strength and desirable properties such as resistance to exposure conditions. Fine aggregates (less than 4.75 mm) and coarse aggregates (more than 4.75 mm) must be graded in the production of concrete (Ukala, 2019).

Fineness Modulus of Fine and Coarse Aggregate

Aggregate grading is the term used to describe the particle size distribution of an aggregate. Grading is the process of filling in the spaces left by larger particles. Graded aggregate can be used to create dense concrete with less fine aggregate and cement. Sieves with mesh sizes of (20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan) (Table 2.2) are used to grade coarse material (Haque et al., 2012). Moreover, for grading fine aggregate, IS sieves with the following specifications are used: 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm, 0.15 mm, and pan (Table 2.3).

Table 2. 2 Coarse Aggregate Grading Limit

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

Table 2. 3 Fine Aggregate Grading Limit

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

Specific Gravity and Water Absorption of Fine and Coarse Aggregates

Specific gravity is defined as the mass of a unit volume of aggregate divided by the mass of the same volume of water at a certain temperature. It's a non-dimensional value that's used to assess material strength and quality. To distinguish between unwanted particles that are lighter than other particles and excellent aggregates, specific gravity is used. It's used to calculate the amount of solid aggregate in a concrete mix (Zaniewski et al., 2012).

Silt Content of Fine Aggregate

Sand typically contains clay, silt, loam, and dust. Materials with a thickness of 0.06 mm to 0.002 mm are classified as silt (Ayodele & Ayeni, 2015). Concrete's compressive strength and long-term durability are impacted by sand that contains such particles. In comparison to other fine aggregates, silt is less durable. They may absorb water and alter its characteristics. Silt will inhibit aggregates in concrete from adhering to cement. The silt in the air spaces of hardened concrete may shrink or swell when it comes into contact with water, increasing internal pressure or creating larger voids and weakening the concrete. However, if there is too much silt or clay in the concrete, which shouldn't be more than 4%, it might cause huge fractures or unsightly hairlines (Zimar et al., 2017). More than a certain amount of silt or clay in fine aggregates necessitates the use of additional cement to coat other concrete components.

2.2.3 Water

Water is one of the main components of concrete, that actively participates in the chemical reaction with cement (Shabalala & Ekolu, 2019). The cementitious gel that gives concrete its strength is formed as a result of it. When using water to produce concrete, the quantity and quality of the water should be carefully assessed (Kurdowski, 2014). The quality of cement paste is determined by the water-to-cement ratio. Water and cement interact chemically to provide hydration, a complete chemical reaction that is prevented by a shortage of water.

2.2.4 Concrete Mix Design

Concrete mix design is a composite and multistage process, to find the proper composition of ingredients to make concrete with the required quality. The designer decides on the design mix ratios after analyzing the properties of each ingredient used. It is required to conduct mix design using advanced mix design methodologies because concrete mix design can have very broad parameters that cannot be addressed by simple nominal mixes (Ziolkowski et al., 2021). There are various mixed-design methodologies; the American Concrete Institute methodologies are the most popular (ACI). The predicted weight of the concrete per unit volume serves as the foundation for the ACI technique of concrete mix design. This method takes into consideration the requirements for consistency, workability, strength, and durability (Pachipala, 2017). The concrete building is more affordable when the concrete mix design is precise. Because huge buildings like bridges and dams require a lot of concrete, using the right amount allows for an economical structure (Kant Sahdeo et al., 2020).

2.2.5 Concrete Batching

Concrete batching is the process of weighing or volumetrically proportioning the various components of concrete (cement, sand, coarse aggregate, and water) before mixing (Joshua et al., 2018). According to a study on concrete (Hedidor & Bondinuba, 2017), the volumetric batching method for producing concrete is a poor building practice.

2.2.6 Fresh Concrete Test

2.2.6.1 Slump Test

The slump test is used to determine the consistency of fresh concrete before it hardens. Concrete workability refers to how easily fresh concrete mixtures may be handled, poured, compacted, and finished without components separating. It is deemed feasible if freshly mixed concrete can be compacted, finished, and given its final shape and texture with the least amount of labor while maintaining structural integrity. Fresh concrete's processing capacity is influenced by the mixture's cohesiveness and consistency, which are influenced by the cement content, aggregate quality, water content, and chemical additives (Daniel, 2006).

2.2.7 Concrete Casting and Curing

During curing, the cement must be given the right amount of moisture, heat, and time to continue hydrating until the concrete has the appropriate qualities. Curing hardened concrete increases its strength, tensile strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing (Mac-Eteli & Sopakirite, 2021).

Among the curing techniques are immersion, spraying, and moist coating (Krakowiak et al., 2015) This study uses the immersion curing procedure in water to evaluate the features of hardened concrete.

2.2.8 Hardened Concrete

A building material that really can support structural and service loads, hardened concrete is one of the most robust and long-lasting materials currently accessible. Compressive strength and durability are characteristics of hardened concrete.

2.2.8.1 Strength of Concrete

Concrete's strength, which indicates the greatest load it can support without failing, is a crucial characteristic. Flexural strength, compressive strength, and split tensile strength are the three methods used to determine the strength of concrete. While flexural strength and tensile strength upon separation are measurements of concrete's tensile strength, compressive strength is a measure of the failure of cubes under compression. Concrete's tensile and flexural strengths are somewhat less than its significant compressive strength.

Compressive strength is the capacity of hardened concrete to withstand axial pressures without deflection or fracture. Concrete's compressive strength is calculated by dividing the failure force by the cross-sectional area that is resisting the load. Compressive strength is a widely employed measure to evaluate how well a concrete mixture performs. This concrete component must be taken into account since it determines how well concrete can support loads that affect its size. It indicates whether a particular mix is suitable to fulfill the requirements of a particular project. Concrete is especially resistant to compressive loads (Dadhich et al., 2014). For this reason, it can be used to construct columns, dams, foundations, and tunnel linings. The amount of cement and aggregate quality used have a significant impact on the compressive strength of concrete. In addition, it is influenced by the water-to-cement ratio, correct mixing, and pouring (Beycioglu et al., 2017). The degree of hydration and curing techniques also have an impact on the compressive strength of concrete (Ogunjiofor et al., 2017).

2.2.8.2 Durability of Concrete

The ability of concrete to survive weathering, chemical attacks, abrasions, and other disintegrating processes is what is meant by the term "durability." This feature of concrete extends its life of the concrete by preventing the entry of moisture, which may contain harmful substances, as well as the flow of water during heating and freezing (Goshu, 2019).

2.3 Geopolymer

According to Geopolymer Institute (2010), the name geopolymer was formed by French Professor Davidovits in 1978 to represent a broad range of materials characterized by networks of inorganic molecules. The geopolymer depends on thermally activated natural materials like Meta kaolinite or industrial by-products like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). These Silicon and Aluminium are dissolved in an alkaline activating solution and subsequently polymerize into molecular chains and become the binder (Geopolymer Institute, 2010). Geopolymer is a material produced by inorganic poly-condensation, i.e., by so-called “polymerization.” The process comprises the dissolution of aluminosilicate followed by condensation of free silicate and aluminate species to form a three-dimensional structure of silicon-aluminate structures (Raijiwala & Patil, 2010).

Geopolymer concretes are produced by the polymerization process. The polymerization process involves a substantially fast chemical reaction under alkaline conditions on Si- Al minerals, which results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. This polymerization process can be seen in the step-by-step reaction below.

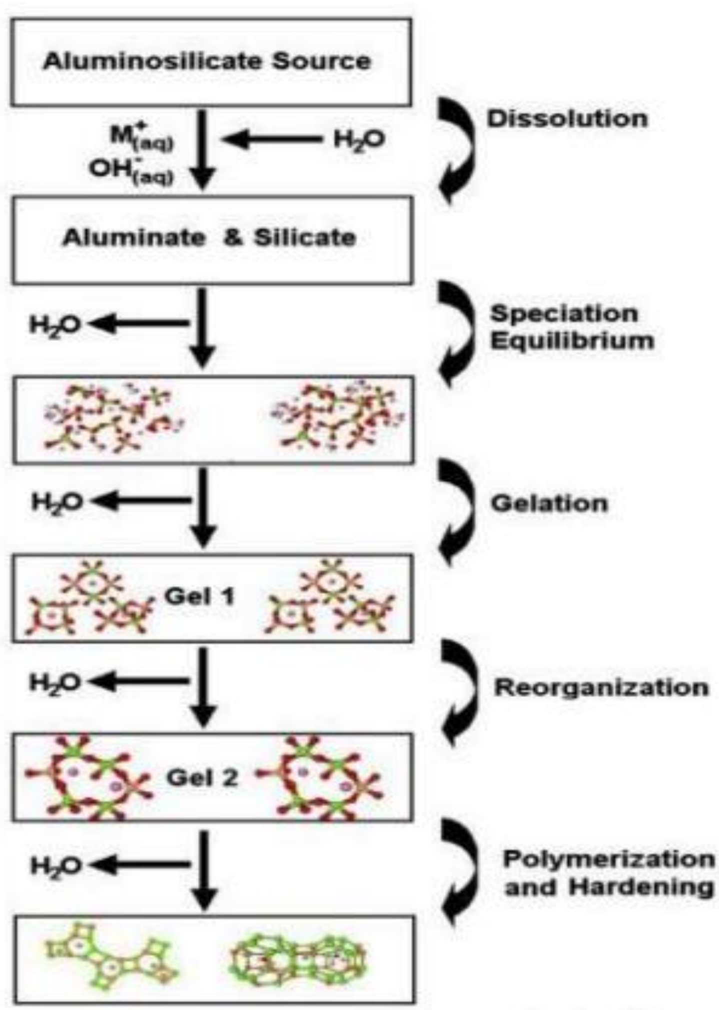


Figure 2. 1 Polymerization process

Davidovits (2013) studied Geopolymer cement as an innovative material and a real alternative to conventional Portland cement for use in transportation infrastructure, construction, and offshore applications. It relies on minimally processed natural materials or industrial by-products to significantly reduce its carbon footprint and energy usage, while also being very resistant to many of the durability issues that can plague conventional concretes. Their unique properties include high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance, and corrosion resistance, making them ideal for long them containment in surface disposal facilities (Singh et al., 2015). Geopolymer concrete is typically made from a combination of source materials such as fly ash, blast furnace slag, or rice husk ash, along with alkaline activators such as sodium hydroxide or potassium hydroxide. Water is also used in the production process to help with mixing and form the chemical bonds that give the concrete its strength. The specific composition of the mix can vary depending on the desired properties of the final product (Raijiwala & Patil, 2017).

2.3.1 Constituents of Geopolymer Concrete

2.3.1.1 Aggregate

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. (Rangan, 2008) stated that combined aggregate was used in Geopolymer concrete. Local aggregates comprising 20mm (0.78 inches), 10 mm (0.39 inches), and 7mm (0.273 inches) coarse aggregates in saturated surface dry (SSD) condition were used. The coarse aggregate (CA) was crushed granite and basalt-type aggregates Fine aggregates used are mostly locally available grit sand and river sand. The coarse and fine aggregate used by the concrete industry is suitable to manufacture Geopolymer concrete. A coarse and fine aggregate of approximately 75% to 80% of the entire mixture by mass is used in a geopolymer concrete mixture; this value is similar to that used in OPC concrete.

In a geopolymer concrete mixture, the coarse and fine aggregates must not be too dry to absorb water from the entire mix or too wet to add water to the mixture. Aggregates may contain water in practical applications, in addition to the SSD condition. As a result, while calculating the ratio of the water-to-geopolymer solid, the additional water in the aggregates over the SSD requirement must be taken into account.

2.3.1.2 Source Materials

For geopolymer based on alumina-silicate, the source materials should be abundant in silicon (Si) and aluminum (Al). These might be organic minerals like kaolinite, clays, etc. As an alternative, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. could be used as source materials. The selection of the raw materials used for producing geopolymer is influenced by several factors, including cost, the type of application, and end-user demand (Rangan, 2008).

2.3.1.3 Alkaline Activator Solution

Activators such as sodium silicate are crucial to the polymerization process. When soluble silicate is present in the alkaline activator, reactions occur rapidly. The soluble alkali metals that are used to make the alkaline liquids are typically sodium-or potassium-based. In polymerization, sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (SiO2) or potassium silicate are the most frequently utilized alkaline liquids (Rangan, 2008).

Alkaline activators, such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (or potassium silicate), are frequently employed in the production of geopolymer concrete. When soluble silicate is present in the alkaline activator, reactions occur rapidly. The way that source material dissolves depends on the kind and concentration of the solution. In general, NaOH solution leaches Al^{+3} and Si^{+4} ions more readily than KOH solution. Therefore, alkali concentration plays a key role in regulating the polymerization process of alumina and silica from source material particles as well as the strength of hardened geopolymer concrete (Rangan, 2008). The alkaline activator concentration used in geopolymer concrete can have a significant impact on the properties of the final product. In general, higher alkaline activator concentrations can result in faster reaction times and stronger, more durable concrete. However, the optimal concentration will depend on the specific materials used and the desired properties of the final product. If the alkaline activator concentration is too low, it can impact the setting time and strength development of the geopolymer concrete. On the other hand, if it is too high, it can lead to issues such as excessive heat development during setting or a decrease in workability (Sathisa & Mamatha, 2015).

Hardjito et al. (2004) studied a combination of sodium silicate solution and sodium hydroxide (NaOH) solution that can be used as an alkaline liquid. It is recommended that the alkaline liquid is prepared by mixing both solutions at least 24 hours before use. The sodium hydroxide with 97-98% purity, in flake or pellet form, is commercially available. The solids must be dissolved in water to make a solution with the required concentration (Memon et al., 2013).

Figure 2. 2 Sodium silicate and Sodium hydroxide pellets (alkaline activators)

2.3.2 Mix Design of Geopolymer Concrete

A novel binding substance called geopolymer is created when a source material reacts with an alkaline solution. No Portland cement is used at all in geopolymer mortar (Hardjito & Rangan, 2005). The key difference between geopolymer and Portland cement concrete lies in their binders. Geopolymer paste binds the coarse and fine aggregates, as well as other unused ingredients together, resulting in geopolymer concrete. This paste is created by the reaction of silicon and aluminum oxides with an alkaline liquid. In both geopolymer and Portland cement concrete, the coarse and fine components make up approximately 75-80% of the mixture's total weight (Gupta et al., 2017).

A few mixed-design methodologies have been proposed earlier for GPC. Of them, Saloma et al., (2016) were propose a mix design methodology for fly ash-based geopolymer concrete. This method fixed the total aggregate content at 80% and assumed that GPC had a density of 2400 kg/m3. The total mass of fly ash and alkaline activator solution was determined by subtracting the total aggregate content from the 2400 kg/m3 density that was estimated. As a result, the ratio of the activator solution to the fly ash was used to calculate the fly ash content. Additionally, based on the Na_2SiO_3/NaOH ratio used, individual sodium silicate and sodium hydroxide contents were calculated. Finally, water-to-geopolymer solid ratios were used to calculate the specified compressive strength and workability. This method's primary shortcoming is that it neglects the specific gravity of the materials being employed.

Pavithra et al. (2016) suggested a design procedure using Indian specifications for several grades of GPC. In this procedure, the fly ash content and the activator solution to fly ash ratio were chosen based on the needed strength and by keeping the same fine aggregate percentage. The content of the activator solution used was found to be excessive for the designated strength.

Ferdous et al. (2013) considered the concrete density variability, material-specific gravities, air content, workability, and strength requirements to suggest a mixed design for fly ash-based GPC. The key challenge in their design process may be choosing the activator solution to fly ash ratio and figuring out the precise activator solution content about the fly ash content. The alkaline solution is an expensive component in GPC, so its use must be limited while maintaining the appropriate strength and workability from the perspective of economic design. Owing to the limited study on GPC mix design, no one method takes into account all the crucial factors.

Therefore, this technique has made an effort to provide a mixed design procedure that considers the shortcomings of the earlier proposed methods. Without sacrificing the desired strength and workability, a strong emphasis has been placed on cutting costs.

2.3.3 Properties of Geopolymer Concrete

2.3.3.1 Water Absorption

The concrete's capacity to absorb water has a significant impact on how long a structure will last. Concrete deteriorates when water enters it, and in structures made of reinforced concrete, corrosion of the bars caused the concrete to crack and spell. This shortens the structure's lifespan. The outcome suggests that geopolymer concrete absorbs less water than control concrete. Nevertheless, the difference in weight increase percentage is relatively small. The findings of the water absorption test reveal that the geopolymer concrete has less porosity than control concrete since fly ash is finer than OPC and has a lower water absorption rate (Luhar & Khandelwal, 2015).

2.3.3.2 Compressive Strength

The ability of the material to withstand some of the imposed load was assessed using compressive strength. The compressive strength of geopolymer concrete is made under heat and ambient curing conditions with various fly ash and aluminum fine contents. It was shown that increasing the fly ash content from 350 to 400 kg/m3 under ambient curing caused the early age (7 days) compressive strength of GPC to increase from 7.5 MPa to 14 MPa. When cured at ambient temperature, the compressive strength increased significantly over 28 days, rising to 25 MPa from 14 MPa (Jindal et al., 2018).

2.3.3.3 Scanning Electron Microscope (SEM)

The SEM data demonstrated that smaller particle size distributions densified the microstructure and accelerated the polymerization process. A smaller particle size distribution decreased the voids and micro-cracks in the case of the unheated samples (Assi et al., 2018).

2.3.3.4 X-ray Diffraction (XRD)

XRD is a method that determines the chemicals a compound contains based on its crystal structure. Additionally, it provides details regarding the crystal structure and chemical makeup of a substance (Chau-Khun Ma et al., 2018).

2.3.4 Economic Feasibility of Geopolymer Concrete

Geopolymer concrete, being a highly adaptable material, is an economically viable alternative to traditional OPC concrete. Geopolymer technology was developed with the aim of reducing the environmental impact of cement production by minimizing the use of cement and utilizing industrial by-products that would have otherwise been waste. Furthermore, the use of precast geopolymer elements can accelerate construction and reduce costs over time (Chithra et al., 2021). Geopolymer concrete can replace Portland cement in a cost-effective manner since it uses industrial by-products like fly ash and blast furnace slag, which are often cheaper than traditional cement. Moreover, geopolymer concrete reduces carbon dioxide emissions during production and thus can lead to cost savings as well (Mathew et al., 2013). The feasibility of using geopolymer concrete from an economic standpoint is contingent on several factors including the availability of raw materials, market prices, and regulatory policies. The key motivation for scientific research is to develop innovative and environmentally sustainable products, with cost savings as a crucial consideration for promoting widespread adoption and mass production. Ultimately, for geopolymer concrete to be accessible to the general population, it needs to offer a cost-effective alternative to traditional cement. (Thaarrini & Dhivya, 2016).

Past studies have shown that geopolymer concrete can be developed using aluminosilicate materials and a highly alkaline solution, and that the water content in the mix plays a significant role in achieving the desired compressive strength. Additionally, geopolymer concrete modified with calcium oxide has been found to exhibit improved properties. Most previous studies have employed heat curing for setting and hardening of geopolymer mixtures.

The final products of polymerization are influenced by many factors regarding the chemical composition of the source materials and alkaline activators (Pavithra et al., 2016; Raijiwala & Patil, 2010; Vijai et al., 2010). Generally speaking, the polymerization process accelerates at temperatures higher than ambient. Initially, fly ash-based geopolymers formed at room temperature are less strong than heat-cured samples (Chidhambar & Manjunath, 2019). In this respect, the beneficial effect of calcium content in the source materials can be noted. The resulting hardened geopolymer was shown to be significantly influenced by the fly ash precursor's calcium oxide (CaO) content.

Together with the geopolymer network made of aluminum-silicate hydrate, the extra CaO produces hydrated products such as calcium silicate hydrates (C-S-H) (Hongen Zhang et al., 2019; Songrit Puttala et al., 2021). With an increase in CaO content, strength increased and setting time decreased. Recently, the suitability of fly ash-based geopolymer mixed with silica fume, metakaolin (Kumaravel, 2014). However, most of the findings are reported for mortar and paste samples initially cured at a temperature higher than ambient for variable lengths of time. Geopolymer concrete produced without using elevated heat for curing will widen its application to the areas beyond precast members.

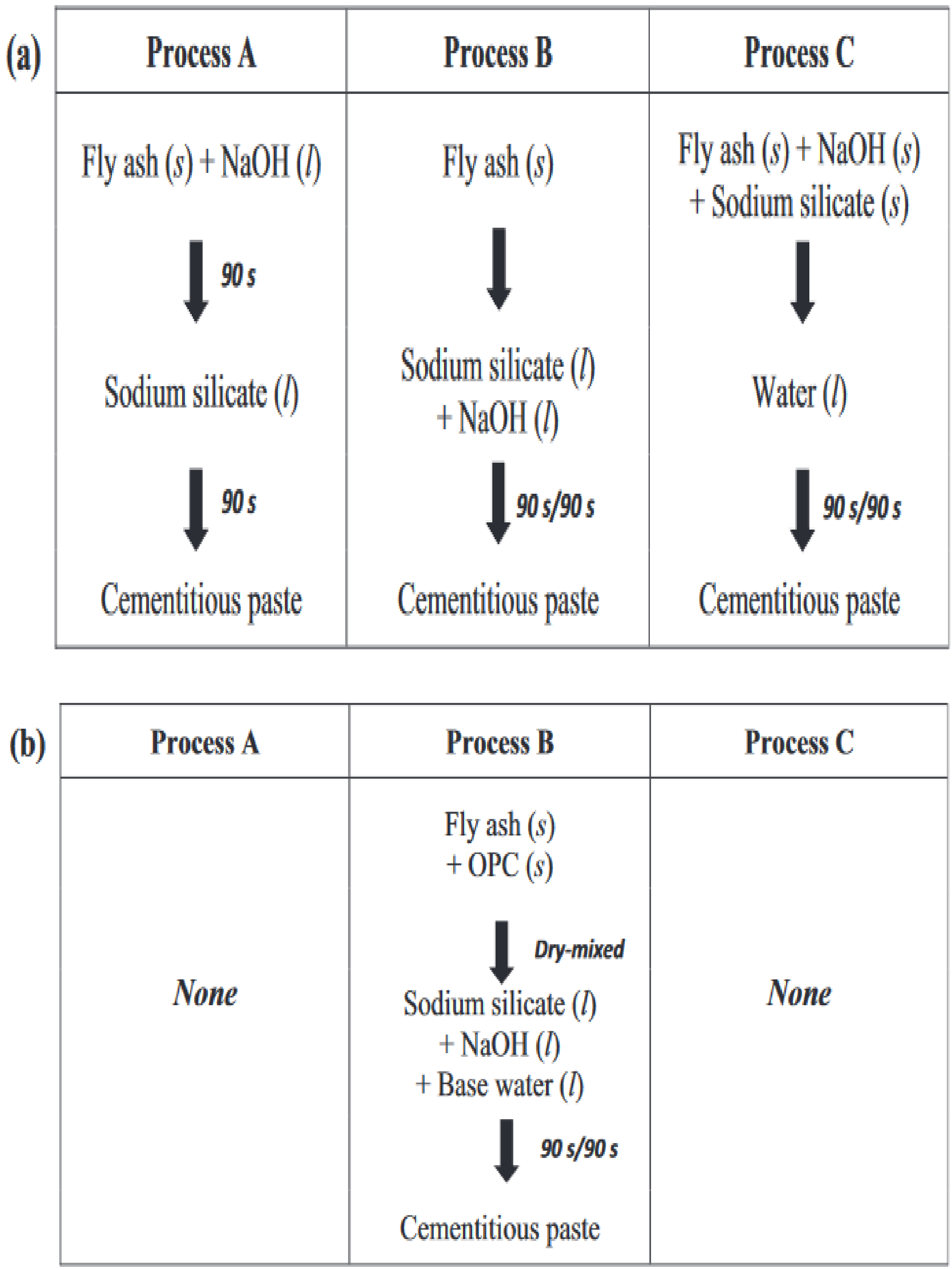
2.3.5 Hybrid Geopolymer Concrete

A mixture of geopolymer and Ordinary Portland cement (OPC), or alternative binders, are combined to produce a hybrid geopolymer. This new binder can be used to convert low-quality fly ash into multi-purpose concrete. The study conducted an analysis of various M30 concrete mix designs using RHA, FA, and GGBFS as source materials. For alkali activation, a mixture of NaOH and Na2SiO3 in a 0.5 ratio was used. The hybrid specimens included coconut fibers.

By adding 0.2% of binder material in the form of coconut fiber during heat curing, the results revealed a significant increase in compressive strength after seven and twenty-eight days (Wattanachai & Suwan, 2017). A study was conducted to analyze the setting time, workability, and strength properties of geopolymer concrete by mixing ground blast furnace slag with low calcium fly ash (Nath & Sarker, 2012).

Hardjito & Fung, (2010) conducted research was performed to investigate the influence of OPC content on the sulfate resistance of geopolymer concrete made with 10% SCBA and 90% fly ash, activated by KOH and K_2SiO_3. It was observed that incorporating 15-20% OPC, based on the total weight of binders in the mix, minimized the formation of thaumasite. This mineral can form in sulfate-rich environments and lead to concrete damage. The addition of OPC increased sulphate resistance, allowing the concrete to withstand sulfate attack. The study found that the concrete achieved a compressive strength of 70 Mpa after 28 days of curing at 800C for 24 hours. Suwan & Fan, (2014) focuses on the curing processes and properties (i.e. setting time and early strength development) of Geopolymer-Portland cementitious materials (GeoPC) affected by calcium content (from OPC) in alkaline presence (from geopolymers) and different manufacturing processes.

Khater1 H. M., (2012) studied that decreasing the development of secondary ettringite and other sulfate-related compounds by adding 10% OPC by weight of the total binders in the mix improved the sulfate resistance of geopolymer concrete prepared with 50% SCBA and 50% metakaolin. It is concluded that by producing geopolymer concrete with micro silica & nano silica an high strength concrete can be achieved, though which the use of cement shall be reduced. And geopolymer concrete with m-sand, micro silica and nano silica is attained that required strength, which was 35Mpa at 28 days of curing at 85^0C for 48 hrs. The durability chacteristics of geopolymer concrete with m-sand, micro silica and nano silica also increased (Dutta et al., 2010). It is possible to activate natural-pozzolan and to produce geopolymer cement using a proportioned mixture of sodium hydroxide and sodium silicate as an alkali-activator and the compressive strength of 63Mpa was gained at 28 days of curing at ambient temperature (Alahverdi et al., 2008).



Note: *s*, solid state; *l*, liquid state; *Base water*, water use in OPC synthesis

Figure 2. 3 Synthesis of (a) geopolymer and (b) geopolymer-Portland (GeoPC).

Table 2. 4 Compressive strength of hybrid geopolymer by different materials

Prime material (%wt)	Additives (%wt)	Compression (Mpa)/Aged a	Alkaline materials	Curing		Reference
				°C	hrs.	
FA F	-	95.0 / 28	NaOH + Na_2SiO_3	85	20	(Fernandez-Jimenez et al., 2007)
FA (80)	RHA (20)	70.6 / 90	-	Ambient		(Wattanachai & Suwan, 2017)
FA class F (90)	BA (10)	70.0 / 28	KOH + K_2SiO_3	80	24	(Hardjito & Fung, 2010)
Natural Pozzolan (100)	-	63.0 / 28	NaOH + Na_2SiO_3	Ambient		(Alahverdi et al., 2008)
FA (95) class F	Silica fume (5)	35.0 / 28	NaOH + Na_2SiO_3	85	48	(Dutta et al., 2010)
SCBA(50),MK(40)	OPC (10)	26.1 / 7	NaOH + Na_2SiO_3	80	24	(Khater1 H. M., 2012)
Waste Paper Sludge (100)	-	17.5 / 28	NaOH + Na_2SiO_3	Ambient		(Anuar et al., 2011)
Silty Clay (75)	FA (25)	14.0/28	NaOH + Na_2SiO_3	75	48	(Sukmak Patimapon et al., 2012)

2.3.6 Sugarcane Bagasse Ash

Sugar cane bagasse is an industrial waste that is used worldwide as fuel in the same sugar-cane industry. The combustion yields ashes containing high amounts of unburned matter, silicon, and aluminum oxides as main components (Srinivas et al., 2021). The bagasse ash is about 8-10% of the bagasse and contains unburned matter, silica, and alumina (Lamba et al., 2021).

Bagasse is a by-product of the sugar industry that is burned to generate power for various factory activities. Bagasse waste has been used as a primary fuel source in cogeneration plants to generate electricity. When bagasse is burned as fuel, it produces a large amount of sugar cane bagasse ash (SCBA) (Bahurudeen et al., 2015). The specific gravity of SCBA is 2.36, which is much lower than the specific gravity of cement (3.15). Bagasse ash has a specific surface area of 4716 cm2 /g and a particle size of 40.10 µm on average (where 50% of the particle passes). Furthermore, it is in the form of powder and is black in color (Adero, 2019)

Studies recommend that sugarcane bagasse ash could be used as cement replacement material to improve quality and reduce the cost of concrete and the chemical composition of SCBA (sugar cane bagasse ash) can vary depending on the source and processing methods, but it typically contains high amounts of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and calcium oxide (CaO). Other constituents may include iron oxide (Fe_2O_3), magnesium oxide (MgO), sodium oxide (Na_2O), and potassium oxide (K_2O) along with trace amounts of other elements. (Arslan Akbar et al., 2020, 2020; GOSHU, 2018; Lamba et al., 2021). Table 2.5 shows the oxide composition of SCBA that was examined by various researchers.

Table 2. 5 Oxide Composition of SCBA

No	Oxide Composition by Weight Percentage								Reference
	SiO_2	Al_2O_3	Fe2O3	CaO	MgO	K2O	NaO2	LOI	
1	65.58	5.87	4.32	1.78	1.23	6.41	1.02	10.48	(Hailu& Dinku, 2012)
2	61.04	6.12	3.52	1.36	2.56	5.92	1.08	10	(GOSHU, 2018)
3	66.7	9.24	1.53	10.07	4.6	4.32	1.3	-	(Arslan Akbar et al., 2020)
4	71.3	9.0	4.41	4.11	3.2	3.01	0.79	14.5	(Ankur Laxman Yadav et al., 2020)
5	66.9	-	14.8	6.2	1.3	7.3	-	6.4	(Songrit Puttala et al., 2021)

Sugarcane bagasse ash can be used in concrete production as a sustainable and cost-effective alternative to traditional Portland cement. Incorporating waste products made of aluminosilicate materials such as SCBA can result in a more environmentally friendly and durable concrete. The percentage of replacement of SCBA in concrete can vary depending on the mix design and desired properties. Generally, studies have found that using SCBA as a partial replacement for cement can be effective. Common replacement levels range from 10%

to 30% by weight of cement. However, the optimal replacement percentage may also depend on factors such as the source and quality of the SCBA, as well as other materials used in the concrete mix. Careful mix design is needed to balance sustainability and desirable properties. The use of bagasse ash is more environmentally friendly which reduces the final cost of Geopolymer Concrete. Bagasse ash is rich in silicate and alumina, hence reacts with an alkaline solution to produce aluminosilicate gel which will bind the fine and coarse aggregate in a suitable manner, which also provides good resistance against adverse conditions (Dilip Srinivas, Guide et al., 2017).

Figure 2. 4 Sugarcane, Sugarcane Bagasse, and Bagasse Ash Respectively

2.4 Research Gap and Summary

From various studies conducted it can be concluded that geopolymer concrete is preferred over conventional concrete because it performs better in many areas, including compressive strength, tolerance to hostile environments, workability, and exposure to high temperatures. But only when high heat curing (40°C –90°C) is used can geopolymer paste (GP) achieve its exceptional strength. Therefore, especially small-scale parts and pre-cast components may utilize geopolymer. The development of geopolymer curing at ambient temperature is, therefore, attracting much greater attention to overcome the restriction of employing curing units and be more convenient in practical operations. Recently, a lot of effort has been put into synthesizing geopolymer that can acquire adequate strength under ambient curing conditions (Wattanachai & Suwan, 2017; Alahverdi et al., 2008; Anuar et al., 2011).

The incorporation of OPC into GP (the GeoPC system) has been investigated to accelerate (C, N)-A-S-H formation and to achieve reasonable strength at ambient curing temperature.

However, there is a gap in the use of SCBA GeoPC in ambient curing temperature. As a result, conducting an experimental study to close the current gap using OPC as a partial replacement of SCBA at ambient curing temperature is necessary to provide the most recent alternative curing methods for geopolymer-Portland concrete to initiate commercial viability, on-site operation, and energy savings aspects. Therefore, the current study focused on checking the economic feasibility of the agricultural byproduct bagasse ash with different cement replacements and its long-term properties to enhance the workability, strength, and physical properties of SCBA hybrid geopolymer-Portland concrete.

In this chapter various research works carried out across the world in the area of geopolymer concrete were reviewed to identify the research gaps that enabled setting the objective for this research. The next chapter discusses the research methodology adopted to achieve the objectives of the study.

3 MATERIALS AND METHODS

3.1 Introduction

The previous chapter's literature review included a variety of prior studies and research gaps related to sugarcane bagasse ash (SCBA) based hybrid geopolymer concrete. The research goals for this study are outlined in Chapter One based on the found research gaps. Based on the necessary material specifications, numerous standards, and methodologies, this chapter discussed the tools and methods used to carry out this study.

3.2 Materials Used

The materials used in this experiment were examined to ensure that their physical and microstructural characteristics complied with the standard's specifications. The experiment's material characteristics for: - Cement, Coarse Aggregate, Fine Aggregate, and Sugarcane Bagasse ash (SCBA) were conducted and discussed.

3.2.1 Cement

Cement is a material that is utilized in building and construction to bind and solidify other materials. In the current study, the use of locally available OPC cement was chosen due to its quick early strength in the first 28 days. The National OPC cement was specifically chosen to match the concrete specifications outlined in Figure 3.1(D) and was obtained from a supplier in Adama, Ethiopia that complied with ASTM C150 (2016) regulations. The cement was properly stored in a dry location away from moisture to ensure its quality was maintained throughout the experimental period.

3.2.2 Coarse Aggregate

Coarse aggregates are those that were retained on the 4.75mm sieve. It is a granular, irregular material consisting of crushed stone that is obtained from quarries through manual or mechanical crushing. Clay, silt, filth, and other contaminants like biological matter must not be present in the coarse aggregate. The strength and wear resistance of soft, porous rock can be limited. It may also break down as the concrete is mixed, which reduces the workability of new concrete by adding more fines. The coarse aggregate in the concrete samples utilized in this study was crushed gravel. The gravel was procured from a nearby quarry, and it complies with ASTM C33 standards. Generally, the coarse aggregate used for the experiment should be strong, durable, free from vegetable matter, with less than 5% water absorption, and not sharp and angular as per ASTM C33 was obtained to conduct this study as seen from Figure 3.1(E).

3.2.3 Fine Aggregate

Sand is a by-product of the disintegration of rock and minerals, which can occur both artificially and naturally. It is found in rivers, lakes, residual deposits, and wind-blown deposits. It should also be strong and long-lasting (Abebe Demissew Gashahun, 2020). Fine aggregate should not absorb more than 5% of water, according to ASTM specifications. In this Investigation, river sand that had been sieved through a 4.75 mm sieve and retained at 150 microns following ASTM C33 was used as mentioned in Figure 3.1(C). The sand shouldn't include any silt, clay, or other organic pollutants. .

3.2.4 Water

Water is the most crucial component of concrete. The quality of concrete is significantly impacted by water impurities and water content. As a result, there shouldn't be any chemicals or other pollutants in the concrete water. Although it is generally safe to use potable water, concrete can be made with unfit-for-drinking water. During the current study, potable water that complies with ASTM C1602 (2006) standards was used one of the main components of concrete is water. Acid, alkali, and oil must all be absent from the water used for mixing. Water that is safe to drink can usually be used.

3.2.5 Sugarcane Bagasse Ash

Bagasse ash was gathered from a by-product disposal site near the Wonji sugar factory. The burning of bagasse leaves bagasse ash as a waste, consisting mainly of silica (SiO_2), which indicates its potential as a mineral admixture for use in concrete as a Pozzolans and which has a pozzolanic property that is used as bagasse ash to concrete mix proportion cementitious material replaces of cement. Figure 3.1(B) illustrates the use of SCBA in this experiment.

3.2.6 Alkali activator Solutions

Alkali activators create an alkaline solution with an equal mass ratio of sodium hydroxide and sodium silicate (Korniejenko et al., 2016). The alkali solutions employed in these studies are sodium hydroxide and a water solution of sodium silicate because of their effective binding properties and availability. Lye or caustic soda, often known as sodium hydroxide, has the chemical formula NaOH. A solid, pure NaOH is available as granules, flakes, and pellets. The 97% pure NaOH used in this study was in the form of pellets. It contains 45.5% solid with 1.35 specific gravity. Sodium silicate solution having 48.2% solid with 1.45 specific gravity was used. Alkaline activators obtained from Heparin Trading PLC were used.

Figure 3.1(A) demonstrates the use of Alkali Activator Solution in this study.

Figure 3. 1 Materials used; A) Alkaline Activator B) SCBA, C) Fine Aggregate, D) National OPC cement, and E) Coarse Aggregate

3.3 Methods

Methods in material research refer to a logical and coherent plan for conducting experimental investigations. The current study discusses and interprets the research output using both qualitative and quantitative research approaches. An experimental research design was used in this study. This section describes in detail the testing methods used to achieve the research objectives. Tables, graphs, and charts were used to display the analysis findings. The experimental program followed is described in the flowchart given in Figure 3.1 below.

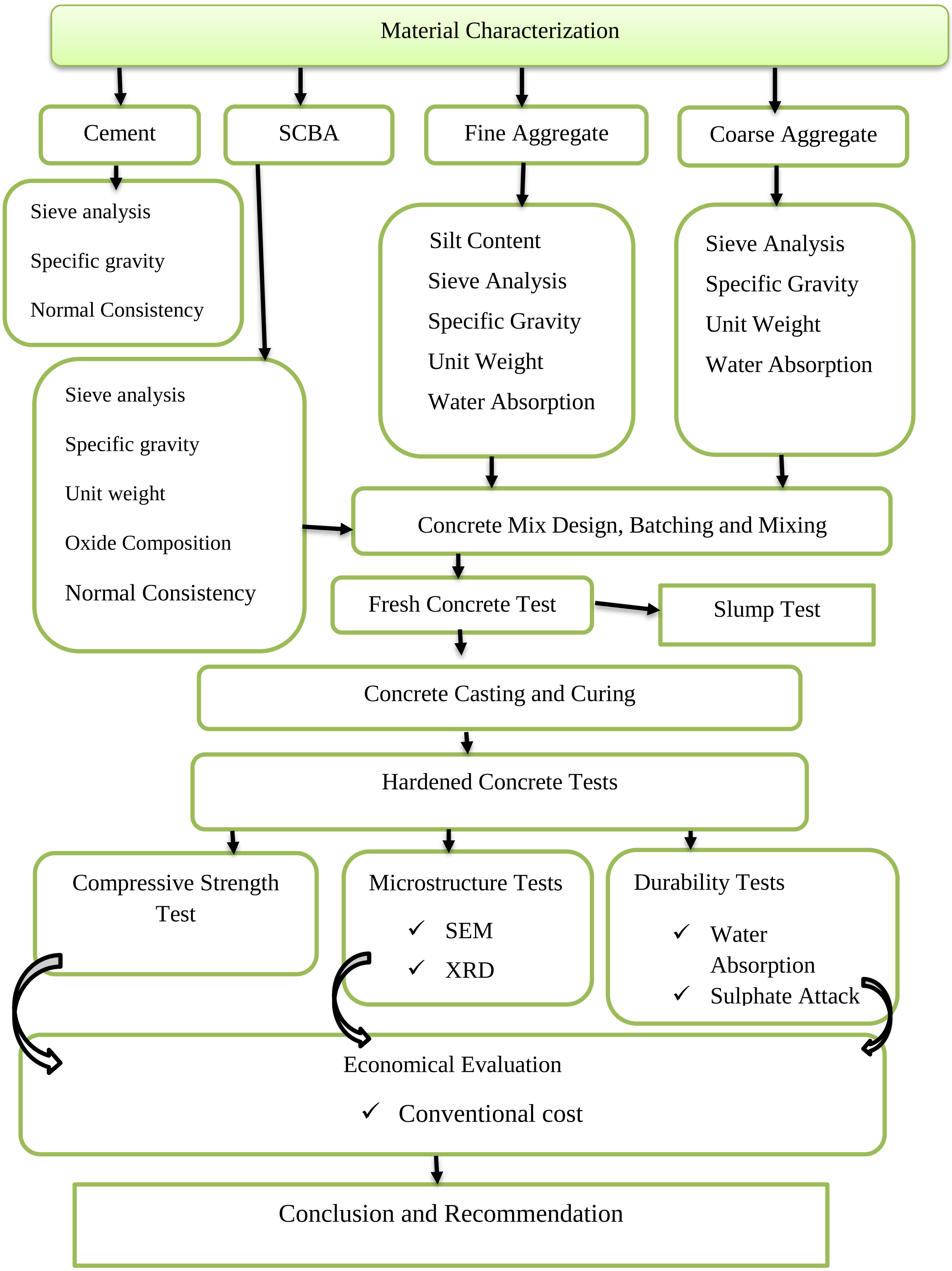


Figure 3. 2 Conceptual framework of the Research

3.3.1 Tests for Fine Aggregate

3.3.1.1 Silt Content of Fine Aggregate

Sand often contains dust, silt, clay, and loam. Sand containing such particles weakens concrete's compressive strength and long-term durability. Testing sand's silt concentration and comparing it to allowed limits is therefore crucial. Finding out how much silt was in the sand was the main objective of this test. Sample sand, pure water, a graduated jar, a spoon, a container for collecting a sand sample, and a funnel were required for this experiment. The following describes the specific steps that were taken per ASTM C 117.

Test Procedure for Silt Content

1) The researcher took a graduated cylinder having a capacity of 1000 ml.

2) 300 ml of sand was poured into the cylinder.

3) Approximately 3/4 of the jar was filled with water.

4) The jar was shaken vigorously for about a minute.

5) The jar was left for an hour to allow the silt to settle on the layer of sand.

6) The amount of fine forming a separate layer on the top was measured.

7) The silt content was calculated based on Equation 3.1.

Figure 3. 3 Silt Content Test

Silt content = $\frac{\text{Silt deposited above the sand (A)}}{\text{Amount of clean sand (B)}}$ x 100% ---------------------------- Equation 3.1

3.3.1.2 Sieve Analysis of Fine Aggregate

The process of sieving granular material through a series of sieves with successively decreasing mesh sizes and weighing the quantity of material retained in each sieve as a percentage of the total mass is known as sieve analysis. This method is used to determine the particle size distribution of granular material.

Therefore, the purpose of this test was to ascertain the fineness modulus of fine aggregate using a series of IS sieves with sizes ranging from top to bottom (4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15, and pan), 500 g of fine aggregate, a balance, sieve shaker, shovel, and sieve brush. According to (ASTM C136), the test was conducted. The range of fineness modulus is 2.3-3.1 (ASTM C33).

Procedure for Grading Fine Aggregate

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

Fineness modulus = $\sum_{n=1}^{7}(\text{Cumulative retained by mass / 100})$------------- Equation 3.2

Figure 3. 4 Sieve Analysis of Fine Aggregate Test: - (A) Sieves on Sieve Shaker and (B) Sieved Fine Aggregate

3.3.1.3 Unit Weight, Specific Gravity, and Water Absorption of Fine Aggregate

The mass of a particular volume of a material divided by the mass of an equal volume of water is called specific gravity, and it indicates how much heavier the material is than water. The difference between the weight of the aggregate in the surface-dried saturated state and the weight of the oven-dried aggregate is used to calculate the water absorption of an aggregate. The density of fine aggregate varies depending on whether it is wet, dry, or loose. The specific gravity and water absorption capacity of fine aggregate were calculated using the ASTM C128 standard in this experiment. The range of specific gravity is 2.5–3 (ASTM C128).

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

1. Fill the measure one-third full and level the surface with your fingers. Rod the layer of aggregate with 25 strokes with the tamping rod evenly distributed over the surface. Then fill the measure to two-thirds capacity, level, and rod as before. Finally, fill the measuring cup to overflowing and rod as above.
2. Level the surface of the aggregate with your fingers in such a way that any slight projections of the large pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

3. When roding the first layer, do not allow the rod to strike the bottom of the measure forcibly. In roding, the second and third layers use only enough force to cause the taping rod to penetrate the previous layers of aggregate.

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

X: Fine aggregate plus cylinder weight

Y: Weight of empty cylinder

V: Cylinder volume

UWFA $= \frac{X-Y}{V}$ --- Equation 3.3

B) Specific Gravity and Water Absorption of Fine Aggregate Preparation of The Test Specimen:

1) Approximately 1 kg of fine aggregate was prepared.

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

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

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

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

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

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

Procedure:

1. The S.S.D sample was weighted at 500 g.
2. Partially fill the Pycnometer with water and put 500 g of saturated surface dry aggregates into the Pycnometer.
3. Then they filled the pycnometer with additional water to fill it to 90% of its capacity.
4. The pycnometer was rolled and inverted to eliminate all air bubbles.
5. Place the Pycnometer in a water bath at 23 °C for an hour.
6. Brought the water level in the pycnometer to its calibrated capacity.
7. Then, the total weight of the pycnometer, specimen, and water was measured.
8. The researcher removed the fine aggregate from the pycnometer, dried it to a constant weight at 105 °C, cooled it in room temperature air for one hour, and measured it.
9. The weight of the pycnometer filled with water was determined at 23°C, and the following data were recorded:

    X: Weight of oven-dry specimen in air

    Y: Weight of water-filled pycnometer

    Z: Weight of the saturated surface-dry specimen

    W: Pycnometer weight with specimen and water to the calibration mark

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

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

$$\text{Water absorption} = \frac{Z-X}{X} \times 100\% \quad \text{-----Equation 3.6}$$

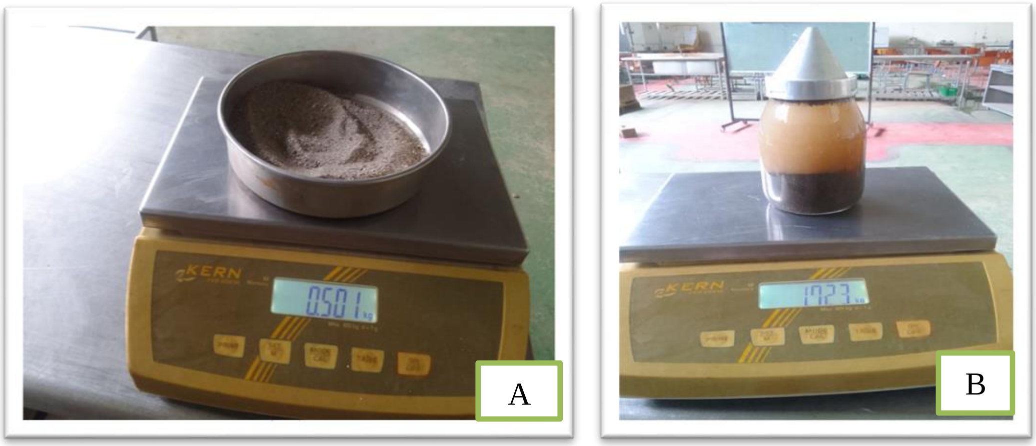


Figure 3. 5 Specific gravity Analysis of Fine Aggregate Test: - (A) Sample Weight and (B) weight of sample with water and pycnometer

3.3.2 Tests on Coarse Aggregate

3.3.2.1 Sieve Analysis of Coarse Aggregate

The coarse aggregate obtained from the local quarry should be tested against gradation to determine its particle size distribution. Hence, this test aims to determine the fineness modulus of coarse aggregate with the help of apparatus like a series of IS sieves of sizes (20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan) from top to bottom, respectively, 2,000 g of coarse aggregate, a balance, sieve shaker, shovel, and sieve brush. The test procedure followed was (ASTM C136).

Sieve Analysis for Coarse Aggregate

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

3.3.2.2 Unit Weight, Specific Gravity, and Water Absorption of Coarse Aggregate

Specific gravity is the ratio of the weight of a certain amount of coarse aggregate to the weight of the same amount of water. Low-density aggregates are weaker than high-density aggregates, indicating their water absorption capacity. The density of coarse aggregate varies depending on the source, nature, and condition, like wet or dry. The researcher determined specific gravity and water absorption capacity based on the (ASTM C127) standard. The unit weight of aggregate ranges from 1200 to 1750 kg/m3 (ASTM C29).

A) Unit Weight of Coarse Aggregate (UWCA)

1. Fill the measure one-third full and level the surface with your fingers. Rod the layer of aggregate with 25 strokes with the tamping rod evenly distributed over the surface. Then fill the measure to two-thirds capacity, level, and rod as before. Finally, fill the measuring cup to overflowing and rod as above.
2. Level the surface of the aggregate with your fingers in such a way that any slight projections of the large pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.
3. When roding the first layer, do not allow the rod to strike the bottom of the measure forcibly. In roding, the second and third layers use only enough force to cause the taping rod to penetrate the previous layers of aggregate.
4. The coarse aggregate was weighted, and the data was recorded as follows.

X = aggregate plus cylinder weight = 6.746 kg

Y = Weight of the empty cylinder = 4.734 kg

V = Volume of the cylinder (m3) = 0.001375 m3

The unit weight of coarse aggregate can be computed by using Equation 3.7

$\text{UWFC} = \frac{X-Y}{V}$ ---Equation 3.7

A) Specific Gravity and Water Absorption Capacity of Coarse Aggregate

Test Procedures

1) The researcher took the sample of coarse aggregate by using the sample splitter.
2) The sample was sieved with a 4.75 mm sieve, and the sample passing through the 4.75 mm sieve was ignored.
3) The sample was washed to remove dust.
4) Put the sample in the oven at 105°C for 24 hours.
5) The sample was taken out of the oven, left to cool, and then the weight was measured.
6) The sample was submerged in water for 24 hours.
7) The researcher removed the sample from the water and rolled it in a large absorbent cloth until all visible films of water were removed.
8) The required weight of the sample in its (S.S.D) condition was taken.
9) The researcher immediately placed the S.S.D sample in the sample container, determined the weight in water at 23 °C, and recorded the data.

H: Weight of air-dried oven-dried specimen

G: Weight of the saturated surface-dry specimen

F: Pycnometer weight with specimen and water to the calibration mark

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

$$\text{Bsg} = \frac{G}{G-\text{F}} \quad \text{--Equation 3.8}$$

$$\text{Asg} = \frac{\text{H}}{\text{H}-\text{F}} \quad \text{--- Equation 3.9}$$

$$\text{Water absorption} = \frac{\text{G}-\text{H}}{\text{H}} \text{x } 100\% \quad \text{---Equation 3.10}$$

3.3.3 Test for Sugarcane Bagasse Ash

3.3.3.1 Preparation of Sugarcane Bagasse Ash

Primarily, Sugar cane bagasse ash was collected from the source and packed for transportation. Then transported to the laboratory and placed around a clean area. After that, the burning of dried bagasse ash in the furnace took place. The sample was incinerated in a furnace for 2 hours at a temperature of 600^{o}C at the laboratory of Adama Science and Technology University, Adama and Ethiopia Geology survey laboratory.

3.3.3.2 Sieve Analysis

The main objective of sieve analysis is to determine the particle size distribution of sugar cane bagasse ash. Sieve analysis of SCBA involves passing the material through a series of sieves with progressively smaller openings to determine the particle size distribution. The material is weighed before and after the sieve analysis to determine the percentage of material that falls within each particle size range. This information can be useful in determining the particle size distribution for use in concrete mixtures.

3.3.3.3 Specific Gravity Test

Specific gravity is the ratio of the mass of a given volume of material to the mass of an equal volume of water. One method of determining the specific gravity of cement is to use a liquid that does not react with cement, such as water-free kerosene, by using a specific gravity pycnometer. A specific gravity pycnometer, in addition to hydraulic cement, can be used to determine the specific gravity of dust, sand, and other fine materials. Due to this reason, the specific gravity of SCBA is also determined by this method. The test was conducted according to ASTM C188 (2009) standard, the specific gravity of Portland cement ranges from 3.1 to 3.16 g/cc. Kerosene is used to determine the specific gravity because when water is used while testing it starts a reaction. This reaction may affect the experiment but kerosene does not react with cement and ash and does not affect the test.

To conduct this test, initially, a specific gravity pycnometer was weighed and recorded. Then 25 g of CBSA was added to the pycnometer and measured. After that, kerosene was added up to the calibration point of the specific gravity pycnometer and weighted. Lastly, kerosene was poured into an empty pycnometer up to the calibration point and weighed.

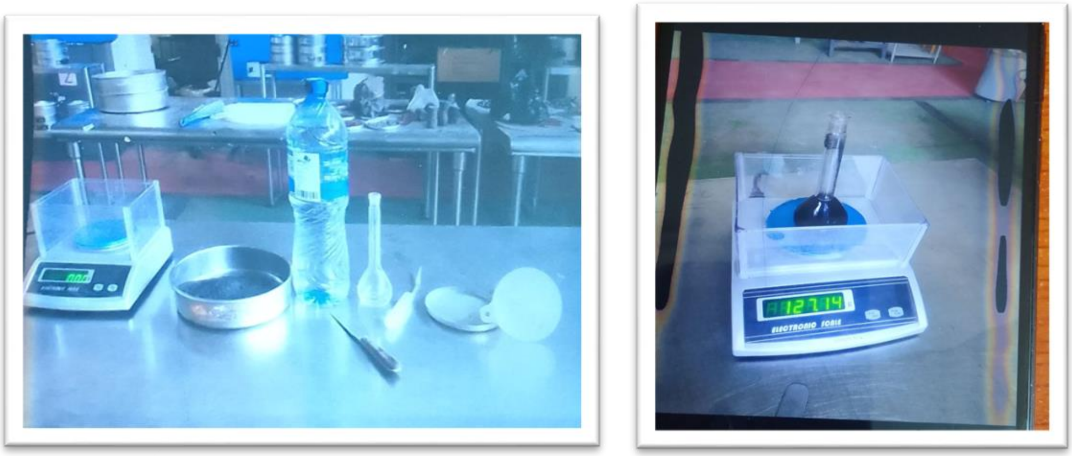


Figure 3. 6 Apparatus and kerosene used to conduct specific gravity of the SCBA.

From obtained data, the specific gravity of CBSA was calculated through equation 3.11.

$$S = \frac{(B-A)}{(B-A)-(C-D)*SK}$$ -- Equation 3.11

Where,

A= weight of specific gravity pycnometer (g)

B= weight of specific gravity pycnometer with SCBA (g)

C= weight of pycnometer with SCBA and kerosene (g)

D=weight of pycnometer with kerosene (g)

SK= specific gravity of kerosene (G)

SK= (weight of pycnometer with kerosene minus the weight of pycnometer) divided by the weight of pycnometer with distilled water minus the weight of pycnometer).

3.3.3.4 Unit Weight Test

The density of SCBA is the weight of the ash that is required to fill a container of a specified unit volume. This test was done to determine the density of SCBA. The test was conducted by using a metal cylinder with a diameter of 100 mm and a height of 175 mm, a tamping rod, and a balance. To undertake this test initial empty cylinder was weighed and recorded, then SCBA was filled into the cylinder through three layers, and each layer was rodded with 25 strokes by the tamping rod. After that, the weight of the filled cylinder with SCBA was measured and recorded. Finally, the unit weight of SCBA was computed through equation 3.12.

$$\text{Unit weight} = \frac{F-C}{V}$$ -- Equation 3.12

Where,

C = weight of empty cylinder (kg)

F = weight cylinder filled with SCBA (kg)

V = volume of a cylinder ($V=\pi d^2 h/4$), while d is diameter and h is denoted height of the cylinder.

3.3.3.5 Chemical Composition Analysis

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

3.3.3.6 Microstructural Test of SCBA

Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) tests were used to determine the microstructure of the SCBA. The shape and size of SCBA particles were determined using SEM, while the amorphous and crystalline structures of SCBA particles were examined using XRD. To conduct an SEM analysis of SCBA, initially, a sample was prepared by taking the ash that passed through a sieve opening 75 μm. Then the prepared sample was taken to the SEM laboratory and analysis was conducted. Finally, the displayed morphological image of SCBA was analysed qualitatively through observation of the image. While performing the XRD analysis of SCBA, the first sample was prepared as the same for SEM analysis and taken to the XRD laboratory. Following the analysis, the peaks were generated on the Origin pro Software using the collected XRD data in terms of intensity and the 2-theta scale.

3.3.4 Normal Consistency Test

Normal or standard consistency refers to the ideal amount of water content that is needed to create a paste with cement. The test used to determine this amount of required water is known as the normal consistency test. This test is conducted according to the ASTM C187 (2016) standard, and to perform the test, a Vicat apparatus is necessary. The test was done for seven different percentages of pastes i.e.100%, 0%, 5%, 10%, 15%, 20%, and 25 % of cement. Because of limited resources and time, a pilot study could not be conducted to determine the optimal replacement interval. As a result, a replacement interval of 5% was selected for the current study. The testing procedure began by mixing 650 g of cement and SCBA, and water to create cement and SCBA paste respectively. The amount of replacement material (OPC) was then subtracted from the total amount of SCBA in each replacement percentage. Once this was done, the paste was put on the ring of the Vicat apparatus and any excess material was removed with a trowel. The plunger was then attached to the movable rod of the Vicat apparatus, and the initial reading could be taken once the movable indicator was seated.

After 30 seconds of forming the paste, the rod was released and the paste was considered to have normal consistency if the rod settled to a point 10 mm below the original surface 30 seconds after being released. Once the trial was completed, the normal consistency result could be determined. The ASTM C187 (2004) standard recommends adding water in the range of 22-30% of the amount of cement required to achieve normal consistency.

Figure 3. 7 Vicat Apparatus (A), Normal Consistency Test (B)

3.4 Mix Design

Mix design can be stated as the process of selecting suitable concrete components and determining their relative proportions to create concrete with a specific minimum strength and durability at the lowest possible cost. The mix design determines the mix ratio. As a result, the concrete mix design for C-25 concrete grade can be described as concrete mixture = cement: fine aggregate: coarse aggregate. C-25 concrete is the most commonly used grade of concrete. The researcher selected the C-25 grade of concrete for the reasons the type of concrete is mostly used.

The mix design for C-25 non-air entrained normal strength concrete was done as per ACI 211.1 design manual (ACI 211.1-91, 2002). It involves producing a basic combination of geopolymer concrete, (SCBA and AAS) and standard concrete that just contains cement as a binder. Additionally, by adjusting the material quantities per unit volume, it incorporates OPC for GeoPC in the required percentage to make final batches.

ACI 211.1-91 (2002) indicates that the initial stage of mix design involves calculating the necessary average compressive strength based on the given characteristic strength of 25MPa.

$fck = f'ck + X$--Equation 3.13

Where,

f'ck - Characteristic compressive strength at 28 days in N/mm².

f ck - Target mean compressive strength at 28 days in N/mm².

X- Factor based on the grade of concrete

fck = f'ck +8.5 = 25 + 8.5 = 33.5 MPa

The next step was to determine the minimum cement content and choose the desired slump value. It is crucial to consider durability when selecting the cement content, and it is not recommended to use less than 300 Kg/m3 of cement in concrete due to weathering agent exposure. In fact, IS 456 (2000) suggests using higher cement contents for more severe weathering conditions. The trial mix's average slump value chosen was 2-10 cm, based on Appendix A2, for non-air entrained concrete, the selected nominal and maximum size of aggregates were 19mm and 20mm, respectively. The amount of water selected was 185 Kg/m3 based on the slump value and maximum aggregate size per Appendix A3, with an entrapped air of 2%.

The water-cement ratio represents the weight of water used in a concrete mix compared to the weight of cement. Using a lower ratio increases the strength and durability of the concrete, but it can also make the mix challenging to work with and form. Appendix A_4 provided an interpolated value of 0.491 for the water-cement ratio (w/c) to attain an average compressive strength of 33.5MPa. Based on this ratio, the required amount of cement was calculated as follows.

$$\text{Cement content} = \frac{\text{Water content}}{\text{water cement ratio}} = \frac{185}{0.491} = 376.87\ \text{kg/m}^3$$

Since the mix cement content is higher than the minimum cement use, when designing a mixture of geopolymer concrete, the first step is to determine the appropriate alkaline activator solution to binder ratio (AAS/B) based on the target compressive strength. Then, the amount of alkaline activator solution (AAS) needed is calculated based on both desired strength and workability of the concrete. AAS/B corresponding to the 28^{th} day target compressive strength can be adopting the standard which curves of normal concrete as per ACI. For 33.5Mpa, AAS/B was 0.55 and AAS content of GPC was 200kg/m^3 for effective workability, better strength and economy aspect. Then the Binder content (BC) was calculated using AAS/B and AAS content.

$$\text{BC} = \frac{\text{AAS content}}{\text{AAS/B}} = \frac{200}{0.55} = 363.64\text{kg/m}^3$$

The alkaline activator is a crucial component of geopolymer concrete as it helps to activate and bind the aluminosilicate materials together. The mass of alkaline activator refers to the total mass of the alkaline solution used to activate the aluminosilicate materials. In this study, an alkaline activator was used which consisted of NaOH (sodium hydroxide) and Na_2SiO_3 (sodium silicate), with a ratio of NS/NH = 2.5.

Mass of AAS = M (NS + NH) = M (2.5NH + NH) = MNH (2.5 +1) = 3.5MNH

MNH = AAS/3.5 = 200/3.5 = 57.14kg/m^3 and

MNS = 2.5MNH = 2.5(57.143) = 142.86kg/m^3

Water to Geopolymer concrete (GPC) ratio is a crucial factor in designing a mixture of SCBA-based GPC. To determine the water to GP solid ratio, the total water in Alkali Activator Solution (AAS) must be calculated. This can be done by adding the mass of water in NH and NS solution, which gives the total water present in the alkaline activator solution. SNH and

SNS, be the percentage of solid in NH and NS. From the specification percentage solid in NH was 45.5% and 48.2% in NS, having specific gravity of 1.35 and 1.45 respectively.

Mass of water in NS = MNS (100% - % solid in NS) = MNS (1 - SNS) = 142.86(1-0.482)

= 74kg/m^3

Mass of water in NH = MNH (100% - % solid in NH) = MNH (1- SNH) = 57.14(1-0.455)

= 31.14kg/m^3

The total water content in the mix was 105.14kg/m^3

The total solid in the mix was 458.5kg/m^3 and water to binder ratio was 0.23.

The water to binder ratio for GPC mix was calculated to be 0.23 using the values of 105.1 and 458.5. On the other hand, the water to binder ratio for the other mixes were presented in Table 3.3.

The recommended coarse aggregate content according to ACI 211.1-91 (2002) is established by the fineness modulus of the fine aggregate and maximum coarse aggregate size. In this study, a fine aggregate with a fineness modulus of 2.82 and a maximum coarse aggregate size of 20 mm were used. Using these values, the oven-dry rodded coarse aggregate per unit volume of concrete was determined to be 0.618 from Appendix A5.

To calculate the weight of coarse aggregate, the dry rodded density of the coarse aggregate was multiplied by the volume of oven-dry rodded coarse aggregate per unit volume of concrete. In this study, the resulting weight of coarse aggregate was 1049.86kg/m3, and the bulk density of the coarse aggregate obtained was 1698.79 kg/m3. The solid volume of the coarse aggregate was computed by dividing the weight of coarse aggregate by its specific gravity, which gave a solid volume of coarse aggregate at 391.74Kg/m3, with a specific gravity that was calculated to be 2.68.

It was calculated that there is a binder volume of 148.45kg/m^3, achieved by dividing the minimum binder content by its specific gravity (363.64/2.45). Additionally, the volume of NS and NH volume were assessed, resulting in 47.49 kg/m^3 (68.86/1.45) and 19.26 kg/m^3 (26/1.35) respectively. The solid volume of the fine aggregate was calculated by subtracting the volume of coarse aggregate, binder, water, and air from 1000, resulting in a total volume of 188.31liters per cubic meter. Weight of fine aggregate was multiplication of its solid volume and specific gravity, which are 188.3kg/m3 and 2.7 respectively and the obtained result, was

508.44 kg/m3. Table 3.1 outlines the mix design for producing one cubic meter of concrete initially, but the results were not used as is, and instead required an adjustment based on the absorption capacity.

Table 3. 1 Summary of mix design for one cubic meter of concrete before adjustment on water absorption.

Ingredients	Volume (l)	Weight (kg)
Binder	214.95	458.5
Fine Aggregate	188.31	508.44
Coarse Aggregate	391.74	1049.86
Water	185	185
Air	20	-
Total	1000	2201.8

To calculate the amount of water absorbed by the coarse aggregate, the weight of the coarse aggregate was multiplied by its moisture content factor of 0.018. Similarly, to calculate the amount of water supplied by the fine aggregate, the weight of the fine aggregate was multiplied by its moisture content factor of 0.027. These calculations resulted in water absorption capacities of 18.96 kg/m3 and 27.68 kg/m3 for the coarse and fine aggregates, respectively.

The adjusted water amount was determined by adding the amount of water absorbed and subtracting the amount of water supplied from the original amount of water.

Adjusted fine aggregate = original fine aggregate amount plus supplied capacity

Adjusted coarse aggregate= original coarse aggregate amount minus absorbed capacity

Table 3.2 shows the adjusted amounts of all concrete ingredients used in this study's mix design.

Table 3. 2 Adjusted amount of concrete ingredients for production of one cubic meter concrete

Ingredients	Weight (kg/m^3)
Binder	458.5
Fine Aggregate	536.12
Coarse Aggregate	1030.90
Water	176.28

Due to the fact that the specific gravity of cement and SCBA were not equivalent, it was determined that 1 kilogram of cement was equivalent to 0.78 kilograms of SCBA. As a result, 0.78 kilograms of SCBA were used to replace by 1 kilogram of cement. Table 3.3 summarized the mix design for producing one cubic meter of concrete, with the amount of cement, binder and water used was varying based on the amount of replacement required. The content of fine and coarse aggregate remained consistent across all mixes.

Table 3. 3 Summary of mix design for the production of one cubic meter of concrete.

Mix code	OPC: SCBA (% weight)	OPC Kg/m^3	SCBA Kg/m^3	NH Kg/m^3	NS Kg/m^3	FA Kg/m^3	CA Kg/m^3	Water Content Kg/m^3	Water/Binder (%)
OPC	100:0	363.64	-	-	-	536.12	1030.90	176.28	0.49
GPC	0:100	-	363.64	57.4	142.8	536.12	1030.90	-	0.23
GeoPc5	5:95	18.18	269.46	54.3	135.7	536.12	1030.90	8.81	0.29
GeoPc10	10:90	36.63	255.28	51.7	128.5	536.12	1030.90	17.63	0.30
GeoPc15	15:85	54.55	241.09	48.8	121.4	536.12	1030.90	26.44	0.31
GeoPc20	20:80	72.73	226.91	45.9	114.2	536.12	1030.90	35.26	0.32
GeoPc25	25:75	90.91	212.73	43.1	107.1	536.12	1030.90	44.07	0.33

The ratio of concrete mix design was determined by dividing the amount of fine and coarse aggregates by the amount of cement or binder. Based on the information provided in Table 3.2, the mix ratio of concrete ingredients is 1:1.2:2.3.

Table 3. 4 Mix design ratio

Ingredients	Binder (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
Quantity	458.5	536.12	1030.90
Ratio	458.5/458.5	536.12/458.5	1030.90/458.5
	1	1.2	2.3

3.5 Batching and Mixing

3.5.1 Batching

To create concrete mixtures, concrete materials must be measured in batches. Since it is challenging to determine the precise volume of granular materials because of their voids, batching by weight was preferred over volume batching for this particular experiment to get a proper mix of concrete ingredients.

3.5.2 Concrete Mixing

To produce effective and high-quality concrete, concrete components like cement, fine aggregate, coarse aggregate, water, and other materials are mixed. To create a uniform, high-quality concrete in this investigation, all of the components were mixed in a mixer. The process of producing geopolymer concrete involves four main stages. Firstly, the alkaline activator solution is prepared, followed by the mixing of dry ingredients. Then, the liquid components are mixed together and finally all the components are combined in a mechanical mixer.

By mixing NaOH pellets in distilled water with the proper proportion, a NaOH solution with a molarity of 12M was prepared at least one day before in advance. To create a 12M NaOH solution, it is recommended to dissolve 480g of NaOH pellets in one litre of the solution. Once the solution is ready, it was added to Na_2SiO_3 and thoroughly mixed. Half an hour following the preparation of the alkaline activator solution, the solution was mixed with coarse aggregate, fine aggregate, and binders in a machine. Once the solution was added to the dry mixture, additional water was incorporated in the mix with differing water-binder ratios. All mixes required 2.5 activators to binder ratio.

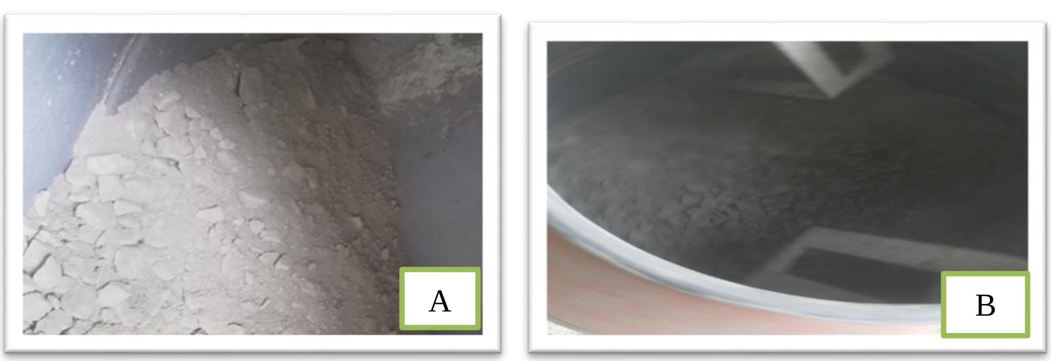


Figure 3. 8 Concrete Mixing: - (A) Dry Mix, (B) Wet mix

3.6 Fresh Concrete Test

3.6.1 Slump Cone Test for Workability of Concrete

A slump test is a type of physical property test done on fresh concrete to determine the concrete's ability to be placed, transported, easy flow, and other properties The concrete slump test determines the flow of new concrete before it hardens to detect incorrect batch mixing, mortar loss, formwork pressure, finishing delays, and segregation if the slump is too high.

According to ASTM C143 (2010), the test was conducted. Tools, a tamper rod (16 mm in diameter and 600 mm in length), a ruler, a flat pan, and a test slump cone (which has the shape of a frustum of a cone and dimensions, base diameter 200 mm, top diameter 10 mm, and height 300 mm) were used.

Slump test procedure

1. First, the slump cone was placed on a smooth metal plate.
2. The slump cone was filled with freshly mixed concrete in three different layers.
3. Each layer of the concrete mix was tapped 25 times with a 600 mm long metal rod that was 16 mm in diameter.
4. Extra concrete was removed after filling the last layer from the top of the cone.
5. The slump cone was then quickly lifted upward with two hands. The concrete is then free to fall.
6. After free fall, the remaining height is known as a slump (the difference between the height of the mold and the height of the vertical axis) and was measured.

3.7 Casting of Concrete Specimens and Curing

3.7.1 Concrete Casting

Concrete was cast in cubes size (150*150*150) mm to investigate the compressive strength of the concrete. Different mixes are prepared at different percentages of replacement SCBA by cement. The concrete was mixed, placed, and compacted in three layers. The specimens were stored in moist air for 24 hours and the specimens were removed from the mold after 24 hours. Three samples were cast for each percentage of replacement at 7, 14, and 28 days of curing for the compressive strength test. Due to concrete gains maximum strength at 28 days and 65 % of the target strength by the time of 7 days, those curing periods were chosen.

In addition, until 14 days concrete shows up to 90 % of the target strength (Gupta et al., 2017) The minimum number of samples specified by ASTM C39 is three. To acquire a reliable value, three samples were prepared for each test in the current study. After thoroughly mixing the geopolymer concrete, the mixture was poured into a mold for compressive and durability tests. The samples were subjected to vibration on a vibrating table for 2 minutes to remove any remaining bubbles in the poured concrete. The molds were then kept in a room with ambient temperature.

3.7.2 Curing of Concrete Specimens

According to ASTM C192, curing concrete is the process of providing enough moisture, heat, and time to allow the cement to continue to hydrate until the concrete reaches the necessary qualities for the intended usage. Concrete curing is the process of hydrating freshly poured concrete to achieve optimal strength and durability. The concrete was cured in a water curing medium at room temperature for 7, 14, and 28 days after the researcher de-molded the concrete specimens. Concrete reaches 65% of its target mean strength after 7 days of curing, 90% after 14 days, and 99% after 28 days.

The properties of hardened concrete were investigated after casting a concrete cube having 150 x 150 x 150 mm size. The experimenter prepared concrete specimens by incorporating major concrete ingredients (SCBA, sand, coarse aggregate, sodium hydroxide, sodium silicate, and water) with different cement percentages.

3.8 Hardened Concrete Test

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

To monitor and validate the quality of cement concrete operations, testing hardened concrete is crucial. Any quality control program for concrete must include systematic testing of raw materials, freshly poured concrete, and hardened concrete. This helps to increase the material's efficiency and provides greater assurance of the concrete's performance in terms of strength and durability. The test procedures must be easy, clear, and practical to use.

3.8.1 Compressive Strength Test

Compressive strength is the ability of hardened concrete to withstand axial loads without any cracks or deflection. Therefore, this test aimed to determine the compressive strength of concrete with and without bacterial concentration and calcium lactate. The balance, mold, temping road, compressive test machine, trowel, shovel, and brush were used in the test.

A concrete cube of sample size 150 x 150 x 150 mm was cast to investigate the compressive strength of bacterial and normal concrete. The researcher determined the compressive strength after 7, 14, and 28 days of curing by using an automatic compressive strength test machine at Adama Science and Technology University, Construction Material Laboratory, per (ASTM C39).

To undergo the compressive strength test, the cast cubes were taken out of the curing water after 7, 14, and 28 curing periods and wiped out excess water from the surface. The test machine was then cleaned, placed the sample in the test machine, and applied the load was at a rate of 14 N/mm2/minute, having a load capacity of 3000 KN. When the specimens failed, the maximum load was recorded, and finally, the compressive strength was calculated.

Compressive strength = Load / cross-sectional area of the sample------------------Equation 3.14

The test results were compared to the target mean and characteristic strengths. The target mean strength is determined by designing the concrete mix according to the code.

According to ASTM C39 / C39M - 20a standard, the variance (S^2) and standard deviation (S) should be calculated using the equations given below:

$S^2 = \Sigma (x_i - \bar{x})^2 / (n - 1)$ -- Equation 3.15

Where, x_i is the strength of the individual specimen, $\bar{x}$ is the average strength of the specimens, and n is the total number of specimens.

$S = \sqrt{S^2}$-- Equation 3.16

Where, √ represents the square root symbol.

3.8.2 Durability Test

3.8.2.1 Water Absorption Test

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

$$\text{Water absorption \%} = \frac{S-O}{O} \text{ X } 100\%$$ ---Equation 3.15

Where; S = Weight of saturated surface dry concrete, O = Weight of oven-dry concrete

3.8.2.3 Sulphate Attack Test

This test method covers the determination of the resistance of concrete to sulfate attack by measuring the mass loss of concrete cubes after immersion in a sodium sulfate solution for a specified period of time. The test method is applicable to concretes that are to be exposed to sulfate rich environments and not applicable to concretes that are to be exposed to environments that are highly acidic or alkaline. The sulfate attack index should not exceed 0.5% and concrete cubes with a sulfate attack index greater than 0.5% are considered to be suspected to be sulfate attack. The test was conducted as per ASTM C1012.

Apparatus: Balance, Mold, Stirrer, Container, Graduated Cylinder

Procedure: - Prepare the concrete cubes in accordance with the requirements of ASTM C1012 standard. Prepare the sulfate solution by dissolving 50g of sodium sulfate (Na_2SO_4) in 1000ml of water. Immerse the concrete cubes in the sulfate solution so that all six sides are exposed to the solution. Expose the concrete cubes to the sulfate solution for a period of 30 days. Remove the concrete cubes from the sulfate solution and weigh them.

Calculate the mass loss of the concrete cubes by subtracting the weight of the dry concrete cubes from the weight of the wet concrete cubes.

Calculate the sulfate attack index by dividing the mass loss of the concrete cubes by the original mass of the concrete cubes.

Loss in Kg = W1-W2--Equation 3.16

% of Loss = (W1-W2)/ (W1)*100%--Equation 3.17

Where, W1= weight of the concrete before exposure to sulfate solution

W2 = weight of the concrete after exposure to the sulfate solution

3.9 Microstructural Test for Hardened Concrete

A technique for identifying the morphological properties of concrete is concrete microstructural analysis. Studying under a microscope and using X-ray microanalysis has been extremely helpful in the research of concrete microstructure. To take pictures of the complex microstructure of concrete and produce images with a sub-micrometre resolution, SEM and XRD techniques have been developed.

The SEM scans the specimen with a concentrated electron beam and records any signals created by the beam's interactions with the sample. Topography photos are used to examine a surface's size, form, surface roughness, and fracture. X-ray microanalysis provides element distribution maps and quantitative spot chemical analysis (Stutzman, 2000). To undertake an SEM study of the concrete, samples from the control mix and the 15% replacement were obtained after 28 days of curing. At first, the samples were made by taking a piece of the cured specimen and cutting it down to size. The produced samples were then brought to the SEM lab. The exhibited morphological images of the samples were then qualitatively analysed through observation once the analysis was completed.

To perform XRD analysis on the concrete, portions of the concrete were extracted from the control, and 15% of replacement specimens were cured for 28 days. The portions were taken from the top, middle, and bottom of the specimens. Then the portions were ground to powder and taken to the XRD laboratory. Following the analysis, the peaks were generated and interpreted on the Origin Software using the collected XRD data in terms of intensity and degree of diffraction.

3.10 Economic Evaluation of SCBA based Hybrid Geopolymer Concrete

The economic implications of using Hybrid geopolymer concrete over cement concrete were explored in terms of raw materials usage, energy usage, and economic implications. To investigate raw material usage, raw material consumption for the production of one cubic meter of conventional concrete and hybrid geopolymer concrete was calculated and compared.

The difference in incineration temperatures of cement clinker and SCBA was employed as a parameter to investigate the energy usage and coal consumption of conventional concrete and hybrid geopolymer concrete. Lastly, the cost of one cubic meter of conventional concrete and 15% of OPC hybrid geopolymer concrete was computed to explore cost implications. The current market price of materials and the cost of SCBA production were used to calculate the concrete cost.

3.11 Summary

The chapter covers the research methodology, starting with an overview of the approach taken, followed by a detailed explanation of the methods used to achieve each individual objective. The study involved experimental research in which the workability, compressive strength, water absorption, and resistance to sulphate attack of hybrid geopolymer concrete were tested, along with microstructural analysis. Additionally, the economic feasibility of using hybrid geopolymer concrete was evaluated.

Furthermore, the chapter includes a discussion on the materials, experimental techniques, and methods employed to analyse the physical and chemical properties of cement, sand, coarse aggregate, and SCBA. The process for evaluating a material's workability, silt content, gradation, and densities was also addressed. Proportions for achieving compressive strength were determined for the mix. The materials and methods utilized were examined in-depth based on their relevance to the specific objectives of the study. The next chapter covers various analyses and discussions conducted using the research methodology for different objectives of the study.

4. RESULTS AND DISCUSSION

4.1 Introduction

The preceding chapter explained the research methodology used in this study. This chapter presents the test results for cement, SCBA, fine aggregate, and coarse aggregate. The materials used in this research and the chemical analysis of SCBA were discussed. The consistency of the blended paste was also noted, as well as the workability, compressive strength, water absorption, sulfate attack, and microstructure of the concrete. Furthermore, the economic implications of incorporating 15% OPC with SCBA in the production of hybrid geopolymer concrete in compared to conventional concrete was investigated and presented.

4.2 Results of Material Testing and Discussion

This section addressed the test results for cement, SCBA, fine aggregate, and coarse aggregate.

4.2.1 Fine Aggregate Test Result Analysis

Silt content, sieve analysis, unit weight, specific gravity, and water absorption of the fine aggregate were all determined and discussed in this part, along with the findings of the physical tests conducted on the material.

4.2.1.1 Silt Content

The amount of silt deposited over the clean sand was measured by silt content analysis before using fine aggregate for concrete production. For the quality of the mix and to get a better outcome, the fine aggregates were washed after the silt content measurement to remove silt, clay, dirt, and other impurities (ASTM C 11). Equation 3.1 was used to calculate the silt content. As shown in Table 4.1, the fine aggregate's silt content was 2.72%, which falls within the permitted range for use in concrete production as per ASTM C 33.

Table 4. 1 Silt Content Analysis

Items	Trial 1	Trial 2	Trial 3	Average
A	9	8	7.5	8.17
B	300	300	300	300
Silt content (%) = $\frac{A}{B}$ x 100 %	3	2.67	2.5	2.72%

4.2.1.2 Sieve Analysis of Fine Aggregate

The purpose of the laboratory test was to evaluate whether the physical characteristics of the original sand sample met the requirements for grading and to calculate the fineness modulus of the fine aggregate. Sieve analysis is used to measure the particle size distribution of material. 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and pan sieve sizes were used for this investigation.

The fineness modulus of fine aggregate is illustrated in Table 4.2 and Figure 4.1. Using Equation 3.2, the fineness modulus of the fine aggregate was calculated. The results showed that the fine aggregate's fineness modulus was 2.82, and the percent finer was within the range of (ASTM C33).

Table 4. 2 Sieve Analysis of Fine Aggregate

Sieve size (mm)	Weight of container (g)	Weight of container + FA (gm)	The weight of FA retained (g)	Percentof FA retained (g)	Cumulative percent retained (%)	Percentfiner (%)	Range of finer (%)
4.75	440	440	0	0	0	100	98-100
2.36	406	471	65	13	13	87	80-100
1.18	358	438	80	16	29	71	50-85
0.60	329	442	113	22.6	51.6	48.4	25-60
0.30	302	484	182	36.4	88	12	5-30
0.15	278	338	60	12	100	0	0-10
Pan	250	250	0	0	0	0	-
	Total cumulative percentage retained by mass				281.6		

Figure 4.1 below shows the fine aggregate gradation curve.

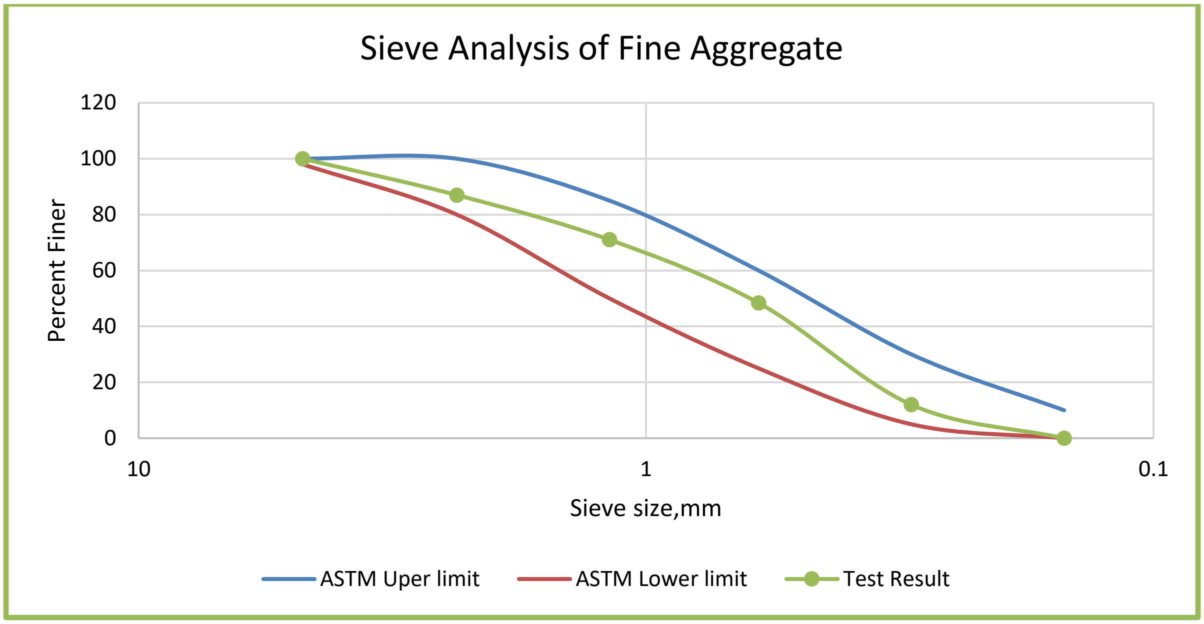


Figure 4. 1 Gradation Curve of Fine Aggregate

4.2.1.3 Unit Weight of Fine Aggregate (UWFA)

The volume that fine aggregate will occupy in the concrete is measured by the unit weight of the material. The unit weight of fine aggregate (UWFA) was calculated using Equation 3.3, and the result showed that it was 1463.27 kg/m3.

- The weight of empty cylinder (Y) was 4.734 kg
- The volume of the cylinder was (V) 0.001375 m3
- The weight of the fine aggregate plus the cylinder (X) was 6.746 kg

Unit weight = $\frac{X-Y}{V} = \frac{(6.746-4.734)kg}{0.001375m3}$ = 1463.27kg/m^3

Therefore, the computed unit weight of fine aggregate was within the range (1200 to 1750) kg/m3 that specified by ASTM C29.

4.2.1.4 Specific Gravity and Water Absorption of Fine Aggregate

The mass of a certain volume of material divided by the mass of a corresponding volume of water is known as specific gravity. The ratio of the difference between the weight of the aggregate in the surface-dried saturated condition and the weight of the oven-dried aggregate is used to calculate an aggregate's water absorption. Equations 3.4, 3.5, and 3.6 were used in this investigation to calculate the bulk specific gravity (Bsg), apparent specific gravity (ASG), and water absorption of fine aggregate. The Bsg, Asg, and water absorption values were 2.78, 2.7, and 2.67%, respectively (Table 4.3), and each value was within the range specified by ASTM C33.

Specific gravity and water absorption of fine aggregate were computed through obtained test results:

- The weight of the oven-dry specimen in the oven (X) was 487 grams.
- The weight of the pycnometer filled with water (Y) was 1420 grams.
- The weight of the saturated surface dry specimen (Z) was 500 grams.
- The weight of the pycnometer with specimen and water to calibration mark (W) was 1740 grams.

Table 4. 3 Specific Gravity and Water Absorption of Fine Aggregate

	Calculation	Result
Bulk specific gravity (BSG)	$\frac{500}{(1420+500-1740)}$	2.78
Apparent specific gravity (ASG)	$\frac{447}{(1420+500-1740)}$	2.7
Water absorption (WA) in %	$\frac{500-487}{487} * 100$	2.67

4.2.2 Tests on Coarse Aggregate

In general, coarse aggregates are defined as those aggregates retained on the 4.75-mm sieve. It is a granular, uneven material developed from crushed stone that can be manually or mechanically crushed in quarries. The information gathered during laboratory work was used to determine and analyze sieve analysis, unit weight, and specific gravity of coarse aggregate in this section.

4.2.2.1 Sieve Analysis for Coarse Aggregate

To determine if the coarse aggregate's physical characteristics complied with ASTM C136's grading requirements, a laboratory test was conducted. The grain size distribution of the coarse aggregate and the grading requirement for coarse aggregate according to ASTM C136 (2006) is as show in Table 4.4

Table 4. 4 Sieve Analysis for Coarse Aggregate

Sieve size (mm)	Weight of container (g)	Weight of container + CA (g)	The weight of CA retained (g)	Percent of CA retained (g)	Cumulative percent retained (%)	Percent finer (%)	Range of finer (%)
20	1,380	1,380	0	0	0	100	100
19	433	498	65	3.25	3.25	96.75	95 -100
12.5	440	1,155	715	35.75	39	61	40 – 80
9.5	443	1,153	710	35.5	74.5	25.5	20 -55
4.75	440	950	510	25.5	100	0	0 -10
Pan	252	252	0	0	0	0	-

The gradation curve of the employed coarse aggregate was within the ASTM lower and higher limits, as shown in Figure 4.2. As a result, the coarse aggregate used in the current study met the ASTM requirements.

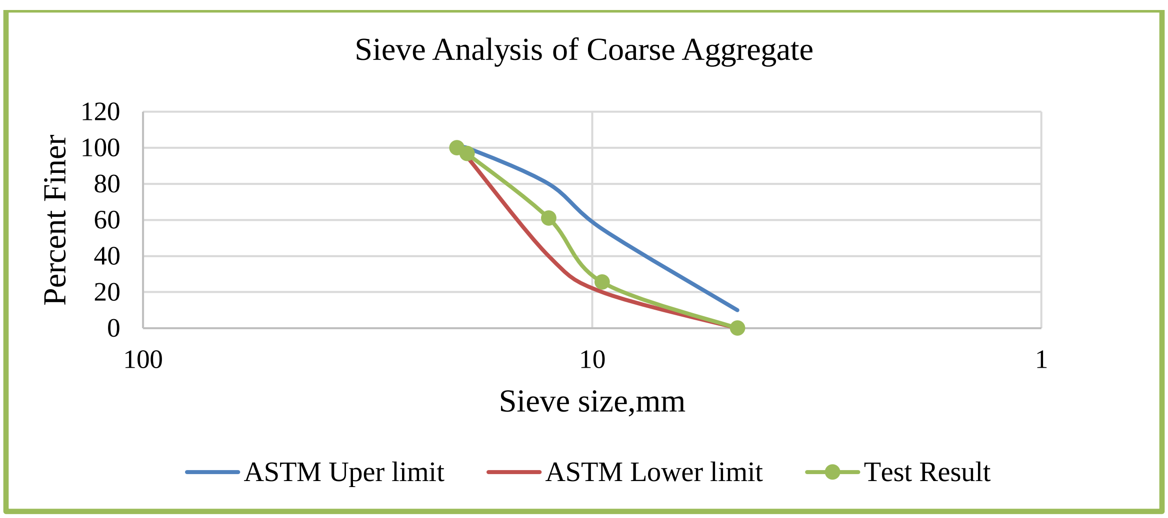


Figure 4. 2 Gradation Curve of Coarse Aggregate

4.2.2.2 Unit Weight of Coarse Aggregate (UWCA)

The volume that the coarse aggregate will occupy in the concrete is measured by the unit weight of the material. Equation 3.8 was used to calculate the UWCA, and the outcome reveals that coarse aggregate weighs 1,634.9kg/m3 per unit. This section's test result complies with the (ASTM C29) standard.

- The weight of empty cylinder (Y) was 4.734 kg
- The volume of the cylinder was (V) 0.001375 m3
- The weight of the coarse aggregate plus the cylinder (X) was 6.982 kg

Unit weight = $\frac{X-Y}{V} = \frac{(6.982-4.734)kg}{0.001375\text{m3}} = 1634.9\text{kg/m}^3$

4.2.2.3 Specific Gravity and Water Absorption Capacity of Coarse Aggregate

Based on the findings of laboratory tests, the bulk specific gravity (Bsg), apparent specific gravity (ASG), and water absorption capacity of coarse aggregate were calculated and analyzed in this thesis work. Equations 3.9, 3.10, and 3.11 were used to calculate the Bsg, Asg, and water absorption of coarse aggregate, which are shown in Table 4.5. According to the test results, coarse aggregate had Bsg, Asg, and water absorption capabilities of 2.61, 2.68, and 1.67%, respectively. The test result obtained in this instance complies with (ASTM C127) standards.

- The weight of the oven-dry specimen in the oven (H) was 2948 grams.
- The weight of the saturated surface dry specimen (G) was 3000 grams.
- The weight of the specimen in the water with the wire basket (F) was 1846 grams.

Table 4. 5 Specific Gravity and Water Absorption Capacity of Coarse Aggregate

	Calculation	Result
Bulk specific gravity (BSG)	$\frac{3000}{3000-1846}$	2.6
Apparent specific gravity (ASG)	$\frac{2948}{2948-1846}$	2.68
Water Absorption (WA) in %	$\frac{3000-2948}{2948} * 100$	1.76

Table 4.6 shows the summary of test results of fine aggregate and coarse aggregate.

Table 4. 6 Summary of test results of fine and coarse aggregate.

Test Description	Fine Aggregate	Coarse Aggregate
Silt Content (%)	2.72	-
Max Size(mm)	4.75	20.00
Unit Weight (kg/m3)	1,463.27	1,634.90
Water Absorption (%)	2.67	1.76
Fineness Modulus	2.82	-
Bulk Specific Gravity	2.78	2.6
Apparent Specific Gravity	2.7	2.68

4.2.3 Sugarcane Bagasse Ash

4.2.3.1 Sieve Analysis of Sugarcane Bagasse Ash and Cement

The fineness of cement affects the hydration rate and in turn the strength. This test was carried out to determine the percentage of fine particles of SCBA and cement that pass through a sieve opening of 75 µm. As shown in Table 4.7, 88% of SCBA was passed through a sieve opening of 75 µm, whereas 78% of cement passed. As a result, SCBA is finer than cement, implying that SCBA has a larger specific surface area than cement. This is because as particle size decreases, the surface area of substances increases (Selamawit W, 2020). Surface area of bagasse ash particles are large. Sometimes the specific surface are of bagasse ash particles are more than three times the surface area of Portland cement (Ganesan et al., 2007). This implies a reduction in particle size utilized to fill the gap between aggregates.

Table 4. 7 Particle size of cement and SCBA

Sieve size (mm)	Wt. of size (g)	Cement			SCBA		
		Wt. of size and retained (g)	Wt. of retained (g)	Percent finer (%)	Wt. of size and retained (g)	Wt.of retained (g)	Percent finer (%)
150	282	282	0	100	282	0	100
75	273	290	22	78	285	12	88
Pan	252	285	78	0	323	88	0
Total			100			100	

4.2.3.2 Specific Gravity of Cement and SCBA

The specific gravity of cement and SCBA were 3.14 and 2.45 respectively. As shown in Table 4.8, the specific gravity of SCBA is smaller than that of cement. This implies SCBA was lighter than cement. Besides, the computed specific gravity of cement was within a range of ASTM C188 (2009) standard, which ranges (from 3.1 to 3.16). The low specific gravity of CBSA causes a reduction in the unit weight of concrete. The specific gravity of SCBA and cement was calculated by using Equation 3.10, where the specific gravity of kerosene was 0.81.

Table 4. 8 The result of the specific gravity of cement and SCBA

	Denotation		Samples(g)			
			1	2	3	Avg.
Weight of flask (g)	A	SCBA	62.48	62.48	62.48	62.48
		Cement	62.48	62.48	62.48	62.48
Weight of pycnometer with SCBA (g)	B	SCBA	87.40	87.41	87.49	87.43
		Cement	87.38	87.40	87.49	87.41
Weight of pycnometer with SCBA and kerosene (g)	C	SCBA	166.8	166.83	166.85	166.83
		Cement	166.87	171.35	169.15	169.79
Weight of pycnometer with kerosene (g)	D	SCBA	148.34	148.37	148.41	148.37
		Cement	148.35	148.56	148.74	148.55
Specific gravity	S			SCBA		2.45
				Cement		3.14

4.2.3.3 Unit Weight of SCBA

Unit weight is the weight per unit volume of a material. In the case of concrete, unit weight is typically reported in pounds per cubic foot or kilograms per cubic meter. Unit weight of SCBA was calculated through obtained test results:

The weight of empty cylinder (C) was 4.740 kg,

The volume of the cylinder was (V) 0.001375 m^3, and

The weight of the cylinder filled with CBSA (F) was 5.985 kg

$$\text{Unit weight} = \frac{F-C}{V} = \frac{5.985-4.740}{0.001375} = 905.47\ kg/m^3$$

As the result, unit weight of SCBA was lower than the cement that is 1440 kg/m3 that indicates concrete with SCBA was lighter than that of cement-based concrete.

4.2.3.4 Chemical Composition of SCBA

The chemical composition of SCBA was determined through complete silica analysis at the laboratory of the Ethiopian Geological Survey and presented in Table 4.9. The results indicate that SCBA has a high LOI percentage and SiO_2 concentration (53.44%). The presence of carbon in the ash from low combustion temperatures is the cause of the high LOI in SCBA. Barrack and Sylvester (2021) assert that low-temperature burning of chemicals improves the value of LOI. The SCBA's LOI value is 10.68%, which is less than the maximum value of 12% allowed by ASTM C618. SiO2, Al2O3, and Fe2O3 make up 71.53% of the total oxide composition, which is less than 70%. Therefore, SCBA exhibited pozzolanic properties and belonged to the class F of pozzolanic materials, as per ASTM specifications.

Table 4. 9 Oxide composition of SCBA

Oxide Composition (%)	SCBA [Appendix C]
SiO_2	53.44
Al_2O_3	15.13
Fe_2O_3	2.96
CaO	1.96
MgO	0.78
Na_2O	1.36
K_2O	2.28
MnO	0.06
P_2O_5	0.66
TiO_2	0.45
H_2O	2.31
LOI	10.68
$SiO_2 + Al_2O_3 + Fe_2O_3$	71.53

4.2.3.5. Microstructure of SCBA

A study was conducted on the morphology of SCBA particles using scanning electron microscopy (SEM). The findings from SEM analysis of SCBA at 20μm and 50μm grid sizes were presented in Figures 4.3. Figure 4.3 (a) displayed micrographs that provided a qualitative description of the phases observed in SCBA, which appeared to have irregular shapes. At higher magnifications, the microstructure revealed the presence of irregularly shaped particles, indicating the presence of silica in the ash. Magnified images of SCBA in Figure 4.3 (b) indicated the presence of a porous network with small cavities on its surface. Due to its porous structure, SCBA can increase the absorptiveness of geopolymer concrete, which can lead to higher permeability and lower durability. On the other hand, the porous structure of SCBA particles can also help to improve the overall workability and strength of the geopolymer concrete, due to its ability to provide a better bond between the aggregate and cementitious materials.

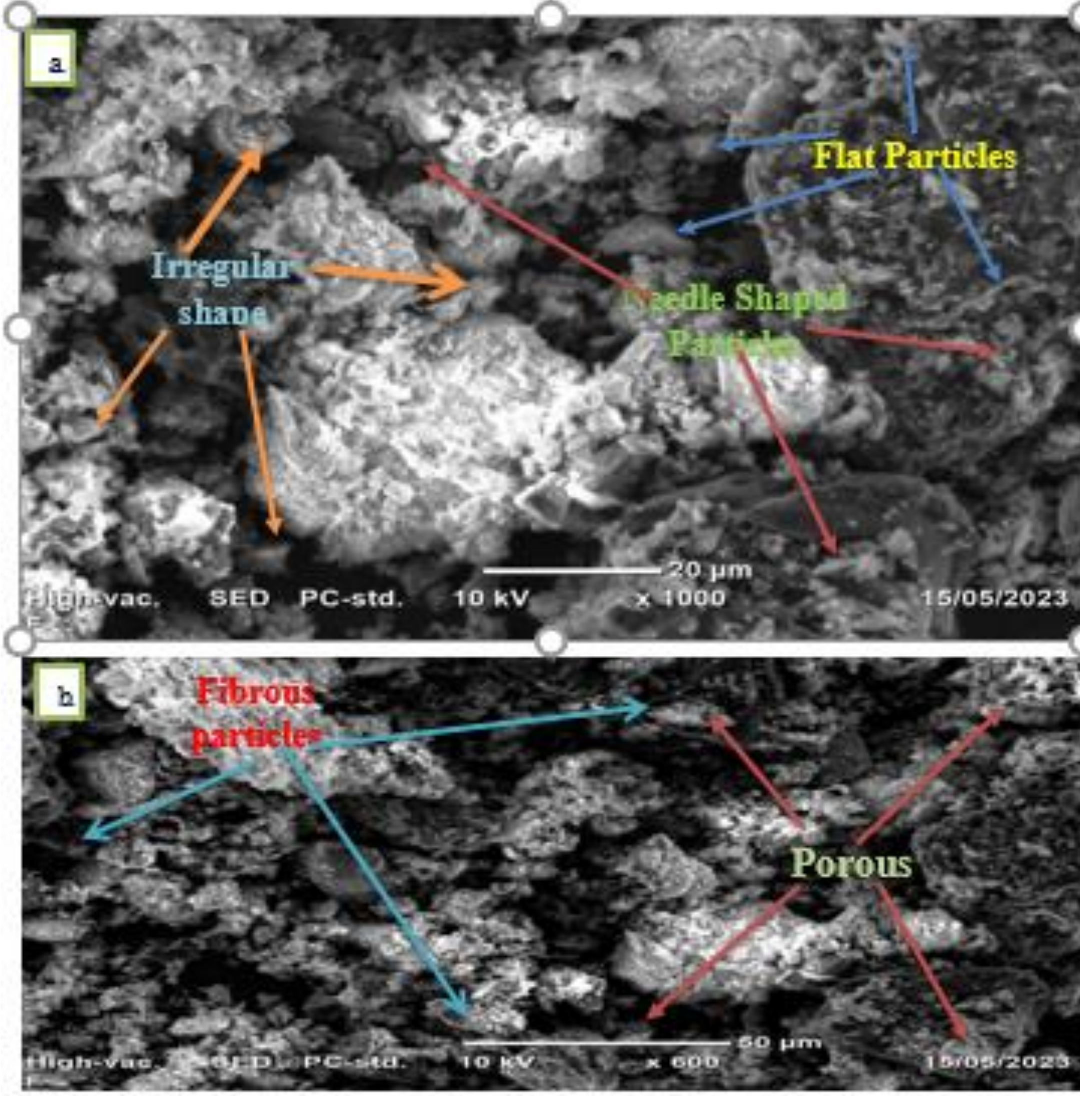


Figure 4. 3 SEM image of SCBA at a) 10µm and b) 50µm magnification.

The X-ray diffraction patterns of SCBA were studied using an XRD diffractometer with specific settings. The resulting data was processed with the Origin Pro software to determine the crystallographic phases of SCBA. Figure 4.4 illustrates the XRD pattern of SCBA. The peak at 2θ values of 28.6° indicated the presence of quartz (SiO_2). Whereas, Calcite (Ca) and cristobalite (C) were found to have a tetragonal crystal system, accounting for 67.2% and 32.8% of quantities, respectively. Additionally, magnetite (Fe_2O_3) was detected at a 2θ value of 24.7°. The qualitative examination of SCBA indicated that silica had an amorphous structure. The intensity of the diffraction peaks associated with a phase reflects the concentration of the crystallographic component that makes up the phase, and the difference in peak intensities indicates a difference in component concentrations (Memon et al., 2021). The diffraction patterns revealed a small amount of amorphous silica in SCBA. Due to its greater reactivity, amorphous silica is preferred over crystalline silica as it accelerates the pozzolanic reaction.

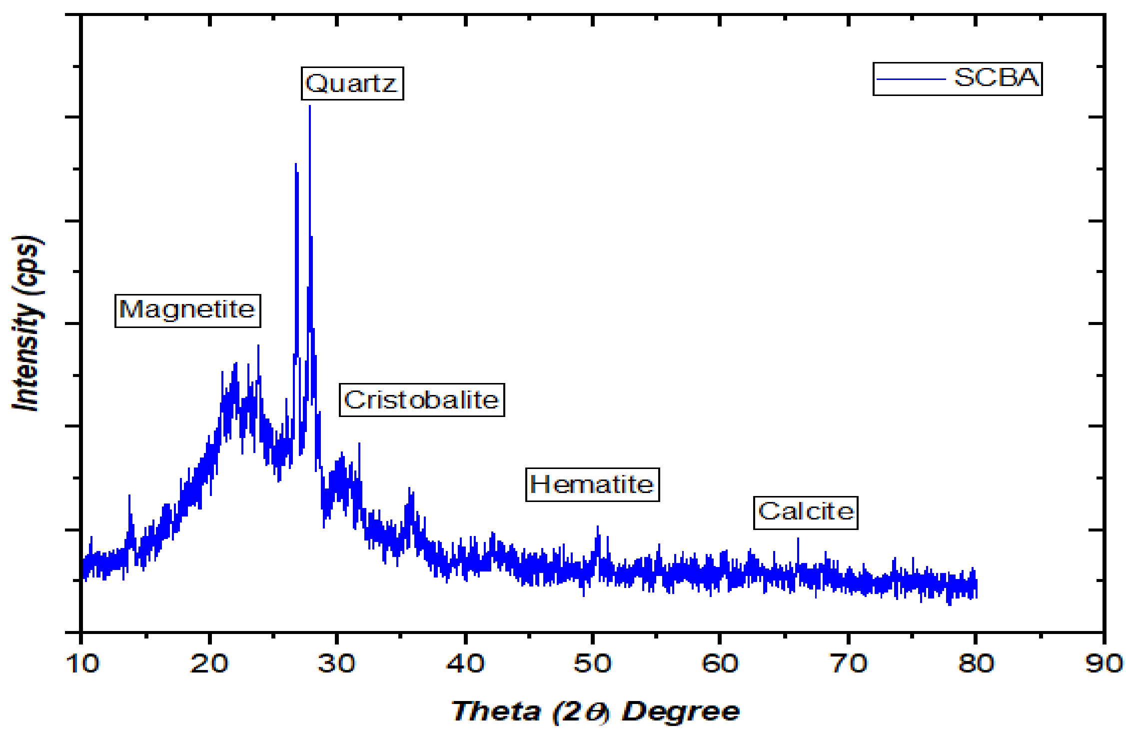


Figure 4. 4 XRD analysis of SCBA

4.2.4 Normal Consistency of Blended Paste

The normal consistency of the control (OPC) paste was 26%. The usual consistency of all blended pastes was greater than the control paste, as shown in Table 4.10. At 0, 5, 10, 15, 20, and 25% of replacement, normal consistency of blended pastes was attained at 35, 33, 31, 28, 28, and 27%, respectively. According to ASTM C187 **(**2016) range, the normal consistency of blended paste at 0%, 15%,20%, and 25%, replacements was in ranges (22-30 %). Whereas at, GPC, 5% and 10% of replacements were beyond the specified range. Based on the current investigation, blended paste with 25% OPC was chosen over other replacement percentages excluding control paste. Table 4.10 displays normal consistency of blended paste.

Table 4. 10 Result of normal consistency of blended paste with OPC

Mix code	Normal consistency (%) (ASTM C187)
OPC	26
GPC	35
GeoPC 5	33
GeoPC 10	31
GeoPC 15	28
GeoPC 20	28
GeoPC 25	27

Figure 4.5 indicates that the normal consistency declined as the replacement percentage increased.

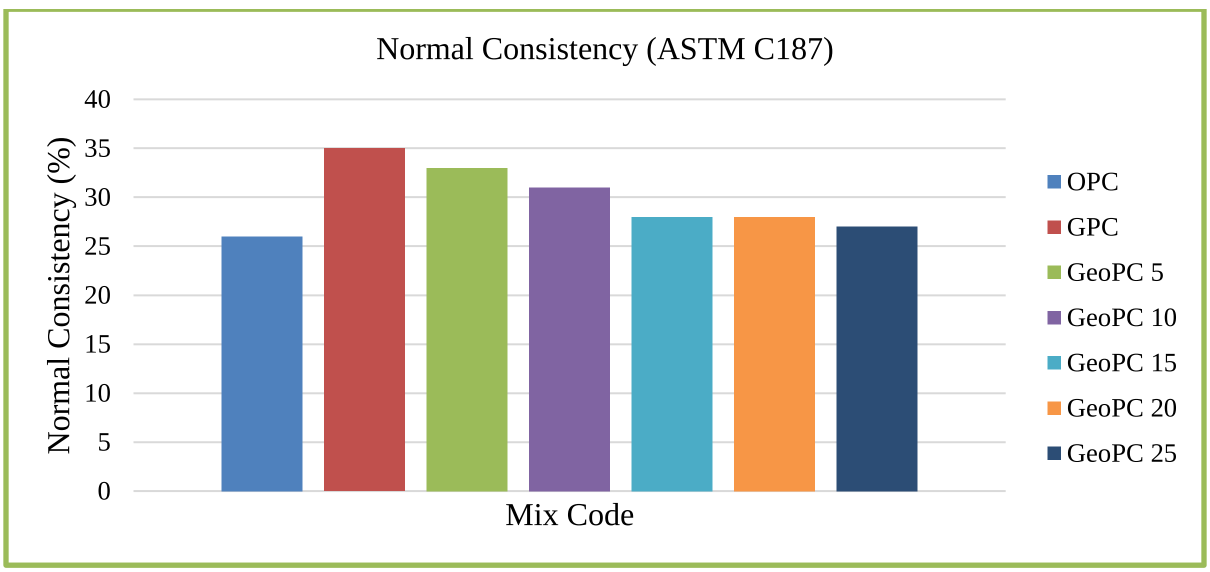


Figure 4. 5 Chart of normal consistency of blended paste

4.3 Workability of the Concrete

The workability of geopolymer concrete with the percentage replacement of SCBA with OPC is depicted in Table 4.11. From the acquired results, it is clear that workability decreases when more SCBA is replaced with OPC increases. The use of some water for the cement hydration process, which enhances the cohesiveness of the geopolymer concrete mix, and the quick reaction of OPC with the alkaline activators are the main causes of a decrease in the workability of geopolymer concrete (Raj R.1 Samuel & Arulraj G Prince, 2020). Detail result for each samples attached in Appendix B1.

Table 4. 11 Result of mean slump value of fresh concrete.

No.	Mix Code	Percent replaced	Slump results in mm
1	OPC	0	27
2	GPC	0	50
3	GeoPC 5	5	45
4	GeoPC 10	10	32
5	GeoPC 15	15	28
6	GeoPC 20	20	23
7	GeoPC 25	25	21

As shown in Figure 4.5, the slump values of samples GPC, GeoPC5, GeoPC10, and GeoPC15 rose by 85.18%, 66.67%, 18.52%, and 3.7% respectively. Whereas, the slump values of samples GeoPC20 and GeoPC25 dropped by 14.81% and 22.22%, respectively, when compared to the control slump value.

In general, the addition of mixing water can aid in simple mixing and workability, but it generates increased porosity, which results in strength and durability degradation (Raj R.1 Samuel & Arulraj G Prince, 2020). In the current study, concrete with 15% of OPC showed better workability when compared to other replacement percentages except for the control mix.

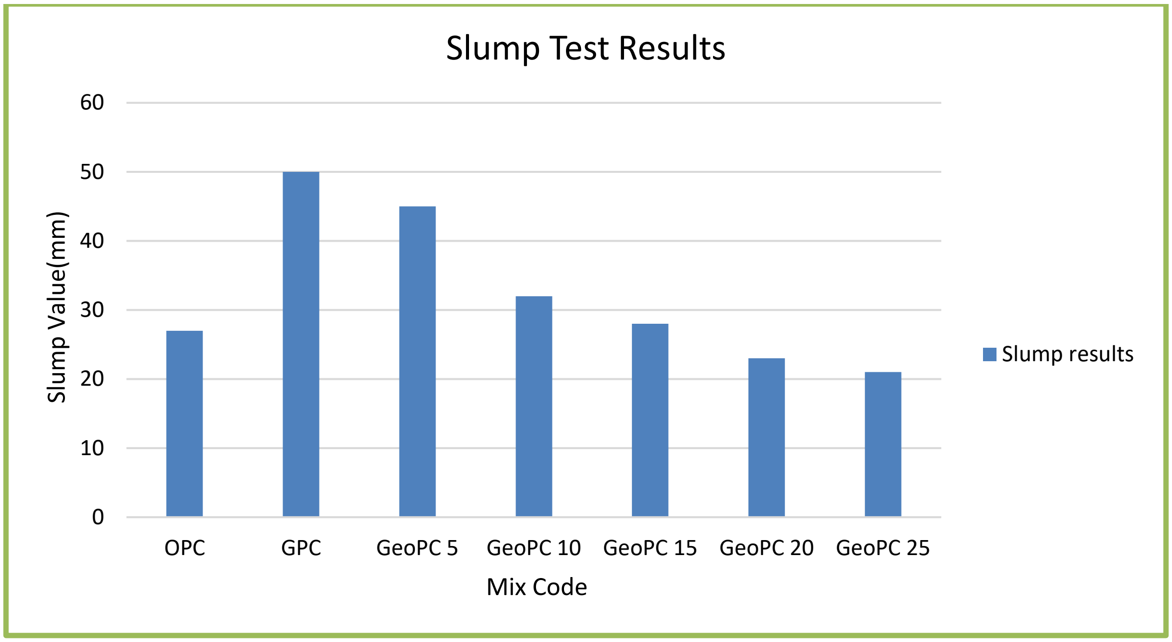


Figure 4. 6 Chart shows the slump value of concrete at different percentages of replacement.

4.4 Hardened Concrete Test Result

Hardened concrete is a strong form of concrete that can withstand service and structural loads. It is one of the most durable and strong building materials. Load capacity refers to properly hardened concrete. Based on the findings of the laboratory tests, the compressive strength, water absorption, sulfate attack, and microstructure of SCBA hybrid GeoPC and conventional concrete were examined in this section.

4.4.1 Compressive Strength

The compressive strength test is the most common test for hardened concrete. On this property, several codes and design manuals have been established. In contrast to other tests, concrete is easy to identify when it comes to additional features that depend on compressive strength. Cubes 150 x 150 x 150 mm in size were used to evaluate the compressive strength of concrete while they were under a 3000 KN compression machine. For each mix code and curing day, three cube samples were analyzed, and the average values were used to calculate the compressive strength of the concrete. The detail results of compressive strength test are presented in Appendix B_2, and average compressive strength results are summarized in Table 4.12.

Table 4.12 Average compressive strength of the concrete with different replacement percentages at 7, 14, and 28 days' age.

No	Mix Code	Average compressive strength in N/mm^2			Improvement (%) at 28 day
		7th day	14th day	28th day	
1	OPC	16.53	22.31	26.82	
2	GPC	0	0	11.09	-58.65
3	GeoPC 5	8.79	10.15	18.91	-29.45
4	GeoPC 10	12.61	18.15	29.11	+8.54
5	GeoPC 15	17.28	25.46	33.07	+23.31
6	GeoPC 20	13.75	18.69	30.84	+14.99
7	GeoPC 25	12.44	16.81	26.46	-1.342

Table 4.12 shows that the compressive strength of concrete with 10%, 15%, and 20% OPC replacement improves by 8.54, 23.31, and 14.99% when compared to conventional concrete. Figure 4.6 illustrates the impact of OPC addition on the compressive strength of geopolymer concrete. Figure 4.6 shows that when SCBA is replaced with OPC for moist curing, the compressive strength of geopolymer concrete increases by up to 15%. The compressive strength drops after 15% replacement is reached. On the other hand, increasing the OPC content can also reduce the ultimate strength of the geopolymer concrete due to its lower Al_2O_3/SiO_2 ratio compared to SCBA. 33.07 N/mm^2 was found to be the maximal strength at the optimal replacement level, which is higher than that of the reference specimens. The mix's poor workability was the main cause of the loss in strength above the desired level of replacement. The workability of the concrete declines when the water in the concrete is used by the cement to hydrate (Hongen Zhang et al., 2019). This causes inappropriate compaction,

which lowers the strength. Moreover, the compressive strength of SCBA based hybrid geopolymer concrete with 15% OPC replacement was greater than the characteristics compressive strength of C-25, which has 25 N/mm^2.

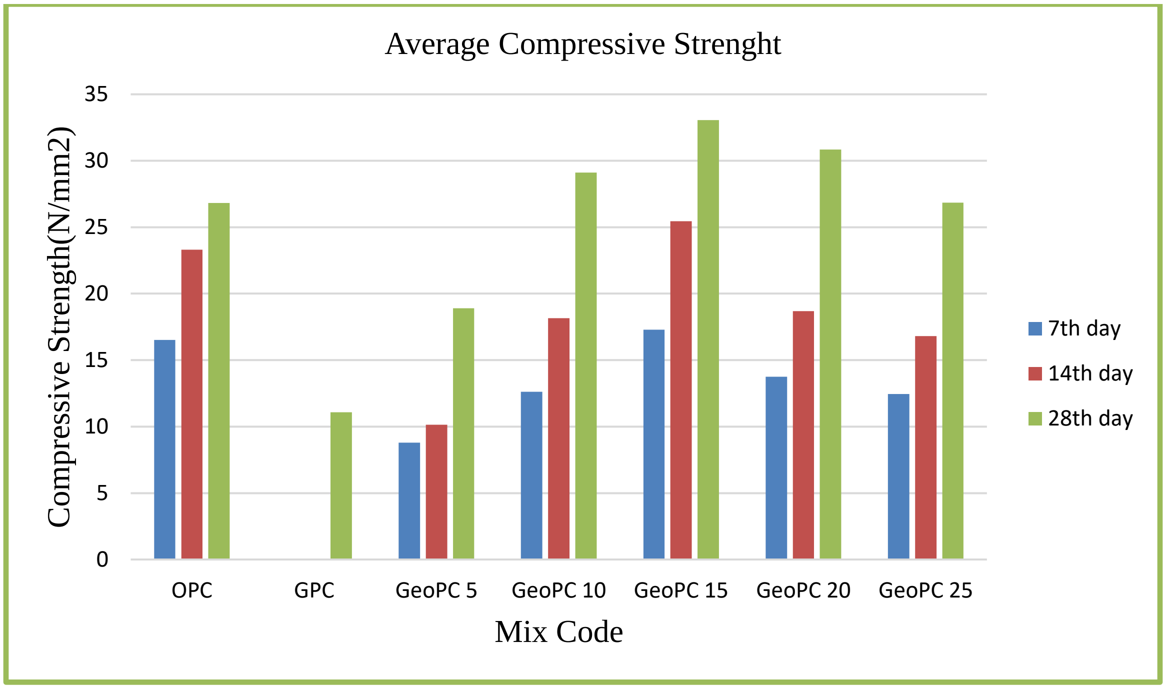


Figure 4. 7 Average compressive strength of the concrete.

As illustrated in Table 4.12 and Figure 4.7, concrete with 10%, 15%, and 20% OPC shows improvement while concrete with 5, and 25%, of OPC, as well as GPC shows negative improvement (reduction).

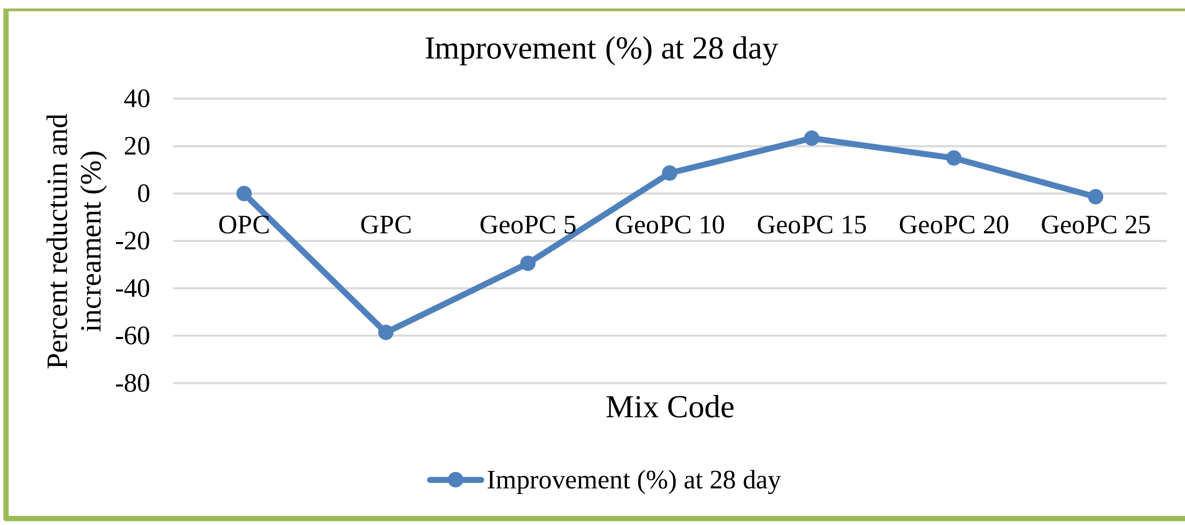


Figure 4. 8 OPC mix code compressive strength compression to other mix codes.

For characteristic compressive strength of concrete, a smaller standard deviation indicates higher consistency or uniformity in strength among different samples, while a larger standard deviation signals more significant variability in strength, which could indicate issues in mix design, curing conditions or variations in raw materials. Therefore, it is an essential parameter to monitor in concrete production and quality control.

Table 4.13 variance and standard deviation of different concrete sample for compressive strength at different curing days

No	Mix Code	Test day	Compressive Strength				Variance	Standard deviation
			S1	S2	S3	Mean		
1	OPC	7	15.24	17.56	16.78	16.53	0.93	0.96
		14	22.37	23.48	24.08	23.31	0.51	0.71
		28	26.45	26.87	27.15	26.82	0.09	0.31
2	GPC	7						
		14						
		28	11.07	10.52	11.63	11.09	0.09	0.44
3	GeoPC5	7	8.24	9.23	8.91	8.79	0.19	0.41
		14	9.61	9.78	11.05	10.15	0.17	0.64
		28	18.71	18.89	19.13	18.91	0.41	0.17
4	GeoPC10	7	12.72	11.63	13.48	12.61	0.03	0.78
		14	17.85	18.64	18.78	18.42	0.61	0.41
		28	29.15	28.91	29.26	29.11	0.17	0.15
5	GeoPC15	1	18.06	17.26	16.53	17.28	0.02	0.63
		14	24.08	25.48	26.81	25.46	0.39	0.49
		28	33.21	33.63	32.28	33.07	0.25	0.57
6	GeoPC20	7	13.63	13.39	14.24	13.75	0.32	0.36
		14	18.08	18.75	19.24	18.69	0.23	0.48
		28	30.46	30.87	31.19	30.84	0.09	0.29
7	GeoPC25	7	11.72	13.01	12.59	12.44	0.29	0.54
		14	16.54	16.82	17.03	16.81	0.04	0.21
		28	26.51	26.37	27.69	26.86	0.04	0.59

4.4.2 Water Absorption

Water absorption is used to determine the amount of water absorbed under specified conditions. A water absorption test was conducted to measure the durability of the concrete. This test is performed to assess the water retention qualities and evaluate water penetrability. GPC has less water absorption, and less porosity as the geopolymer materials are finer than control concrete components (Niveditha, 2020). The specimen with lesser water absorption yields greater compressive strength. The water absorption was computed using Equation 3.14.Detailed results for all samples are presented in Appendix B_3.

Table 4. 14 Average water absorption of concrete at 7 days and 28 days in percentage.

Mix code	Average of water absorption percentage					
	At 7th day			At 28th day		
	O(g)	S(g)	% of water absorption	O(g)	S(g)	% of water absorption
OPC	749	7795	6.14	757	801	5.81
GPC		`		732	765	4.51
GeoPC 5	737	761	3.26	735	759	3.18
GeoPC 10	729	758	3.96	743	766	3.09
GeoPC 15	745	768	3.09	758	778	2.64
GeoPC 20	734	765	4.22	733	761	2.77
GeoPC 25	756	725	4.28	737	766	2.94

The incorporation of more OPC results in an increase in water absorption, which reduces the durability of the concrete. This is due to the formation of weaker and more permeable calcium hydroxide (CH)(Koniki, 2020). From the current study finding using concrete with 15%, replacement is acceptable rather than the other replacement percentages in terms of water absorption of the concrete. This could explain why the compressive strength was higher at 15% replacement as compared to the control mix, which had reduced water absorption capabilities.

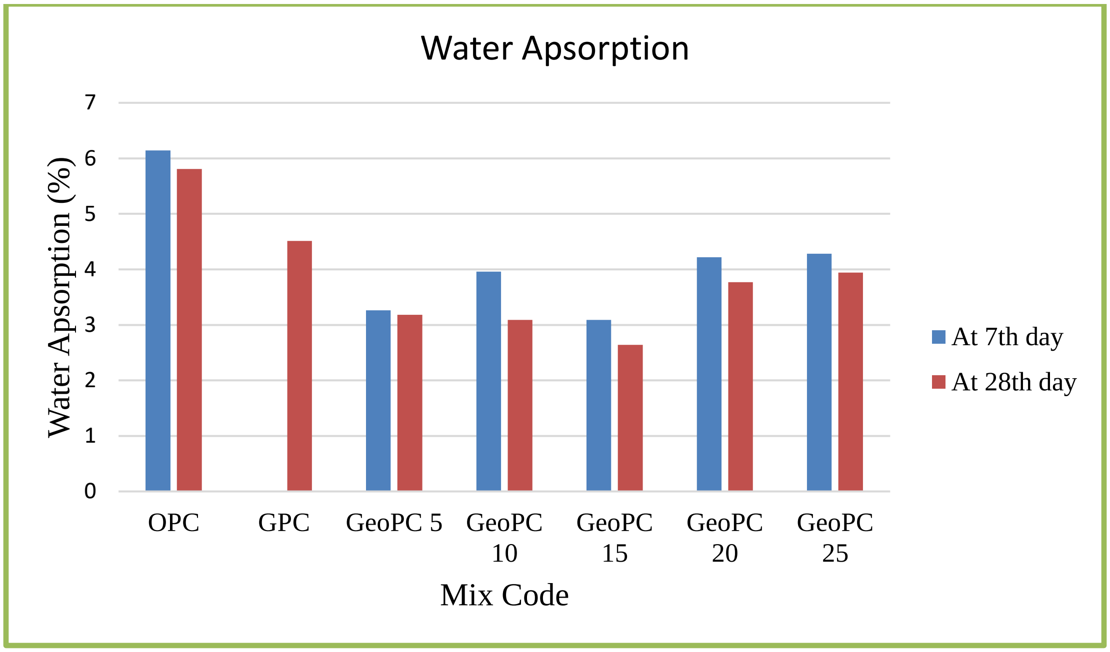


Figure 4. 9 Water Absorption of Concrete at 7 and 28 Days of Curing

4.4.3 Sulfate Attack

The weight loss from various types of concrete was measured through tests conducted following ASTM C1012 guidelines. Results of the sulfate attack test can be found in Table 4.13. The results indicate that when exposed to a sulfate attack solution for 30 days, hybrid geopolymer concrete exhibited a smaller percentage of weight loss compared to conventional concrete. Detailed results for all samples are presented in Appendix $B_{4.}$

Table 4. 15 Average Sulfate Attack of concrete at 28 days in percentage.

Mix Code	W_1(kg)	W_2(kg	Weight loss in kg @ 28 days	% Loss
OPC	7.688	7.648	0.041	0.52
GPC	7.571	7.538	0.035	0.45
GeoPC 5	7.482	7.449	0.033	0.44
GeoPC 10	7.722	7.701	0.022	0.29
GeoPC 15	7.421	7.404	0.016	0.26
GeoPC 20	7.356	7.339	0.010	0.23
GeoPC 25	7.555	7.533	0.009	0.22

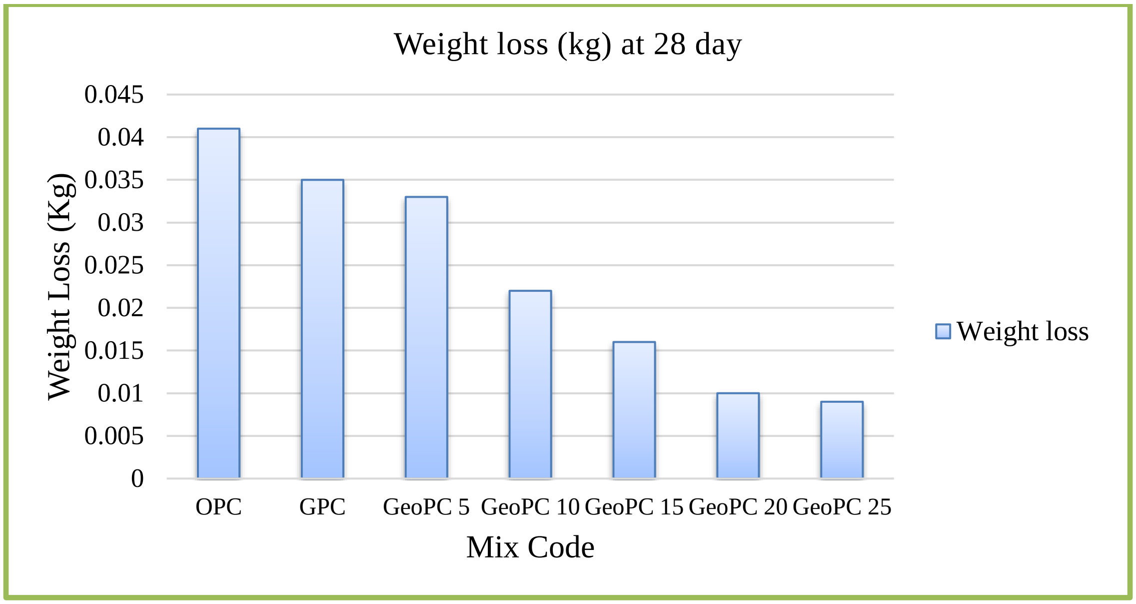


Figure 4. 10 Sulfate attack of Concrete at 28 Days of Curing

Based on the data presented in Figure 4.10, it was observed that the weight loss of concrete specimens with replacements of 5%, 10%, 15%, 20%, and 25% OPC were lower than that of the control specimens. Studies have shown that adding OPC (Ordinary Portland Cement) to SCBA based geopolymer concrete mixes can improve their sulfate attack resistance. This improvement is due to the addition of calcium oxide from OPC, which reacts with sulfate ions present in the environment and forms calcium sulfates. However, excessive use of OPC may result in a negative impact on the sustainability of the geopolymer concrete, and a balance is required between improving sulfate attack resistance and maintaining overall sustainability.

4.4.4 Microstructure of the Concrete

Microstructural observations of control and 15% OPC mixtures using SEM investigation can be seen in Figure 4.10 shows. Due to the greatest compressive strength, improved workability reported reduced water absorption, and less weight loss during sulfate attack at 15% replacement compared to other replacement percentages, the GeoPC15 mix was studied using SEM. The capture of SEM pictures follows a prolonged 28-day curing process. The microstructure of each blend was examined under (x1000) magnification. By its comparative brightness and hexagonal patterns in the concrete, calcium hydroxide can be identified (Stutzman, 2000). Figure 4.10(a) depicts the thin, brilliant structure that was seen in the control mixture and may have been CH. The SEM analysis revealed that the GeoPC15 micrograph displays a geo-polymeric gel formation with partial CSH gel scattered throughout the entire network as shows in figure 4.10(b). A report of fly ash-slag based geopolymers found that both geopolymeric gel and C-SH were formed, along with unreacted slag particles, through SEM analysis (Suwan & Fan, 2014a). In systems where the main formation is geo-polymeric gel, the coexistence of both geo-polymeric gel and CS-H gel phases provides fast setting behavior due to the presence of calcium content. The reaction between the calcium content (from OPC) and alkaline is considered to result in quick solidifying characteristics, leading to the formation of two separate phases - geopolymer and C-S-H gel.

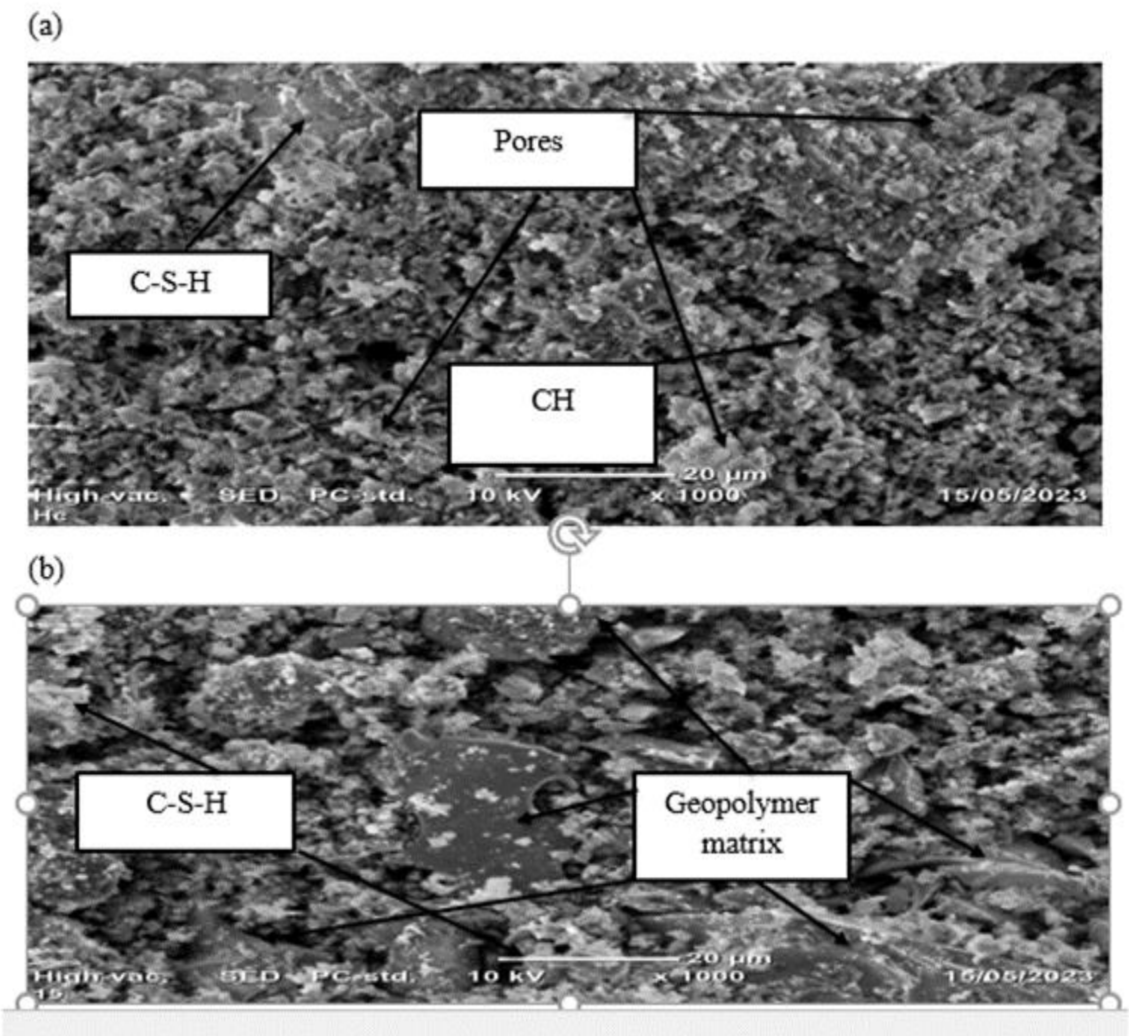


Figure 4. 11 SEM images of at 1000 magnification: a) OPC and b) Geopc15

The XRD patterns for OPC and GeoPC15 are shown in Figure 4.12 and Figure 4.13, respectively. These plots illustrate the results of the X-ray diffraction analysesThe hydrated OPC is composed of C-S-H gel phase, ettringite, and portlandite (as shown in figure 4.12). When analyzing geopolymer, quartz was observed as sharp peaks, alongside an amorphous structure indicated by a broad hump in the 18-20° region at2θ. In the GeoPC15 systems, the broad and amorphous hump was also present, indicating the coexistence of geopolymeric and hydrated OPC products in a single binder. The presence of N-A-S-H gel (nepheline) was observed based on the alkalinity of Na-containing solution (as shown in figure 4.13). Bagasse ash mainly consists of silica and alumina, which can combine with the available calcium mineral to form C-A-S-H phase concrete (Hongen Zhang et al., 2019; Nath & Sarker, 2012). The results indicate that the GeoPC system follows different reaction pathways based on the OH concentration and composition of starting materials, leading to the coexistence of amorphous C-S-H/semi-crystalline phase (detected by XRD peak and hump) or N-A-S-H and C-A-S-H (the main reaction product of bagasse ash activation) interfering in the hydration product of GeoPC matrices.

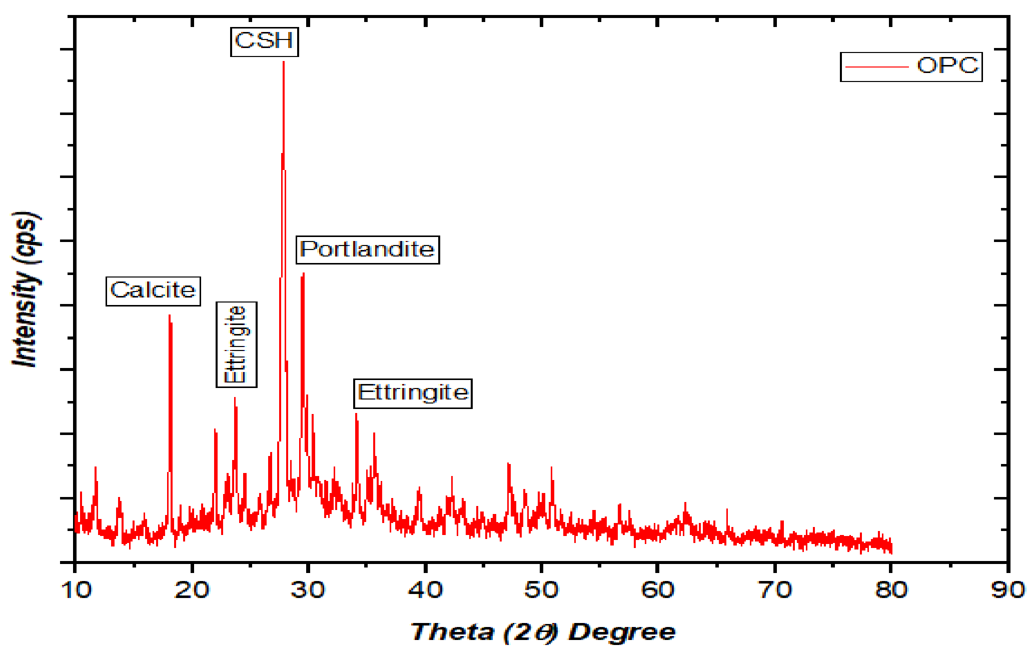


Figure 4. 12 XRD analysis of OPC

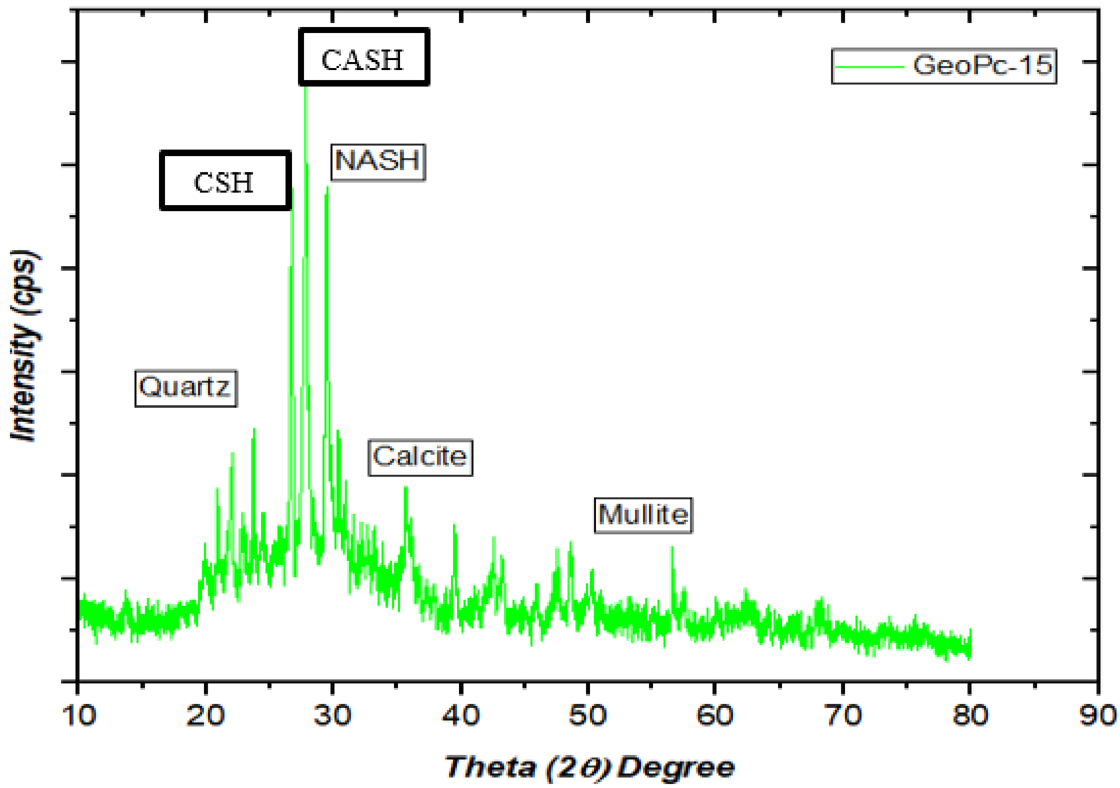


Figure 4. 13 XRD analysis GeoPC15 concrete specimens

4.5 Economic Evaluation of SCBA Hybrid Geopolymer Concrete

The fact that geopolymer concrete regularly uses waste materials is one of the factors driving its economic advantages. Today's challenge is not just to advance the science of construction materials but also to select the best materials while balancing cost and long-term performance.

4.5.1 Energy Saving

Energy is used a lot throughout the cement-making process. The production of Portland clinker requires a significant amount of energy because the raw materials are burned at a temperature of 1450°C (Abebaw et al., 2021). While the current study's SCBA formation requires just 600°C, this results in a reduction of 850°C (58.62%) in the temperature needed to make clinker. In addressing global warming and energy costs, this is very important. On the other hand, according to (Demissew et al., 2019), 0.164 tons of coal and 43,223.8 KJ of energy are needed to generate one ton of clinker.

Table 4.16 shows that Cement production uses 0.164 tons, while the production of SCBA uses 0.068 tons of coal. SCBA uses 17,894.65 kJ of energy, which is less than one of cement's 43,223.80

kJ of energy. Both the amount of coal consumed and the amount of energy SCBA needs to operate are decreased by 0.096 tons and 25,329.15 kJ, respectively. As a result, the use of SCBA in geopolymer concrete has several advantages since it lowers the amount of energy needed and the amount of coal consumed by 58.62% and 58.6%, respectively. This significantly lowers the cost of cement.

Table 4. 16 Energy requirement for the production of cement and SCBA per ton.

	Required Temperature (^0C)	Ratio of required temperature for SCBA to cement	Required coal (ton)	Required Energy(kJ)
Cement	1450		0.164	43223.8
SCBA	600	600/1450 = 0.414	0.164*0.414 = 0.068	43223.8*0.414 = 17894.65
Reduction	850		0.096	**25,329.15**

NB: the amount of required coal and energy for the production of SCBA were calculated by multiplying the ratio of the required temperature for the production of SCBA to cement and the amount of coal and energy required for cement production.

Additionally, one cubic concrete of concrete's embodied energy was calculated and is shown in Table 4.17. To make the best decision for reducing the overall energy consumption and environmental impact of a structure, embodied energy calculations for concrete materials are essential. Taffese & Abegaz's (2019) studies were used because Ethiopia has insufficient study, Senegal embodied energy coefficient.

The embodied energy of concrete can be computed by adding the embodied energies of its constituent elements. As a result, embodied energy is the result of multiplying the quantity of each material by the coefficient of embodied energy. According to the results in Table 4.17, Cement has the most embodied energy, accounting for 1,404.39 MJ. The embodied energy of concrete can be significantly decreased by lowering the cement content as a result.

Table 4. 17 Embodied energy of one cubic meter of concrete

Materials	Quantity of materials (Kg)	Embodied energy coefficient (MJ/Kg) (Taffese & Abegaz, 2019)	Required Energy(kJ)
Cement	363.64	3.32	1,207.28
Fine aggregate	536.12	0.06	32.17
Coarse aggregate	1030.90	0.16	164.94
Total embodied energy			**1,404.39**

4.5.2 Reduction of CO2 Emissions

The cement and construction industries have a significant environmental impact, as one ton of Portland cement emits approximately one ton of CO2 into the atmosphere during the manufacturing process. The cement industry accounts for approximately 8% of total global CO2 emissions (Akpenpuun et al., 2019). The majority of CO2 emissions and energy use in the cement industry are related to clinker production. The calcination process, which is used to produce clinker, accounts for 63% of CO2 emissions during cement production. The combustion of fossil fuels to feed the calcination process accounts for the remaining 37% of CO2 emissions. The weighted average globally is approximately 0.83 kg of CO2 per kg of cement (Moya et al., 2010). Therefore, emission per kg of cement comes from fossil fuel (coal) consumption is 0.31 kg of CO2 (37%*0.83) as illustrated in Table 4.18. While when the ratio of SCBA to cement is 0.415 in terms of the required coal and the CO2 emission of cement per kg due to coal is 0.31, the CO2 emission due to coal per kg of SCBA is 0.129 kg (0.415*0.31). When compared to cement, the use of SCBA reduced CO2 emissions by 0.181 kg of CO2 per kg. In general, using SCBA as cementitious material will help to minimize CO2 emissions and costs associated with coal consumption.

Table 4. 18 CO_2 emission due to coal consumption of cement and SCBA.

	Required Coal per kg (Kg)	Ratio of Required Coal for SCBA to Cement	Emission of CO_2
Cement	0.164		0.310
SCBA	0.068	0.068/0.164 = 0.415	0.415 * 0.310 = 0.129
Reduction	0.096		0.181

4.5.3 Economic Implication

According to predicted material prices for the manufacturing of conventional concrete and SCBA hybrid geopolymer concrete, the investigation into the economic consequences of employing SCBA geopolymer concrete with 15% OPC was examined. The cost estimation is based on the materials' current market pricing as of April 30, 2023.

OPC National Cement costs about 1,800 ETB per quantal, based on the current market rates for construction materials. When converted, it was around 11 ETB per kilogram. While coarse aggregate costs 1,450 ETB per cubic meter, fine aggregate costs 1,500 ETB. In addition, the price of water is 20 ETB per cubic meter. According to Table 4.17, the anticipated total material cost to produce one cubic meter of conventional concrete was 7712.34 ETB.

Table 4. 19 Estimated total cost of materials for production of one cubic meter of conventional concrete based on the current market price (the day of May 30, 2023).

Materials Item	Unit	Quantity	Rate	Amount (ETB)
Cement	Kg	363.64	18	6545.52
Fine Aggregate	M^3	0.2	1500	300
Coarse Aggregate	M^3	0.38	1450	551
Water	M^3	0.18	20	3.6
Total				**7,400.12**

Costs incurred during SCBA production

SCBA cost was exclusively calculated in terms of labor costs during material collection and burning of sugar cane bagasse ash. To produce SCBA initially, one employee was employed as a collector on one day and worked for two hours during the SCBA collection. The collector's hourly rate was 30 ETB, and the total labor cost for the SCBA collection was 60 ETB. While one lab assistant worked three hours every day for 20 days to complete SCBA production. The assistant's hourly rate was 40 ETB, and the total cost was 2400 ETB. The total cost of producing 80 kg of SCBA was 2460 ETB.

Table 4. 20 Illustrates costs incurred during the production of SCBA.

Item	Quantity	Working day	Working hour	Rate per hour	Amount (ETB)
Collection	1	1	2	30	60
Production	1	20	3	40	2,400
Total					**2,460.00**

Based on the cost of producing 80kg of SCBA, the rate of SCBA per kg was 30.75 ETB, which was more than the rate of cement per kg. As a result, when compared to ordinary concrete, the anticipated total cost of one cubic meter of SCBA geopolymer concrete with 15% OPC rises by 1.87 times. The SCBA may, however, cost less than cement if it were mass-produced in the same way. Additionally, the advantages of conserving non-renewable resources and energy outweigh the costs associated with using SCBA in the production of geopolymer concrete. Table 4.19 shows the estimated total cost of materials for the production of one cubic meter of SCBA hybrid geopolymer concrete with 15% of OPC.

Table 4. 21 Estimated total cost of materials for production of hybrid geopolymer concrete with 15% of OPC

Materials Item	Unit	Quantity	Rate	Amount (ETB)
Cement	Kg	54.55	18	918.90
Fine Aggregate	m^3	0.20	1500	300
Coarse Aggregate	m^3	0.38	1450	551
SCBA	Kg	241.09	30.75	7,413.52
NH	Kg	48.8	50	2440
NS	Kg	121.4	18	2185.2
Water	m^3	0.03	20	0.60
Total				**13,809.22**

It is clear from the study above that the cost of producing M 25 HGPC is 6,409.10 more expensive than the conventional M 25 mix, even though the materials used in its manufacturing are industrial by-products. This is a result of the alkaline activator solution costs. M 25 HGPC mix strength can be compared to M 30 conventional mix strength. Therefore, it can be stated that SCBA hybrid geopolymer concrete with 15% OPC is preferable to OPC-based concrete when the strength and cost of the various mixes are compared.

The availability of raw materials close to the cement manufacturing environment is also necessary for the energy-intensive process of cement manufacturing. With more than 90% of the fuel used in the process going towards burning clinker, it is an energy-intensive process. Cement plants use a lot of energy since fuel prices make up a significant portion of the cost of manufacturing cement (Rahman et al., 2017). As a result, compared to the manufacturing of cement, the production of SCBA reduces fuel usage by 58.62%, indicating the cost of fuel has also decreased by 58.62%.

Generally speaking, utilizing SCBA with 15% OPC in hybrid geopolymer concrete reduces the need for non-renewable materials in conventional concrete, assisting in the preservation of natural resources. Additionally, it decreases the amount of coal and energy used to produce cement. Additionally, the price of cement lowers as coal use does. There are financial advantages to using SCBA hybrid geopolymer concrete rather than conventional concrete.

5 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations for this study were derived from analyzing the experiment's results and overall outcomes.

5.1 Conclusions

The production of geopolymer concrete from SCBA incorporating with OPC was investigated in this study. The results of the complete silica analysis indicate that the chemical composition of SCBA falls under the classification of class F pozzolana as prescribed by ASTM, with a total of $SiO_2 + Al_2O_3 + Fe_2O_3$ exceeding 70%. The blended paste's normal consistency varied from mix to mix, which is a common challenge encountered with by-product materials. Increasing the amount of OPC in the paste resulted in a lower normal consistency. The research showed that the workability of the geopolymer was influenced by the amount of OPC used in the mix, with an increase in OPC leading to a decrease in workability. Additionally, substituting bagasse ash with OPC directly affected the strength of bagasse ash geopolymer. By adding 15% OPC, the compressive strength of the concrete increased by 23.31% after 28 days of curing, compared to conventional concrete. This improvement is due to the formation of additional amorphous C-S-H and semi-crystalline geopolymer network resulting from the reaction of calcium minerals with the high alkaline present in the binder. On the other hand, as the replacement percentage rose up to 25%, the compressive strength of the concrete reduced by 1.34%. This decrease can be attributed to the higher cement content and the slower polymerization process. These results suggest that 15% replacement is the optimal percentage for achieving the maximum attainable compressive strength. It was also discovered that for all replacement concrete specimens, water absorption of GeoPC decreased after 7 and 28 days of curing. At the end of the 28-day curing period, the smallest amount of water absorption (2.64) was observed in the 15% OPC sample in comparison to conventional concrete and other GeoPC samples. This could be due to the filling of pores in the concrete matrix resulting from the formation of CSH and geopolymer gel. Furthermore, after 30 days, all specimens containing OPC placed in sulfate solution experienced less weight loss compared to their corresponding control specimens. With regard to weight loss, specimens with 25% OPC experienced the lowest weight loss among all the GeoPC specimens and control specimen. Moreover, the microstructure of the concrete with a 15% OPC content on day 28 indicates the development of additional C-S-H gel and geopolymer gel in the concrete as a result of calcium presence in the cement. Ultimately, replacing some of the sugarcane bagasse ash with OPC in geopolymer concrete results in lower consumption of non-renewable materials, saves energy, lowers the cost involved in using cement and reduce CO_2 emission.

5.2 Recommendations

Hybrid geopolymer concrete is a cost-effective option that displays improved workability, strength, water absorption, and sulfate attack compared to conventional concrete. SCBA hybrid geopolymer concrete has proven to be particularly advantageous. It is also safe to use and helps to simplify current construction challenges whilst revolutionizing construction processes. However, there are still some issues such as the increasing cost of alkaline solution, concrete mix design, international codes, and standards that require addressing before this cost-effective and efficient technology can be fully utilized in practice. The current study's tests were restricted to workability, compressive strength, water absorption, sulphate attack, SEM, and XRD analysis, as well as an economic analysis.

In future studies, additional testing will be conducted to evaluate other concrete properties like

- Tensile strength, flexural strength, and modulus of elasticity.
- Chloride attack and sulphuric acid tests will be conducted to assess the long-term durability of concrete.
- Prepare an alkaline activator solution using waste materials.

REFERENCE

Abebaw, G., Bewket, B., & Getahun, S. (2021). Research Article Experimental Investigation on Effect of Partial Replacement of Cement with Bamboo Leaf Ash on Concrete Property.

Abebe Demissew Gashahun. (2020). Assessment on Cement Production Practice and Potential Cement Replacing Materials in Ethiopia. Civil and Environmental Research. https://doi.org/10.7176/CER/12-1-03

Alahverdi, A., Mehrpour, K., & Najafikani, E. (2008). Taftan pozzolan-based geopolymer cement.

Ankur Laxman Yadav, V. Sairam, K. Srinivasan, & L. Muruganandam. (2020). Synthesis and characterization of geopolymer from metakaolin and sugarcane bagasse ash.

Anuar, K. A., Ridzuan, A. R. M., & Ismail, S. (2011). Strength characteristic of geopolymer concrete containing recycled concrete aggregate. International Journal of Civil & Environmental Engineering, 11(1), 59–62.

Arslan Akbar, Furqan Farooq, Muhammad Shafique, Fahid Aslam, Rayed Alyousaf, & Hisham Abduljabba. (2020). Sugarcane bagasse ash-based engineered geopolymer mortar 1 incorporating propylene fibers.

Assi, L. N., Deaver, E. E., & Ziehl, P. (2018). Effect of source and particle size distribution on the mechanical and microstructural properties of fly Ash-Based geopolymer concrete. Construction and Building Materials, 167, 372–380.

ASTM, C. 33-16, Standards Specification for Concrete Aggregates. Annual Book of ASTM Standard.

ASTM, C. 39/C39 M-10.(2010). Standard test method for compressive strength of cylindrical concrete specimens. American Society for Testing and Materials, West Conshohocken,.

ASTM, C. 143/C-143 M, 2000. Standard Test Method for Slump of Hydraulic-Cement Concrete.

ASTM, C. (1998). 187-98. Standard Test Method for Normal Consistency of Hydraulic Cement. *United States: ASTM International, 11*(1).

ASTM, C. (2006). 192. 2004. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. Annual book of ASTM Standards, 4.

Ayodele, F. O., & Ayeni, I. S. (2015). Analysis of influence of silt/clay impurities present in fine aggregates on the compressive strength of concrete. International Journal of Engineering Research and Science and Technology, 15(4), 6.

Beycioglu, A., Gultekin, A., Aruntas, H. Y., Gencel, O., Dobiszewska, M., & Brostow, W. (2017). Mechanical properties of blended cements at elevated temperatures predicted using a fuzzy logic model. Comput. Concr, 20(2), 247–255.

Bogale, B. (2007). Comparison of concrete durability as produced by various cements manufactured in Ethiopia. Addis Ababa University Department of Civil Engineering, School of Graduate Studies.

Chau-Khun Ma, Abdullah Zawawi Awang, & Wahid Omar. (2018). Structural and material performance of geopolymer concrete: A review.

Chidhambar, E., & Manjunath, Y. M. (2019). Experimental investigation on geopolymer concrete subjected to elevated temperature. Int. J. Adv. Res. Ideas Innov. Technol, 5, 290–296.

Chithra, K. S., Binoy, T., Harismitha, A., Ananth, R. K., & Deepa, M. (2021). A study on economic feasibility of fly ash and ground granulated blast furnace slag based geopolymer concrete. IOP Conference Series: Materials Science and Engineering, 1114(1), 012007.

Dadhich, P. N., Sharma, R. K., Shekhawat, S., Jain, C., & Gopal, B. (2014). Impact of water quality on compressive strength of reinforced concrete. International Journal of Engineering Research & Technology, 3(03).

Daniel, D. G. (2006). Factors influencing concrete workability. In Significance of tests and properties of concrete and concrete-making materials. ASTM International.

Davidovits, J. (2013). Geopolymer Cement a review 2013. 1–11.

Demissew, A., Fufa, F., & Assefa, S. (2019). Partial replacement of cement by coffee husk ash for C-25 concrete production. Journal of Civil Engineering, Science and Technology, 10(1), 12–21.

Dilip Srinivas, Guide, Madan Kumar L, Madhusudan R, Dilip Kumar N V, Sumantha S, & THE NATIONAL INSTITUTE OF ENGINEERING, MYSORE. (2017). Feasibility Analysis of use of Bagasse Ash for the Production of Geo Polymer Concrete. International Journal of Engineering Research And, V6(05), IJERTV6IS050086. https://doi.org/10.17577/IJERTV6IS050086

Dutta, D., Thokchom, S., Ghosh, P., & Ghosh, S. (2010). Effect of silica fume additions on porosity of fly ash geopolymers. J. Eng. Appl. Sci, 5(10), 74–79.

Ferdous, M. W., Kayali, O., & Khennane, A. (2013). A detailed procedure of mix design for fly ash based geopolymer concrete. Proceedings of the Fourth Asia-Pacific Conference on FRP in Structures (APFIS 2013), Melbourne, Australia, 11–13.

Fernandez-Jimenez, A., García-Lodeiro, I., & Palomo, A. (2007). Durability of alkali-activated fly ash cementitious materials. Journal of Materials Science, 42(9), 3055–3065. https://doi.org/10.1007/s10853-006-0584-8

Geopolymer Institute – Promoting the geopolymer science since 1979. (n.d.). Retrieved May 18, 2023, from https://www.geopolymer.org/

Goshu, T. F. (2019). Optimization of bagasse ash to cement mix proportion for M30 Grade concrete. National Academic Digital Repository of Ethiopia (NADRE).

Gupta, S., Chandrakar, G., & Scholar, P. (2017). Experimental Studies on Fly Ash Based Geopolymer Concrete without Portland Cement-An Eco Friendly Construction.

Hailu, B., & Dinku, A. (2012). Application of sugarcane bagasse ash as a partial cement replacement material. Zede Journal, 29, 1–12.

Haque, M. B., Tuhin, I. A., & Farid, M. S. S. (2012). Effect of aggregate size distribution on concrete compressive strength. SUST Journal of Science and Technology, 19(5), 35–39.

Hardjito, D., & Fung, S. S. (2010). Fly ash-based geopolymer mortar incorporating bottom ash. Modern Applied Science, 4(1), 44.

Hongen Zhang, Lang Li, Tao Long, Prabir Kumar Sarker, Xiaoshuang Shi, Gaochuang Cai, & Qingyuan Wang. (2019). The Effect of Ordinary Portland Cement Substitution on the Thermal Stability of Geopolymer Concrete.

Hu, S., Wang, H., Zhang, G., & Ding, Q. (2008). Bonding and abrasion resistance of geopolymeric repair material made with steel slag. Cement and Concrete Composites, 3(30), 239–244. https://doi.org/10.1016/j.cemconcomp.2007.04.004

Jindal, B. B., Singhal, D., Sharma, S., & Parveen, J. (2018). Enhancing mechanical and durability properties of geopolymer concrete with mineral admixture. Computers and Concrete, 21(3), 345–353.

Joshua, O., Fagbenle, O. I., Olusola, K. O., Shamaki, S. J., Abuka-Joshua, J. A., Ogunde, A. O., Amusan, L. M., & Omuh, I. O. (2018). A comparative analysis of batching by weight and volume towards improved concrete production. Construction Research Congress 2018, 582–591.

Kant Sahdeo, S., Ransinchung R.N., G. D., Rahul, K. L., & Debbarma, S. (2020). Effect of mix proportion on the structural and functional properties of pervious concrete paving mixtures. Construction and Building Materials, 255, 119260. https://doi.org/10.1016/j.conbuildmat.2020.119260

Khater, H. M. (2012). Effect of calcium on geopolymerization of aluminosilicate wastes. Journal of Materials in Civil Engineering, 24(1), 92–101.

Kiran, K., & Kishore, I. S. (2017). AN EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT WITH BAGASSE ASH IN CONCRETE MIX.

Korniejenko, K., Frączek, E., Pytlak, E., & Adamski, M. (2016). Mechanical properties of geopolymer composites reinforced with natural fibers. Procedia Engineering, 151, 388–393.

Krakowiak, K. J., Thomas, J. J., Musso, S., James, S., Akono, A.-T., & Ulm, F.-J. (2015). Nano-chemo-mechanical signature of conventional oil-well cement systems: Effects of elevated temperature and curing time. Cement and Concrete Research, 67, 103–121.

Kumaravel, S. (2014). Development of various curing effect of nominal strength Geopolymer concrete. Journal of Engineering Science and Technology Review, 7(1), 116–119.

Lamba, M. A., Agrawal, M. S., & Dubey, M. A. (2021). ANALYSIS OF USE OF SUGARCANE BAGASSE ASH FOR THE PRODUCTION OF GEO POLYMER CONCRETE. International Research Journal of Modernization in Engineering Technology and Science, 3.

Lloyd, N., & Rangan, B. (2010). Geopolymer Concrete with Fly Ash. Second International Conference on Sustainable Construction Materials and Technologies, 3.

Luhar, S., & Khandelwal, U. (2015). A study on water absorption and sorptivity of geopolymer concrete. SSRG Int. J. Civil Eng, 2(8), 1–10.

Mathew, B. J., Sudhakar, M., & Natarajan, C. (2013). Strength, economic and sustainability characteristics of coal ash–GGBS based geopolymer concrete. International Journal of Computational Engineering Research, 3(1), 207–212.

Memon, F. A., Nuruddin, M. F., Khan, S., Shafiq, N., & Ayub, T. (2013). Effect of sodium hydroxide concentration on fresh properties and compressive strength of self-compacting geopolymer concrete. J. Eng. Sci. Technol, 8(1), 44–56.

Nath, P., & Sarker, P. K. (2012). Geopolymer concrete for ambient curing condition. Proceedings of the Australasian Structural Engineering Conference, Perth, Australia, 11–13.

Newman, J., & Choo, B. S. (2003). Advanced concrete technology set. Elsevier.

Niveditha, M., & Koniki, S. (2020). Effect of Durability properties on Geopolymer concrete– A Review. E3S Web of Conferences, 184, 01092.

Pachipala, S. (2017). A study on mechanical properties of concrete using silica sand as partial replacement of cement. International Journal of Civil Engineering, 4(5), 34–39.

Pavithra, P., Reddy, M. S., Dinakar, P., Rao, B. H., Satpathy, B. K., & Mohanty, A. N. (2016). A mix design procedure for geopolymer concrete with fly ash. Journal of Cleaner Production, 133, 117–125.

Prabhath, N., Kumara, B. S., Vithanage, V., Samarathunga, A. I., Sewwandi, N., Maduwantha, K., Madusanka, M., & Koswattage, K. (2022). A Review on the Optimization of the Mechanical Properties of Sugarcane-Bagasse-Ash-Integrated Concretes. Journal of Composites Science, 6(10), 283.

Rahman, A., Rasul, M. G., Khan, M. M. K., & Sharma, S. C. (2017). Assessment of Energy Performance and Emission Control Using Alternative Fuels in Cement Industry throughaProcessModel. Energies, 10(12), Article 12. https://doi.org/10.3390/en10121996

Raijiwala, D. B., & Patil, H. S. (2010a). Geopolymer concrete A green concrete. 2010 2nd International Conference on Chemical, Biological and Environmental Engineering, 202–206.

Raj R.1 Samuvel & Arulraj G Prince. (2020). Effects of Addition of Cement in Flyash based Geopolymer Concrete.

Rangan, B. (2008). Studies on low-calcium fly ash-based geopolymer concrete. Indian Concr J, 3, 9–17. https://doi.org/10.1201/9781420007657.ch26

Richardson, I. G. (2000). The nature of the hydration products in hardened cement pastes. Cement and Concrete Composites, 22(2), 97–113. https://doi.org/10.1016/S0958-9465(99)00036-0

Saloma, Hanafiah, & Kartika Ilma Pratiw. (2016). Effect NaOH Concentration on Bagasse Ash Based Geopolymerization.

SATHISHA B L & MAMATHA. A2. (2015). Effect Of Concentration Of Sodium Hydroxide On Strength Of Geopolymer Concrete.

Shabalala, A. N., & Ekolu, S. O. (2019). Assessment of the Suitability of Mine Water Treated with Pervious Concrete for Irrigation Use. Mine Water and the Environment, 38(4), 798–807. https://doi.org/10.1007/s10230-019-00633-1

Srinivas, D., Madankumar, L., & Madhusudan, R. (2017). Feasibility Analysis of use of Bagasse Ash for the Production of Geo Polymer Concrete. International Journal of Engineering Research & Technology (IJERT) ISSN, 2278–0181.

Sukmak Patimapon, Horpibulsuk Suksun, & Shen Shui-Long. (2012). Strength development in clay–fly ash geopolymer.

Suwan, T., & Fan, M. (2014a). Influence of OPC replacement and manufacturing procedures on the properties of self-cured geopolymer. Construction and Building Materials, 73, 551–561. https://doi.org/10.1016/j.conbuildmat.2014.09.065

Suwan, T., & Fan, M. (2014b). Influence of OPC replacement and manufacturing procedures on the properties of self-cured geopolymer. Construction and Building Materials, 73, 551–561.

Taffese, W. Z., & Abegaz, K. A. (2019). Embodied Energy and CO2 Emissions of Widely Used Building Materials: The Ethiopian Context. Buildings, 9(6), Article 6. https://doi.org/10.3390/buildings9060136

Thaarrini, J., & Dhivya, S. (2016). Comparative study on the production cost of geopolymer and conventional concretes. International Journal of Civil Engineering Research, 7(2), 117–124.

Thakur, P., Student, P. G., Singh, K., & Sharma, R. (2018). AN EXPERIMENTAL STUDY ON GEOPOLYMER CONCRETE WITH BAGASSE ASH AND METAKAOLIN: A GREEN CONCRETE.

Trivedi, M. V., & Shrivastava, L. P. (2020). A STUDY ON GEO POLYMER CONCRETE USING SUGARCANE BAGASSE ASH: A BRIEF REVIEW. 5(10).

Ukala, D. C. (2019). Effects of combined aggregate gradation on the compression strength and workability of concrete using fineness modulus. Journal of Applied Sciences and Environmental Management, 23(5), 851–856.

Verma, M., Upreti, K., Vats, P., Singh, S., Singh, P., Dev, N., Kumar Mishra, D., & Tiwari, B. (2022). Experimental Analysis of Geopolymer Concrete: A Sustainable and Economic Concrete Using the Cost Estimation Model. Advances in Materials Science and Engineering, 2022, 1–16. https://doi.org/10.1155/2022/7488254

Vijai, K., Kumutha, R., & Vishnuram, B. G. (2010a). Effect of types of curing on strength of geopolymer concrete. International Journal of the Physical Sciences, 5(9), 1419–1423.

Vijai, K., Kumutha, R., & Vishnuram, B. G. (2010b). Effect of types of curing on strength of geopolymer concrete. International Journal of the Physical Sciences, 5(9), 1419–1423.

Wattanachai, P., & Suwan, T. (2017). Strength of geopolymer cement curing at ambient temperature by non-oven curing approaches: An overview. IOP Conference Series: Materials Science and Engineering, 212(1), 012014.

Zaniewski, J. P., Bessette, L., Rashidi, H., & Bikya, R. (2012). Evaluation of Methods for Measuring Aggregate Specific Gravity. Department of Civil and Environmental Engineering Morgantown, West Virginia.

Zannerni, G. M., Fattah, K. P., & Al-Tamimi, A. K. (2020). Ambient-cured geopolymer concrete with single alkali activator. Sustainable Materials and Technologies, 23, e00131.

Zimar, A., Samarawickrama, G., Karunarathna, W., & Jayakody, S. (2017). Effect of manufactured sand as a replacement for fine aggregates in concrete. 8th International Conference on Structural Engineering and Construction Management, 2017.

Ziolkowski, P., Niedostatkiewicz, M., & Kang, S.-B. (2021). Model-based adaptive machine learning approach in concrete mix design. Materials, 14(7), 1661.

APPENDIX

Appendix A: Tables for ACI concrete mix design

Appendix A1: Factor based on the grade of concrete.

Specified characteristic compressive strength (fck,Mpa)	Required average compressive strength (f'ck,Mpa)
<21	fck + 7
21-35	fck + 8.5
>35	1.1 * fck + 5

Appendix A2: Recommended slumps for various types of constructions.

Types of constructions	Slump (cm)	
	Minimum	Maximum
Reinforced foundations, walls, and footings	2	8
Plain footings, cassoins ,and substructure walls	2	8
Beams and reinforced walls	2	10
Building columns	2	10
Pavements and slabs	2	8
Heavy mass concrete	2	8

Appendix A3: Approximate mixing water requirements for different slumps and maximum sizes of aggregates.

Slump (cm)	Water kg/m3 of concrete for indicated max. sizes of aggregate (mm)							
	10	12.5	20	25	40	50	70	150
Non-air entrained concrete								
2 – 10	205	200	185	180	160	155	145	125
8 – 10	225	215	200	195	175	170	160	140
15 - 18	240	230	210	205	185	180	70	0
Approx. amount of entrapped air in nonentrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air entrained concrete								
3 – 5	180	175	165	160	145	140	135	120
8 - 10	215	206	190	185	170	165	160	0
Recommended average total air content (%)	8	7	6	5	4.5	4	3.5	3

Appendix A4: Estimated water cement ration for average compressive strength concrete.

Compressive strength at 28 days (MPa)	Water cement ratio by mass	
	Non-air entrained	Air entrained
45	0.38	0
40	0.42	0
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.6
15	0.79	0.71

Appendix A5: Volume of coarse Aggregate per unit Volume of concrete.

Maximum size of aggregate	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness modulus		
	2.6	2.8	3
10	0.50	0.46	0.44
12.5	0.59	0.55	0.53
20	0.66	0.62	0.60
25	0.71	0.67	0.65
40	0.76	0.72	0.70
50	0.78	0.74	0.72
70	0.81	0.77	0.75

Appendix B: Different Test Results

Appendix B1: Detail slump value for fresh concrete that blended with OPC for each mix code three trail was tested.

No	Mix Code	Percent replacement (%)	Trail	Slump result(mm)	Average(mm)
			1	26	
			2	28	
1	OPC	0	3	27	27
			1	50	
			2	51	
2	GPC	0	3	49	50
			1	44	
			2	46	
3	GeoPC5	5	3	45	45
			1	32	
			2	31	
4	GeoPC10	10	3	30	32
			1	27	
			2	28	
5	GeoPC15	15	3	29	28

6	GeoPC20	20	1	23	23
			2	22	
			3	24	
7	GeoPC25	25	1	20	21
			2	22	
			3	21	

Appendix B2: Detail result of compressive strength for different mix code at different curing Periods.

No	Mix Code	Samples	compressive Strength Results (N/mm²)					
			7th day		14th day		28th day	
			Load (KN)	Strength	Load(KN)	Strength	Load (KN)	Strength
1	OPC	1	343	15.24	504	22.37	596	26.45
		2	395	17.56	529	23.48	605	26.87
		3	378	16.78	542	24.08	611	27.15
		Average	**372**	**16.53**	**525**	**23.31**	**604**	**26.82**
2	GPC	1	0	0	0	0	249	11.07
		2	0	0	0	0	238	10.56
		3	0	0	0	0	262	11.63
		Average	**0**	**0**	**0**	**0**	**250**	**11.09**
3	GeoPC5	1	186	8.24	216	9.61	421	18.71
		2	208	9.23	220	9.78	425	18.89
		3	200	8.91	249	11.05	431	19.13
		Average	**198**	**8.79**	**228**	**10.15**	**426**	**18.91**
4	GeoPC10	1	286	12.72	401	17.85	656	29.15
		2	**262**	11.63	420	18.64	651	28.91
		3	304	13.48	423	18.78	659	29.26
		Average	**284**	**12.61**	**415**	**18.42**	**656**	**29.11**
5	GeoPC15	1	407	18.06	542	24.08	748	33.21
		2	389	17.26	574	25.48	757	33.63
		3	372	16.53	604	26.81	729	32.38
		Average	**389**	**17.28**	**573**	**25.46**	**745**	**33.07**
6	GeoPC20	1	307	13.63	407	18.08	686	30.46
		2	**302**	13.39	422	18.75	695	30.87
		3	321	14.24	433	19.24	702	31.19
		Average	**310**	**13.75**	**421**	**18.69**	**696**	**30.84**
7	GeoPC25	1	264	11.72	372	16.54	597	26.51
		2	**293**	13.01	379	16.82	594	26.37
		3	284	12.59	384	17.03	624	27.69
		Average	**280**	**12.44**	**379**	**16.81**	**605**	**26.86**

Appendix B3: Water absorption result for each sample at different mix code and curing days.

Mix Code	Samples	Water Absorption (%)					
		7th day			28 th day		
OPC		O	S	%	O	S	%
	1	748	794	6.15	757	802	5.94
	2	752	792	5.32	758	796	5.01
	3	746	798	6.97	756	805	6.48
	Average	**749**	**795**	**6.14**	**757**	**801**	**5.81**
GPC	1	0	0	0	726	756	4.13
	2	0	0	0	727	768	5.66
	3	0	0	0	743	772	3.91
	Average	**0**	**0**	**0**	**732**	**765**	**4.51**
GeoPC5	1	720	761	5.69	728	751	3.16
	2	728	758	4.12	732	758	3.55
	3	742	765	3.11	746	767	2.82
	Average	**737**	**761**	**3.26**	**735**	**759**	**3.18**
GeoPC10	1	734	762	3.11	751	786	4.66
	2	726	756	4.13	746	764	2.41
	3	728	757	3.98	732	748	2.19
	Average	**729**	**758**	**3.96**	**743**	**766**	**3.09**
GeoPC15	1	748	771	3.07	756	781	3.31
	2	745	768	3.09	761	772	1.45
	3	741	764	3.11	758	780	2.91
	Average	**745**	**768**	**3.09**	**758**	**778**	**2.64**
GeoPC20	1	743	762	4.49	720	761	5.69
	2	731	774	5.88	728	758	4.12
	3	729	760	4.25	752	765	3.11
	Average	**734**	**765**	**4.22**	**733**	**761**	**3.77**
GeoPC25	1	746	710	5.07	730	756	3.56
	2	768	728	5.49	732	767	4.78
	3	754	737	2.31	748	774	3.48
	Average	**756**	**725**	**4.28**	**737**	**766**	**3.94**

Appendix B4: Sulphate attack result for each sample at different mix code and 28 curing days.

Mix Code	Samples	Sulphate Attack at 28 day			
		W_1 (kg)	W_2(kg)	Weight Loss (kg)	% Loss
OPC	1	7.673	7.645	0.028	0.37
	2	7.708	7.693	0.015	0.21
	3	7.682	7.606	0.076	0.84
	Average	**7.688**	**7.648**	**0.041**	**0.52**
GPC	1	7.573	7.543	0.032	0.42
	2	7.562	7.527	0.035	0.46
	3	7.578	7.543	0.036	0.48
	Average	**7.571**	**7.538**	**0.035**	**0.45**
GeoPC5	1	7.418	7.405	0.013	0.18
	2	7.423	7.398	0.025	0.34
	3	7.392	7.379	0.013	0.47
	Average	**7.482**	**7.449**	**0.033**	**0.44**
GeoPC10	1	7.752	7.736	0.013	0.26
	2	7.696	7.661	0.035	0.46
	3	7.718	7.702	0.016	0.21
	Average	**7.722**	**7.701**	**0.022**	**0.29**
GeoPC15	1	7.43	7.418	0.012	0.16
	2	7.396	7.376	0.021	0.27
	3	7.435	7.417	0.018	0.24
	Average	**7.421**	**7.404**	**0.016**	**0.26**
GeoPC20	1	7.365	7.337	0.028	0.38
	2	7.408	7.397	0.011	0.15
	3	7.296	7.284	0.021	0.29
	Average	**7.356**	**7.339**	**0.010**	**0.23**
GeoPC25	1	7.567	7.544	0.023	0.31
	2	7.496	7.472	0.024	0.32
	3	7.601	7.583	0.018	0.24
	Average	**7.555**	**7.533**	**0.009**	**0.22**

Appendix C: oxide composition of SCBA

	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:- Heran Bogale Degefu

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 D: Pictures taken during experimental works.

Appendix D_1: Pictures captured during conducting unit weight test for fine aggregate and Coarse aggregate.

Appendix D_2: Picture taken during Preparation of Alkaline Activator Solution

Appendix D_3: Pictures captured during slump test.

Appendix D_4: Pictures shows casted samples: (150*150*150) mm sized cube for compressive, water absorption test and Sulfate attack test.

Appendix D_5: Pictures shows tests for compressive, water absorption test and Sulfate attack.