Mechanical and Durability Property of Concrete with Partial Replacement of Cement by Waste Glass Powder

Megersa Lamessa Abera

A Thesis Submitted to the Department of Civil Engineering

College of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Construction Engineering and Management

Office of Graduate Studies

Adama Science and Technology University

June, 2025
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DECLARATION

I declare that this thesis entitled " Mechanical and Durability property of concrete with partial replacement of cement by Waste Glass Powder " is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

Megersa Lamessa	___________________	_____________________
Name of Student	Signature	Date

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I, the advisor of this research thesis, hereby certify that I have closely advised the student while developing this thesis and read the draft thesis entitled " Mechanical and Durability property of concrete with partial replacement of cement by Waste Glass Powder" prepared under my guidance by Megersa Lamessa Abera. Therefore, I recommend the submission of the thesis to the department for further review and evaluation.

Dr. Bahiru Bewket	____________________	______________________
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I/we, the advisors of the thesis entitled "Mechanical and Durability property of concrete with partial replacement of cement by Waste Glass Powder" and developed by Megersa Lamessa Abera, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Co-advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Megersa Lamessa Abera have read and evaluated the thesis entitled "Mechanical and Durability property of concrete with partial replacement of cement by Waste Glass Powder" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Construction Engineering and management

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

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LIST OF ACRONYMS AND SYMBOLS

ACI	America Concrete Institution
ASR	Alkali- Silica Reaction
ASTM	American Society for Testing Materials
C-H	Calcium hydrate
C-S-H	Calcium silica Hydrate
LOI	Loss Of Ignition
SCMs	Supplementary Cementitious Materials
SEM	Scanning Electro Microscope
W/C	Water Cement ration
WGP	Waste Glass Powder
m3	Meter cube
M-25	Concrete with 25MPa at 28days of Compressive Strength
µm	Micrometer
%	Percent

ABSTRACT

*Concrete as a construction material plays vital role across worldwide construction industries. The constituent of concrete cement, due its property when acted with the water it act as binding material in concrete production. Different materials can enhance the property of concrete like mechanical and durability when they used as replacement of cement. Supplementary cement materials can be used as cement replacing material in different scenarios. Glass powder due to its binding property can be used as supplementary cement material in different dosage. In this study partial replacement of waste glass powder to cement was examined by investigating experiments like workability, compressive strengthen, flexural strengthen ,water absorption, sulphate attack and morphological properties of concrete. For this experimental investigation waste glass powder (wgp) grinded into size of 75micrometer was used as cement with different ratios of replacement were utilized in concrete production:That is, 0%, 10%, 20% and 30%. And studies were performed specifically on concrete had 25mpa compressive strength with water-cement ratio of 0.6. The workability of concrete performed at early strengthen of concrete shows that workability of concrete decreases from 80mm to 62mm as amount of glass powder increases. For the other tests cubic sample 150mm *150mm *150mm where prepared and compressive strengthen , water absorption and sulphate attack were tested. For flexural strengthen 100mm *100mm *500mm sample size were prepared and test performed on the 7th and 28th after cured in water and sulphate attack of concrete property test done on the 56th day. From the experimental investigation partial replacement of wgp was optimized when cement replaced at 20% to waste glass powder . The compressive strengthen and flexural strengthen increases until it reach 20% on the 7th and 28th day the value were 19.4 and 28.9 and 4.21 and 8.1 respectively and after optimum value were then it decreases. Sulphate attack and water absorption of the concrete decreases from 6.38 % to 3.4% and 3.98% to 3.4% as the wgp percentage increases. Due to the pozzolanic activity for the wgp which C-S turned to C-S-H gel, the concrete that contains wgp is denser and less porous that enhances the durability of concrete.*

Keywords: *Waste glass powder, concrete property, concrete durability, cement replacement, micro structural, environmetal impact*

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Industrialization, infrastructure and urbanization growth of the a country could be measured by the position of construction conditions including building structures, roadways.the construction sector should keep up with the needs of the increasing population in the country, which requires a large amount of building materials((Abreha, Yifru et al. 2023). There are different construction material used in construction industry. From these materials the most critical one is concrete. Concrete is the most extensively used structure material in construction sector. It's a formed from homogeneous admixture of cement, fine aggregate (sand), coarse aggregate and water. The strength of concrete is substantially depends upon the cement content present within the concrete (Sakale, Jain et al. 2015).

Cement is a finely ground substance that does not act as a binder on its own, but acquires binding properties when it undergoes reaction with water or in hydration process. This binding ability is primarily attributed to the presence of silica in its composition. The chemical composition present in the cement contributes the property of the cement to be used as binding material.

However, the incorporation of cement as an essential ingredient in concrete production leads to significant environmental issues (Chandrasekaran, Vasanth et al. 2018). The production of cement passed through different processes in order to attain the end goal of cement property. The product of cement uses a lot of energy and emits a lot of carbon dioxide(co2), which increases the amount of gases in the atmosphere contributes to climate change(Zeybek, Özkılıç et al. 2022). Likewise, the raw material used for cement production influences the environment. The destruction and biodiversity loss faces due to extraction of raw materials like limestone used in the manufacture of cement (Mohamad, Muthusamy et al. 2022).

A mitigation way to reduce the effect of the cement on the environment is to use supplementary Cementitious materials (SCMs) to replace some of the cement in concrete(Abdelli, Mokrani et al. 2020), (Martina, Kinanti et al. 2022). Different supplementary Cementitious materials researched from earlier researchers.from these waste glass powder is the recent concept that mainly applied as the SCMs.

Waste glass powder (wgp), though it has the implicit to be an SCMs. Glass is highly amorphous material that has high silica content within it self as chemical composition. And also it contains other major or minor compounds that provide the pozzolanic property. More than 70 percent of glass structure is composed of amorphous silica which is a primary demand for a pozzolanic materials and in order to manage the socially generated bulk glass waste. Different experimenters have looked into the use of glass powder as an fresh cementitious component for concrete product in the construction sector(Tamanna and Tuladhar 2020) (Aliabdo, Abd Elmoaty et al. 2016).

Waste glass powder(wgp) has a high pozzolanic reactivity and contains amorphous silica, both of which are desirable in scm, which is used in concrete because they may increase the chemical resistance and continuity of the ultimate(Rashad 2014, Siddika, Hajimohammadi et al. 2021). The critical factor that impact the pozzolanic property of wgp and most of the pozzolanic in concrete are fineness, chemical composition, and the severance result available for response(Zeybek, Özkılıç et al. 2022) (Idir, Cyr et al. 2011). Glass waste is material that is non-biodegradable in nature that raises impact on the environment.glass accumulates landfills and other disposal facilities because, in discrepancy to organic materials, it takes an extremely long time to putrefy naturally. In addition to this glass waste consumes high energy when it is recycled. In order to reduces this impact of waste glass on the environment different researchers looked into replacing this pozzolanic material in to cement. In related to the environment issues concrete can faces situation related to sulphate exposed areas.in this century exposure to sulphate, saltwater, acids, and carbonation are the main areas of challenges of concrete (aci committee 201, 2016).

Since the environmental issue is crucial different researchers tried to be solve problem stated above related to the waste glass, cement and sulphate exposed to the concrete but additional scientific researches to be conducted to solve these problems from the root.

This experimental investigation focus on the replacement of waste glass powder to the cement in consideration fresh and hardened concrete property. Further more this study focused on the impact of sulphate compounds exposed to surface of concrete with replacement of cement to waste glass powder examined with different amount of waste glass replaced to cement.

1.2 Statement of problem

There are different industries that release carbon dioxide in to the environment. From these industries cement manufacturing is the one and that produce about 7% of greenhouse gas emission that results global warming. In Ethiopia cement industry has become one of the nation's fastest-growing industries, the industry energy consumption and releasing CO_2 are expected to increase, due to burning of fossil fuels. In addition to this the manufacture of cement 0.16381 metric tons of CO_2 was released from Ethiopia in the year 2019(Kedir 2023).

Globally million tons of waste glass dispose annually in everywhere, which contributes to land pollution that affects the environment conditions (Suganthi, Kumar et al. 2024). Moreover, there is a considerable construction and demolition in the construction industry and the wastes of bottle glasses around our area which results in a huge accumulation of glass waste to the environment.

While there is a potential to reuse construction demolition wastes and other glass waste products for construction purposes, this practice is currently almost non-existence in Ethiopia and worldwide. Even if the problems have worldwide concern, as our country Ethiopia is one of the developing country in Africa, it will be a big deal and it needs concentration to be mitigated(Mulatu, Habte et al. 2018), (Bank, Ok et al. 2020).

On the other hand recycling waste glass requires huge amount of energy consumption's. This energy consumption increases the carbon dioxide in the atmosphere that results global warming. To lessen down consumption of energy, waste glass can be used as cement replacing material.

Different researcher declared that while waste glass used as cement it enhances the concrete property, it reduces the impact of cement on the environment and reduces the effect on the structure of concrete. However researches that investigated till now is not enough to reduces the impact on the environment it requires detail experimental investigation in consideration of different concrete property that contains engineering solution in consideration of environment that have Sulphate solution.

This research addressed the gap from the previous researchers and prepare the experimental investigation using waste glass by replacing the cement and experimentally investigation of different concrete property based on the standard declared by ASTM and in consideration of different scenarios.

1.3 Objective Of the Study

1.3.1 General Objective

Mechanical and durability properties of concrete with partial replacement of cement by waste glass powder

1.3.2 Specific objective

1. To characterize chemical property of waste glass powder and the physical property of other concrete constituents.
2. To experimentally investigate the effects of different percentages of glass waste powder on mechanical property(workability, compressive and flexural strengthen) of concrete.
3. To investigate the effect of different percentages of waste glass powder on durability properties(water absorption and sulphate attack) of concrete.
4. To investigate the effect of different percentages of waste glass powder on micro structure properties of concrete.

1.4 Scope of the Study

The scope of this thesis is to identify the effect of replacing cement partially with waste glass powder in concrete composites.The characterization of the waste glass material performed to understand its chemical composition and it performed under 75 micrometer size of glass powder. Other concrete composition(Fine and Coarse aggregate) physical properties done according to standard. This thesis limited to produce concrete with a strength of C-25 and to a constant water cement ratio of 0.6 with constant amount fine and coarse aggregate for each samples. The study concentrated on Four amounts of waste glass content 0, 10, 20 and 30 percentage of waste glass powder replacement to cement to determine the optimal amount of waste glass powder.

This research involved conducting laboratory tests at early and hardened concrete strengthen to analysis the workability, Mechanical(Compressive and Flexural Strengthen) and Durability property (Water absorption and Sulphate Attack) of the concrete samples. Concrete mix designs optimized by replacing cement with the specified amount of waste glass within three samples for each test.

The test of Workability done on fresh concrete time and the Flexural and Compressive Strengthen test done on 7 and 28 days. Water Absorption test result done on 28 days and

Sulphate attack of concrete test done by Using Sodium sulphate as Sulphate compound on 56 days. The concrete samples conducted experimental investigation on Micro-structure in of concrete in consideration of different amount of waste glass powder to determine its morphological structure of the samples.

1.5 Significance Of The Study

Finding the best way to use waste glass powder as a partial replacement for cement in concrete is very important. This practice benefits both the construction industry and the environment. It helps reduce waste that could cause pollution and cuts down the amount of cement needed, which in turn lowers CO2 emissions that contribute to climate change.

Using waste glass powder in cement also supports sustainable growth by recycling materials and reducing the need for new resources. Since waste glass used high energy consumption in order to recycled its more advantageous to use as SCM for environmental sustainability in energy concern and it improves property of concrete. And by studying the chemical properties of waste glass powder replacement with these different percentages and giving scientific conclusions on how to use waste glass powder in concrete production and studying their effect on Mechanical and Durability of concrete properties can serve for scholars and researchers pursuing additional studies in this area.

1.6 Limitation of the study

This research primarily utilizes waste glass powder sourced from locally available waste of window glasses which may not encompass the full variability in composition and quality found in waste glass from different regions or sources. The study investigates only partial cement replacement levels up to 30 percentage starting from 0 at increment of 10 percentage, limiting insights into the performance of higher replacement percentages that could potentially optimize sustainability benefits or reveal different durability characteristics. Furthermore, the durability assessments and mechanical tests were conducted over a relatively short duration, typically up to 28 and 56 days, which may not fully capture the long-term performance and aging behavior of concrete incorporating waste glass powder. Longer-term studies are necessary to evaluate the sustained durability and potential deterioration mechanisms over time.

1.7 Arrangement of the research work

The research is structured as follows:

Chapter 1: Introduction – Provides the background of the study, problem statement, objectives, scope, significance, Limitation and structure of the study.

Chapter 2: Literature Review –this chapter covers property of concrete at fresh and hardened time within consideration of objective of the investigation .

Chapter 3: Research Methodology – Under this chapter the materials used, mix design, experimental procedures, testing methods and test type described.

Chapter 4: Results and Discussion of the study–Under this chapter different concrete property Presented

Chapter 5: Conclusions and Recommendations – The result obtained in the study concluded and recommended for the future studies.

CHAPTER TWO

LITERACTURE REVIEW

2.1 Introduction

This chapter presents the findings from various studies on using waste glass powder as a partial replacement for cement in concrete. It covers topics such as alternative materials for cement, the use of waste glass powder in concrete, its chemical composition (including oxides), and how it affects the fresh and hardened properties of concrete. The chapter reviews the conclusions drawn by different authors regarding the feasibility of using waste glass powder as a cement substitute. Additionally, it highlights the key quality requirements, with a particular focus on workability, mechanical strength, durability, and the micro structural effects of the glass powder on concrete.

2.2 Concrete in construction Industries

Recognized for its inherent strength, remarkable durability, and adaptability across numerous construction uses, from homes to major infrastructure like bridges and highways, concrete stands as a fundamental material in the industry. Its simple composition of water, aggregates, and cement forms the basis for a wide range of building projects(Almusaed, Yitmen et al. 2024). Recent research highlights the successful integration of concrete constituent with waste materials.

These waste materials have been shown to not only meet necessary structural performance standards but also significantly decrease the amount of waste directed to landfills, thereby encouraging a circular economy within the construction sector. This move towards more environmentally conscious concrete solutions aligns with global initiatives aimed at reducing the ecological footprint of construction and represents a crucial step towards more accountable building practices. Furthermore, contemporary concrete technology is increasingly designed to withstand the challenges of climate change and extreme weather, making it vital for preparing urban infrastructure for future conditions (SHIRVANI DASTGERDI 2023).

Studies have explored the inclusion of advanced materials to boost the durability and longevity of structures against environmental pressures. This research suggests that such innovations could be instrumental in lowering maintenance expenses and extending the overall service life of concrete structures. The incorporation of supplementary

Cementitious materials further enhances concrete's mechanical properties while simultaneously reducing its environmental impact by decreasing carbon dioxide emissions during its creation (Leza 2020). This progression reflects the industry's dual commitment to achieving high performance and promoting sustainability, underscoring that modern concrete can effectively address current construction needs while also contributing to climate solutions.

The drive for sustainability has spurred significant research into environmentally friendly concrete alternatives, resulting in innovative methods for utilizing recycled materials and local resources. By emphasizing both resilience and sustainability, the construction industry ensures that concrete remains not just a basic building block but a crucial element of sustainable construction practices in an era increasingly shaped by environmental concerns.

2.3 Supplementary Cementitious Material for Cement

Concrete fundamentally consists of cement, sand, coarse aggregate, and water. Modern mixes often incorporate supplementary Cementitious materials (SCMs) as part of their binding component in replacement of cement (Biyani, Patil et al. 2020). These SCMs are typically by products from other industries or naturally occurring substances, sometimes processed further for concrete use. Interestingly, some of these materials, known as pozzolanic, lack inherent Cementitious properties but react with Portland cement to form binding compounds. To be used in concrete, SCMs must adhere to established standards and can be added individually or combined, either as a blended cement or separately batched at the ready-mix plant.

Today ASTM standards recommend specific SCMs for concrete production, including Coal Fly Ash (conforming to ASTM C618), Ground Granulated Blast-Furnace Slag (ASTM C989), and Silica Fume (ASTM C1240). In a compelling move towards sustainability, non-recyclable waste glass presents a significant challenge due to its non-biodegradable nature and the limited availability of landfills, particularly in urban areas.

Pozzolanic materials are a siliceous or alumino-siliceous material that chemically reacts with calcium hydroxide released during the hydration of Portland cement to form calcium silicate hydrate and other Cementitious compounds. Pozzolanic materials and slags are generally characterized as supplementary Cementitious materials or mineral admixtures(Abreha, Yifru et al. 2023).

However, waste glass offers a promising alternative, possessing physical properties and a chemical makeup similar to sand and cement, allowing its use as a supplementary Cementitious material in concrete production. Its pozzolanic tendency makes it a highly recommended substitute for cement. The key to waste glass's pozzolanic behavior lies in its particle size; smaller glass particles exhibit a stronger pozzolanic effect. Utilizing smaller particle sizes can also help mitigate alkali-silica reaction (ASR) expansion.

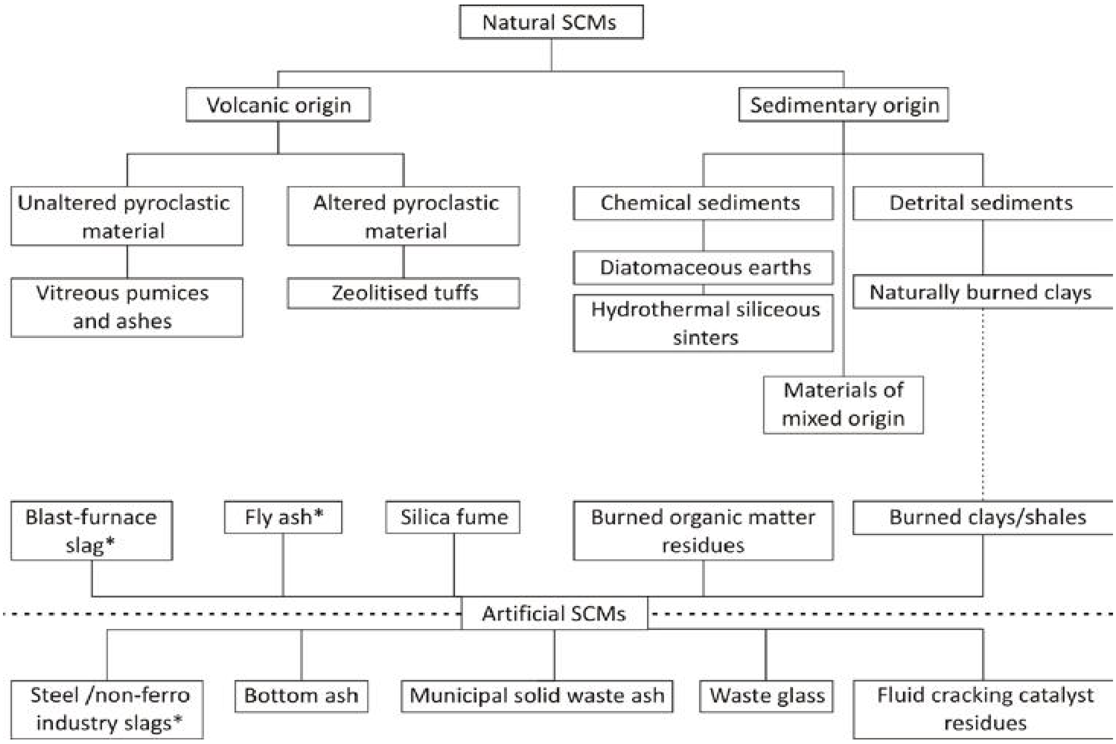


Figure 2. 1 Supplementary Cementitious Materials (Snellings, Mertens et al. 2012)

Waste glass powder is a really good example of an SCM because it helps us deal with all the glass we throw away that doesn't break down. When you grind up waste glass into a fine powder, it can act like a helper to the Portland cement. It reacts with something in the cement to make the concrete stronger and last longer.

Using waste glass powder also means we need less new cement, which is good for the environment because making cement creates a lot of pollution.

We have to be careful about how fine the glass powder is, because that affects how well it works and can help prevent problems with the concrete later on. Scientists are still figuring out the best ways to use it, but using waste glass powder in concrete is a smart way to turn trash into something useful for building.

Table 2. 1 Supplementary Cementitious materials Standard (Standard 2000)

ASTM C618(Standard 2000)	N	F	O
Silicon dioxide (SiO_2) + aluminum oxide (Al_2O_3) + iron oxide (Fe_2O_3), min, %	70	70	50
Sulfur trioxide (SO_3), max, %	4.0	4.0	5.0
Moisture content, max, %	3.0	3.0	3.0
Loss on ignition, max, %	10.0	6.0	6.0

Class N -Raw or calcined natural pozzolans that comply with the applicable requirements for the class as given here in, such as some diatomaceous earths;opaline cherts and shales; tuffs and volcanic ashes or pumicites, calcined or uncalcined; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales(Standard 2000).

Class F—Fly ash that meets the applicable requirements for this class as given herein. This class of fly ash has pozzolanic properties(Standard 2000).

Class C—Fly ash that meets the applicable requirements for this class as given here in. This class of fly ash, in addition to having pozzolanic properties, also has some Cementitious properties(Standard 2000).

2.4 Glass

Glass is an amorphous & transparent material, which is super-cooled liquid and not a solid. We can make it into all sorts of shapes and sizes. Glass is usually made by melting sand, limestone, and soda ash at very high temperatures and then cooling it down so it hardens without forming crystals.People have used broken glass in roads and buildings before. To use waste glass in concrete, you need to grind it into a fine powder. This powder, made from crushing hard waste glass from places like shops, works best as a cement substitute if the bits are smaller than 100 micrometers. How well this glass powder helps in concrete depends on how fine it is, what chemicals are in it, and how much water is around to react with it(Saidat, Cyr et al. 2021, Zeybek, Özkılıç et al. 2022).

You can find glass in many everyday items like windows, bottles, and light bulbs. For a sustainable future, we should reuse products that don't last forever to prevent the environmental problems caused by throwing them away. Using waste glass in construction is important to create environmentally friendly concrete. If we don't handle and get rid of glass waste correctly, it has a bad effect on the environment.

Figure 2. 2 Waste of glass in ASTU Campus

A major environmental issue with glass waste is that it doesn't break down. Glass stays in landfills for a very long time because it doesn't naturally decompose like organic materials. This long-term presence in the environment is harmful to both land and water environments(Al-jburi Najad, Hasan Kareem et al. 2019, Saidat, Cyr et al. 2021).

2.4.1 Source of Glass

The main ingredient in glass is sand, which is rich in silicon dioxide (SiO2). Soda ash and limestone are also commonly added to help the glass melt at a lower temperature and make it easier to work with. Other materials can be included to give the glass specific qualities like color, strength, or heat resistance.

The process of making glass involves melting these materials at very high temperatures (about 1700°C) and then shaping and cooling the melted glass. Glass used to replace cement comes from waste like old glass decorations, broken light bulbs, and scraps from shops that make glass windows and doors.

2.4.2 Availability of Waste Glass

According to IEA report, in 2005 the global production of glass was estimated to be 130 million tones with container glass and flat glass. The estimated production of glass from the European Union, China and United States was approximately 33, 32 and 20 million tons respectively (Schmitz, Kamiński et al. 2011). According to the EU report the total volume of glass production is anticipated to increase due to increase in industrialization and improvement of the living standard(Schmitz, Kamiński et al. 2011). According to I. J. F report the total is estimated glass waste of Ethiopia about 41 thousand tons, but only 2.4 percent of the waste glass is recycled and the remainder is dumped in landfills(Goa and Sota 2017).

The IEA report states that in 2005, the total global production of glass was around 130 million tons, including both container and flat glass. The European Union, China, and the United States produced approximately 33 million, 32 million, and 20 million tons of glass, respectively(Schmitz, Kamiński et al. 2011). The EU report predicts that glass production will increase in the future due to more industrial activity and better living standards(Schmitz, Kamiński et al. 2011). In Ethiopia, researcher report estimates that about 41,000 tons of glass waste are produced annually. Unfortunately, only about 2.4% of this waste is recycled, with the rest being disposed of in landfills (Goa and Sota 2017).

2.4.3 Impact of Glass Waste on the Environment

Glass is a non-biodegradable material and it is produced in many forms, colors and shapes, including container glass, bottle glass and flat glass, and it is an amorphous material containing relatively large amount of silica and calcium. As waste materials, its poses a major nuisance to waste management especially regarding landfill operations, and due to its nature, glass takes up a significant portion of landfill area, and frequently leading to substantial environmental damage. An impetus exists to utilize industrial by-products and waste materials in the construction industry to attain sustainability within this sector. Waste glass is not biodegradable, and therefore, a rational consideration for alternative utilization necessitates diverting this material from landfill disposal sites.

The incorporation of waste glass into concrete production offers not only substantial environmental benefits but also enhances the performance of the concrete, encompassing both mechanical and durability performance.The waste management practice for non-recyclable waste glass is given low attention, and it is discarded in landfills.

This is attributable to low awareness and motivation for the non-degradable waste glass that in certain cases is used in different applications. As glass is not biodegradable, disposing of it in landfills is not an environmentally friendly solution. This creates a challenge for waste management systems worldwide, due to the low recycling rates of glass and the limited space available in landfills.

2.4.4 Waste Glass Powder As Supplemetary Cementious materials

The very fine glass powder, which has a lot of silica (SiO2), a large surface area, and an amorphous (non-crystalline) structure used as an alternative material to help strengthen concrete. It is mainly used because it is inexpensive and is a waste product from industrial processes and day to day life experience. Since glass does not break down naturally, disposing of it in landfills can harm the environment and be costly. Glass can be recycled many times without changing its chemical makeup. However, because many waste glasses are colored or contain impurities, their recycling rate is lower.

Glass is mainly made of silica and is in a non-crystalline, amorphous form, which means it doesn’t have a regular structure. It can be used in cement-based projects. Glass powder has a lower density than cement, so when added, there are more glass particles in the mix. This helps improve the structure of the concrete, making it less porous and slightly reducing its weight. As more glass powder is used to replace some of the cement, the pH level of the concrete increases, making it more alkaline, which helps protect the steel reinforcement from rusting. Since glass powder doesn’t soak up water, it also makes the concrete easier to work with.

2.5 Characterization of waste glass powder

Waste glass powder is a fine material made by crushing and grinding used glass bottles, window glass and containers into a powder form. It is a type of recycling that helps reduce waste and save natural resources. It can be used in various industries, such as construction to replace some Construction materials. Studying the characteristics of waste glass powder is important to understand its properties, how it behaves when mixed with other materials, and how it can be best used in different applications.2.5.1 Physical Properties of Waste Glass Powder

According to different authors, the physical properties of waste glass powder is shown in the table below.

Table 2. 2 physical property of waste glass powder

Physical properties of WGP	(Otunyo and Okechukwu 2017)	(Sayeeduddin and Chavan 2016)
Property Unit Weight kg/m3	1540	1579
Specific Gravity	2.52	2.58
Water Absorption	0.35	-

2.5.2 Chemical Properties of Waste Glass Powder

According to different authors,the chemical properties of waste glass powder is conforming to the specifications of (Pourkhorshidi, Najimi et al. 2010).From Table below,the sum of the first three major compounds SiO2, Al2O3, and Fe2O3 surpass the value of 70% to be Class F or Class N pozzolanic materials(K Al-Chaar, Alkadi et al. 2013).

Table 2. 3 Chemical Properties of Waste Glass Powder

Oxides	Chemical composition by percentage				ASTM618
	(Pourkhorshidi, Najimi et al. 2010)	(Mageswari, Kareemullah et al. 2024)	(Melaku 2020)	(Kedir, Seid Ali)	
Silica (SiO_2)	71.44	72.5	75.56	73.5	$SiO_2 + Al_2O_2 + Fe_2O_3 >$ 70%
Alumina(Al_2O_2)	1.70	0.4	1.38	1.4	-
Iron Oxide (Fe_2O_3)	0.37	0.2	0.66	0.67	-
Lime(Cao)	10.81	9.7	9.14	9.79	-
Magnesia(MgO)	1.65	3.3	0.48	3.5	-
Sodium oxide	13.24	13.7	12.06	7.2	-
Potassium oxide	0.36	0.1	0.5	0.52	-
Sulphur trioxide	0.16	-	<0.01	0.01	Max 5%
Loss of ignition	0.04	0.36	0.52	0.5	Max 6%

2.6 Mechanical property of Waste Glass Powder on concrete Performance

2.6.1 Fresh concrete property

I. Workability of concrete

The empirical concrete slump test is used to evaluate the workability and consistency of fresh concrete mixes. Research on adding Waste Glass Powder (WGP) has shown that it influences the behavior of concrete. The results from the compacting factor test indicated that the values increased as the WGP content rose, reaching their peak at a 20% replacement of cement, which supports the idea that WGP functions as a pozzolanic material(Abdulazeez, Idi et al. 2020). Similarly, the slump test values generally increased with higher WGP content, except at 5% replacement, where the slump remained the same as the control mix without WGP. All recorded slump values were within the limits specified by BS 1881 (1981) standards(Kumar and Nagar 2017).

Conversely, a study by (Neteti and Maheswari)reported that replacing cement with waste glass powder decreases the workability of concrete as the amount of glass powder increases. This reduction is due to the large surface area and finer particles of the glass powder, which require more water for proper performance. As a result, more water than what is needed for cement alone is required, which indirectly reduces the concrete's workability(Zanwar and Patil 2021).

2.6.2 Hardened Concrete Property

I. Compressive Strength

Laboratory tests have shown that concrete mixes with waste glass powder (WGP) become stronger under compression at different stages of hardening. A study by (Mandal, Ghosh et al. 2023) found that samples with 20% of the cement replaced by WGP had about 15% higher compressive strength after 28 days of curing compared to normal concrete. More recent research agrees, suggesting that adding WGP can also improve concrete's durability and its resistance to harsh environmental conditions (ROSLAN and MOHD 2024). However, how well WGP works as a replacement depends on factors like how finely the glass powder is ground, the water-to-cement ratio, and the specific mix design of the concrete (Anwar, El-Hassan et al.); (Fanache, Vasiliu et al. 2024). It has been found that replacing 30% of the cement with WGP is the best amount for increasing the concrete's strength after 7 days(Du and Tan 2014). Concrete with 30% of the cement replaced by 38-micrometer glass powder achieved strength activity indexes of 91%, 84%, 96%, and 108% at 3, 7, 28, and 90 days, which is higher than the 75% minimum required by ASTM C618 (Contaminants 2007). When 20% of the cement was replaced with WGP, the concrete showed improved strength at 28 days compared to standard concrete (Vasudevan and Pillay 2013). Overall, the strength of concrete increases as more cement is replaced by WGP, reaching its highest point at around 20% replacement after 7, 14, and 28 days(Sakale, Jain et al. 2015). Specifically, replacing 20% of the cement with WGP resulted in a solid compressive strength of 46.54 MPa for M-40 grade concrete.

Due to the chemical reaction properties of glass powder, concrete containing it shows a significant improvement in the development of its compressive strength at 28 days compared to the control sample(Ubeid, Hama et al. 2020). A notable increase in the compressive strength of hardened concrete was observed at 21% replacement by 28 days, after which the strength gradually declined. When 10% and 15% of the cement were replaced with glass powder, the compressive strength increased by 26.34% and 22%, respectively, in comparison to the standard sample (Islam, Rahman et al. 2017).found that a 20% glass content is optimal, resulting in a 2% increase in the compressive strength of mortar and concrete after 90 days relative to traditional mixes.

Researchers examined the replacement of cement with waste glass powder (WGP) and observed that a 15% WGP content resulted in a 29% strength increase at 7 days, which slightly declined to 23% at 28 days. The optimal replacement level for maximizing strength was found to be 10%. The study also demonstrated that replacing 20%, 30%, and 40% of the cement with WGP led to compressive strength increases of 19.6%, 25.3%, and 33.7%, respectively, at 28 and 60 days when compared to the standard mix. Although increasing WGP content generally reduced the mortar's compressive strength, this reduction became less pronounced over longer curing periods(Aliabdo, Abd Elmoaty et al. 2016).

A very important element in achieving strength is the size of the particles of the glass that is used(Nwaubani and Konstatinos 2013). Research indicates that replacing 15% of the cement with a mix of coarse and fine glass powder is the optimal amount (Aliabdo, Abd Elmoaty et al. 2016). Replacing 10% and 15% of the cement with WGP can increase the compressive strength by approximately 9% and 16%, respectively. When the water-to-cement ratio remains unchanged, replacing 20% of the cement results in a 27% increase in the concrete's strength(Jena and Paikaray 2018).

Initially, adding glass powder to concrete improves its compressive strength, reaching a peak at around a 10% replacement level before it begins to decline. The most suitable range for cement replacement to achieve maximum compressive strength in concrete is between 25% and 30% (Meena, Gupta et al. 2018).

II. Flexural Strength

The use of waste glass powder in concrete positively impacts its mechanical properties and overall performance, particularly enhancing its ductility, which is a key characteristic related to flexural behavior. Flexural strength refers to a concrete's ability to resist bending forces before fracturing. The research indicates that incorporating waste glass powder into concrete enhances this capacity. The improved ductility observed in concrete with waste glass means it can bend more under load before failing, which is directly related to its flexural performance.

Research such as the thesis by (Raman and Nateriya 2024) has shown that concrete incorporating up to 10% waste glass exhibits improved ductility when subjected to bending loads. This enhanced load-deflection behavior is crucial for structural resilience, especially in areas prone to seismic activity. Furthermore, the inclusion of waste glass, due to its pozzolanic activity, leads to a more refined microstructure, which (Nassar and Abo 2020) found to improve crack resistance by hindering crack propagation. The long-term durability of concrete with waste glass is also significantly improved, as demonstrated by (Ismaeel, Usman et al. 2023). Their investigation revealed that concrete with up to 15% waste glass exhibits lower permeability and greater resistance to environmental degradation.

Crucially, this improved microstructure helps maintain the concrete's flexural strength even when exposed to challenging environmental conditions. This finding is supported by (Ali 2023), who observed that the pozzolanic effects of waste glass contribute to the preservation of flexural strength in concrete exposed to freeze-thaw cycles.This enhanced bending capacity, along with the improved resistance to cracking contributes to better overall flexural behavior. Moreover, the waste glass helps concrete maintain its ability to withstand bending over time, even when exposed to harsh conditions like freezing and thawing. Additional studies by (Mathur, Sudhanshu et al. 2022) and (Islam, Prova et al. 2025) underscore that the use of waste glass not only optimizes the concrete's flexural properties but also promotes sustainable construction by reducing landfill waste and conserving natural resources.

2.7 Durability property of Waste Glass Powder on concrete Performance

A study by (Mathur and Chhipa 2023) investigated the resistance of concrete incorporating glass powder against sulphate attack. This research specifically examined concrete produced by replacing ordinary Portland Cement (OPC) of 53 grade with waste glass powder (GP) at different proportions. The study involved substituting OPC 53 grade cement with waste glass powder in the range of 5% to 25%, with increments of 5%. Compressive strength tests were performed on concrete cubes at 7 and 28 days. The results showed that concrete containing waste glass powder demonstrated higher strength both with and without sulphate attack.

Importantly, the highest resistance to sulphate attack was observed when 20% of the cement was replaced by waste glass(Mathur and Chhipa 2023). Additionally, increasing the amount of Waste Glass Powder (WGP) was associated with a reduction in water absorption.Compared to concrete without WGP, replacing 10%, 20%, and 30% of the cement with WGP resulted in water absorption reductions of 16%, 33%, 51%, and 60%. The decrease in water absorption with higher WGP addition is due to the pore-filling effect and the pozzolanic reaction. In related research(Kovalev, Abid et al. 2023**)** conducted an experimental study specifically focusing on the replacement of cement with glass powder in concrete mixtures.

Similarly, research by (Venkatesan, Kannan et al. 2022) explored the effects of replacing cement with fine waste glass powder at proportions of 5%, 10%, and 15%.

Their test results demonstrated that incorporating waste glass powder as a partial cement substitute in this fine form positively improved the durability characteristics of both concrete and cement-based materials compared to traditional concrete and conventional mortar. Their findings indicated that substituting quartz sand and glass powder at 15% and 30% of their respective optimal levels led to enhanced performance while maintaining satisfactory workability at a water-to-binder ratio of 0.35.

Based on these findings, they concluded that using glass powder as an alternative construction material is feasible, offering both cost-effectiveness and environmental benefits(Matos and Sousa-Coutinho 2012).

The primary goal of the research conducted was to evaluate the durability of mortar when waste glass powder was used as a cement replacement. To achieve the objectives of this research, waste glass was crushed and ground into a fine powder and incorporated into mortar as a partial replacement for cement at levels of 10% and 20% by cement content.

This was done to determine its applicability in concrete. Scanning Electron Microscopy (SEM) test results revealed that the inclusion of waste glass powder led to the formation of a dense and mature gel structure, which contributed to enhancing the durability of the mortar. Consequently, it was concluded that waste glass powder has the potential to further contribute to achieving sustainability in construction without negatively impacting the properties of conventional cement mortar and, by extension, conventional concrete(Ismaeel, Usman et al. 2023).

These studies collectively highlight the potential of waste glass powder as a sustainable and performance-enhancing in cement-based materials. The improvements in durability observed in these investigations are often attributed to the pozzolanic activity of the finely ground glass powder. Pozzolanic materials react with calcium hydroxide, a by product of cement hydration, to form additional calcium silicate hydrate (C-S-H) gel. This C-S-H gel is the primary binder in concrete and mortar, and its increased formation leads to a denser, less permeable microstructure. A denser microstructure is crucial for enhanced durability as it reduces the ingress of aggressive substances like sulphate and chlorides, which can cause deterioration. The improved workability observed in some studies also contributes to better compaction and reduced porosity, further enhancing durability. Therefore, the beneficial effects of waste glass powder on the durability of concrete and mortar are intrinsically linked to its pozzolanic properties and the resulting refinement of the material's microstructure.

To achieve the objectives of this research, waste glass was crushed and ground into a fine powder and used as a partial replacement for cement at 10% and 20% levels by cement weight. This was done to assess its suitability for use in concrete. Scanning Electron Microscopy (SEM) analysis revealed that incorporating waste glass powder resulted in the formation of a dense and mature gel structure, which contributed to enhancing the mortar's durability. Therefore, it was concluded that waste glass powder has the potential to promote sustainability in construction without adversely affecting the properties of traditional cement mortar and, consequently, conventional concrete(Ismaeel, Usman et al. 2023).

Collectively, these studies highlight the potential of waste glass powder as a sustainable and performance-enhancing additive in cement-based materials. The observed improvements in durability are primarily linked to the pozzolanic activity of the finely ground glass powder. Pozzolanic materials react with calcium hydroxide—a byproduct of cement hydration—to produce additional calcium silicate hydrate (C-S-H) gel(Ismaeel, Usman et al. 2023).

This gel is the main binding phase in concrete and mortar, and increased formation of C-S-H results in a denser, less permeable microstructure. Such a microstructure is crucial for durability because it reduces the ingress of harmful agents like sulfates and chlorides that can cause deterioration. Additionally, improved workability reported in some studies aids in better compaction and reduces porosity, further enhancing durability. Therefore, the beneficial effects of waste glass powder on concrete and mortar durability are fundamentally due to its pozzolanic properties and the resulting micro structural refinement.

2.8 Microstructural property of waste glass powder

The application of waste glass powder as a partial substitute for cement in the manufacturing of concrete offers a complex opportunity to improve the micro-structural characteristics of concrete while simultaneously dealing with environmental issues linked to waste handling. Waste glass, which primarily consists of silica, displays pozzolanic attributes when reduced to a fine powder, enabling it to undergo a chemical reaction with calcium hydroxide (generated during the hydration process of cement) to create additional calcium silicate hydrate (C-S-H).

Based on the research carried out by (ONAIZI and MALAYSIA 2022), the inclusion of waste glass powder at different substitution percentages (5%, 10%, and 15% based on the weight of the cement) resulted in an enhanced micro-structural development within the concrete. Analyses conducted using Scanning Electron Microscopy (SEM) indicated a more compact arrangement and a more refined pore structure, which has a beneficial impact on the overall strength and long-term performance of the concrete matrix.The incorporation of waste glass powder was observed to enhance the durability properties of concrete. In her academic work, Singh (Singh, Choudhury et al. 2024) documented that concrete blends containing waste glass demonstrated decreased permeability and heightened resilience against detrimental environmental elements such as the intrusion of chloride ions and attack by sulfates.

This enhancement can be linked to the generation of supplementary C-S-H gel and the refinement of the pore size distribution, which culminates in a reduction of empty spaces within the concrete matrix. The research also noted that the alterations at the micro-structural level led to diminished water absorption rates, further boosting the concrete's durability and underscoring the advantages of utilizing industrial by-products in minimizing the environmental impact of building materials.

The ramifications of employing waste glass powder extend beyond merely improving performance; they also play a significant role in fostering sustainability within the construction sector. In the investigation conducted by Chen(Guignone, Calmon et al. 2022) it was demonstrated that partially replacing cement with waste glass powder not only lessens the environmental consequences arising from cement manufacturing—which accounts for roughly 8% of worldwide carbon dioxide emissions—but it also presents an efficient means of recycling waste glass.

Through comprehensive life cycle evaluations, it was shown that integrating waste glass powder into concrete production can result in considerable decreases in carbon emissions and overall material usage, thereby positioning this practice as a practical approach for advancing circular economy principles in building. And its also enhances property of concrete in different amount of cement replacement.

2.9 Sulfate attack

Sulfate attack is a chemical deterioration process in which sulfate ions target the constituents of the cement paste. The substances responsible for sulfate attack are water-soluble salts containing sulfate, such as alkali-earth sulfates (including calcium and magnesium) and alkali sulfates (like sodium and potassium), which can chemically interact with concrete components. Sulfate reacts chemically with the hydration products, specifically hydrated lime and hydrated calcium aluminate within the cement paste, to produce calcium sulfate and calcium sulfoaluminate, commonly known as ettringite. These newly formed crystals occupy available space, and their continued formation leads to expansion, disruption, and a loss of adhesion between the cement paste and aggregate. This expansion creates small voids around smaller aggregate particles and larger voids around bigger particles, resulting in the development of micro-cracks; these cracks may cause a decrease in strength or damage to the concrete by changing the chemical composition of the cement paste and impairing its mechanical characteristics(Mathur and Chhipa 2023).

2.9.1 Types/ Causes of Sulphate Attacks

The sulphate attack affecting cement concrete is divided into two main categories: internal and external sulphate attack. Internal sulphate attack occurs due to the formation of ettringite through a reaction involving gypsum, which is added during cement manufacturing to prevent premature or flash setting caused by the presence of C3A (Omopariola 2024). However, the initially formed ettringite is later converted into lightweight mono-sulfate aluminate hydrate following its reaction with C3A. This sulfate-deficient compound is approximately 2.5 times smaller in size (Nadir and Ahmed 2022).

It serves as a protective barrier against damage and further chemical attack until sulfate solution penetrates the hardened concrete, resulting in external sulphate attack from an external source(El-Didamony, El-Sokkari et al. 2012). Upon sulfate exposure, this barrier swells by about 2.5 times, transforming back into ettringite crystals, which leads to cracking or expansion within the concrete (Zhang, Vandeperre et al. 2014). External sulphate attack further converts mono-sulfate aluminate hydrate into long, needle-like ettringite crystals, causing internal cracking of the hardened concrete (Panesar 2019).

On the other hand, the formation of micro-ettringite crystals within voids results in structural expansion (Yuan, Liu et al. 2021). Magnesium sulphate attack produces gypsum and a crumbly, fibrous magnesium-silicate-hydrate gel, which lacks strength and precipitates the ultimate failure of the structure(Nadir and Ahmed 2022).

2.9.2 Sources of Sulphate Attack

The external source may be soil that contains calcium, magnesium, sodium, potassium, or ammonium sulphate (Nadir and Ahmed 2022). Nevertheless, solid sulphate cannot inflict any damage upon hardened concrete. When these minerals are mixed with rain or drainage water and permeate through the soil as groundwater, the water dissolves the minerals and contains aqueous sulphate. This water attacks the surface and is capable of ingress into the hardened concrete or mortar structure via osmosis, using voids (Yuan, Liu et al. 2021).

The bacterial decomposition of organic matter in shallow lakes and marshes generates H2S, which is converted into H2SO4 and causes an acid or sulphate attack (Eštokov, Harbuľáková et al. 2012). Fertilizers within agricultural soil contribute to ammonium sulphate, which can be transported with surface drainage and into sub-soil groundwater. Seawater also contains sulphate minerals and chlorides and can result in significant sulphate or chloride attacks (Nadir and Ahmed 2022).

Water from cooling towers, sewers, acid rains, and poor chemical waste disposal can introduce aqueous sulphate into the soil and groundwater.

2.9.3 Property of Concrete with Waste Glass powder against Sulphate attack resistance

Waste glass powder (WGP) has emerged as a promising supplementary Cementitious material for enhancing the sulphate attack resistance of concrete. The primary mechanism by which WGP improves resistance lies in its pozzolanic activity. When finely ground, the amorphous silica in waste glass reacts with the calcium hydroxide (CH) released during cement hydration. This reaction consumes the readily available CH, which is a key reactant in the formation of expansive products like ettringite and gypsum during sulphate attack (Surendran and Akhas 2024).

By reducing the amount of C-H in the pore solution and solid matrix, the potential for these detrimental reactions is significantly minimized, leading to reduced expansion and cracking of the concrete(Kroviakov, Zavoloka et al. 2019). Furthermore, the pozzolanic reaction of WGP contributes to a denser and less permeable pore structure within the concrete matrix. The formation of additional calcium-silicate-hydrate (C-S-H) gel fills pores and capillaries, reducing the pathways for aggressive sulphate ions to penetrate the concrete(Ramakrishnan, Pugazhmani et al. 2017). Studies have demonstrated that incorporating WGP, particularly at optimal replacement levels leads to lower sulphate expansion values compared to plain concrete mixes.

This improved impermeability not only hinders sulphate ingress but also contributes to overall enhanced durability against other aggressive agents(Pan, Tao et al. 2017).

While the benefits of WGP in improving sulphate resistance are widely reported, it's important to note that the effectiveness can depend on factors such as the fineness of the WGP, its chemical composition, and the specific sulphate environment (Shi, Wu et al. 2005, Carsana, Frassoni et al. 2014, Olutoge and Strength 2016).

Generally, finer WGP exhibits higher pozzolanic activity and thus greater potential for sulphate resistance.

Research indicates that replacing a portion of cement with properly processed WGP offers a sustainable and effective approach to producing concrete with improved long-term performance in sulphate-rich environments(Olutoge and Strength 2016).

2.10 Factors that influence Performance of WGP in concrete

The performance of waste glass powder (WGP) as a supplementary Cementitious material in concrete is not uniform and is significantly influenced by several key factors.

The first factor is the fineness of the WGP. The pozzolanic activity of WGP, which is crucial for its beneficial effects, is directly related to the surface area available for reaction with calcium hydroxide. Finer particles offer a larger surface area, leading to a more complete and rapid pozzolanic reaction(Amin, Agwa et al. 2023).

Studies have consistently shown that WGP ground to a fineness comparable to or exceeding that of cement exhibits superior performance in terms of strength development and durability enhancement compared to coarser WGP. Particle size distribution also plays a role, with an optimal distribution contributing to better packing and reduced porosity(Szudek, Gołek et al. 2022).

The Second critical factor is the chemical composition of the waste glass. The primary active component in WGP is amorphous silica (SiO_2). However, the composition can vary depending on the source of the waste glass (e.g., container glass, flat glass). The presence of other oxides, particularly alkali oxides (Na_2O and K_2O), is a significant concern due to their potential to contribute to alkali-silica reaction (ASR). While the pozzolanic reaction of WGP can consume some of the alkalis from cement, high alkali content in the glass itself can exacerbate ASR, leading to detrimental expansion and cracking.

Therefore, characterizing the chemical composition of the waste glass is essential to assess its suitability for use in concrete, particularly in environments susceptible to ASR(Paul, Šavija et al. 2018).

And also the replacement level of cement with WGP and the curing conditions are crucial determinants of performance. There is often an optimal replacement level for WGP, beyond which the beneficial effects may diminish or even become detrimental (Brwa and Saeed 2020). Excessive replacement can lead to reduced early-age strength due to the slower pozzolanic reaction compared to cement hydration.

Proper curing is also vital to allow the pozzolanic reaction of WGP to proceed effectively, especially at later ages. Adequate moisture and temperature facilitate the dissolution of silica from WGP and its reaction with calcium hydroxide, contributing to improved strength and durability over time. Therefore, careful consideration of these factors is necessary to maximize the positive impact of WGP in concrete mixtures(Olutoge and Strength 2016).

2.11 Case Study of Successful Implementation of Waste Glass Powder

Application of WGP in real world is recently applied in different areas of the world. From these Case studies the research studied in Spain,Madrid declared that WGP suitable for enhancement of concrete using glass powder, it uses of glass powder as a high percentage cement substitute in the manufacture of deactivated concrete to be used as pavement in outdoor areas was examined(Más-López, García del Toro et al. 2021).

Deactivated concrete slabs manufactured with a high percentage of glass dust in the binder represent an Eco friendly alternative that is in line with the circular economy, which is currently imposed as a principle in civil engineering, as a result The experimental results indicated that it is feasible to produce mortar with fine glass powder and that floors made of deactivated concrete with a glass powder binder base are highly stable against atmospheric and mechanical agents.

These characteristics give them a long-life cycle and low maintenance. Exposed aggregate finishes are rough, nonslip, and resistant to wear and tear and the action of atmospheric agents. Its application would be suitable for pedestrian areas such as park streets and outdoor traffic areas in need of a durable pavement, as well as accesses to garages, terraces and patios, swimming pool areas, and roads with light traffic(Más-López, García del Toro et al. 2021).

Regarding alkaline elements, especially sodium, were released in significant quantities, although not in quantities sufficient to cause changes in the electrical conductivity of the soil, so they do not pose an environmental hazard, similar to calcium, which is a nontoxic element and, at the concentration level determined, would not cause a soil pH modification and considerable presence of chromium and boron, potentially contaminating elements, in the filtrate water during the first hours of the test is remarkable(Más-López, García del Toro et al. 2021).

These elements tended to disappear at the end of the process, since they were incorporated into the cement matrix; therefore, they do not cause environmental contamination and finally the rest of the elements detected were found at trace levels in the filtered water, so due to their scarcity, they cannot constitute a danger to the natural environment according to the legislation in force(Más-López, García del Toro et al. 2021).

2.12 Limitation and Challenges

I. Variability in Glass Quality

A challenge in using WGP is the variability in glass quality, which can affect the consistency and performance of the concrete. Differences in glass types and contamination levels can lead to inconsistent results(Kumar and Nagar 2017). Standardizing the quality of WGP is essential to ensure reliable and reproducible results in concrete applications. Recent work by (Venkatesan, Sreenivasaraja et al. 2023) emphasizes the need for rigorous quality control and standardization to address these challenges.

II. Long-Term Performance

While short-term studies have shown promising results, there is limited research on the long-term performance of concrete containing WGP. These researchers declared researches relate to chemically aggressive areas need high concern while conducting the research. Future research is needed to assess the long-term durability and structural performance of WGP concrete under varying environmental conditions(Amin, Zeyad et al. 2024) This includes studying the long-term effects on structural integrity, performance under extreme conditions, and potential issues such as shrinkage and cracking.

Since the incorporation of waste glass powder as a partial replacement for cement in concrete offers a promising approach to sustainable construction, challenges related to variability in glass quality and long-term performance must be addressed through further research and standardization. Overall, the use of WGP aligns with the growing emphasis on eco-friendly construction practices and resource conservation.

2.13 Research Summary

In recent years, there has been a growing focus on finding ways to make construction more eco-friendly and reduce waste by different researchers in consideration different environmental cases. One idea is to use waste glass powder as a partial replacement for cement in concrete production. Waste glass is widely available and often thrown away, so using it in construction can help reduce glass waste and lower the environmental impact of making cement.

This research looks at how adding waste glass powder to concrete affects its Mechanical and durability property of concrete. Here in below table main research that have done on the WGP discussed and their gap were figure outed for further research ideas.

Table 2. 4 Summary of earlier researches

Property of concrete	%of replacement	Author name and citation	Remark
Mechanical property	10% of replacement	(Abdulazeez, Idi et al. 2020), (Agboola Shamsudeen Abdulazeez, Idi et al.),	These thesis done on 7th and 28th day of curing and obtain the optimal value
	15% of replacement	(Du and Tan 2015), (Yohannes 2022), (Khan, Fahad et al. 2015),Swarna dubey,s. S. Goliya, o.s. Dhakre(2016)	This study declared using glass powder as 15% which contributes to the performance of concrete enhancement.
	20% of replacement	(Zhu, Meng et al. 2023), (Arora, Kumar et al. 2022),(Paul,Bindhuetal.2022),(Olii, Hidayat et al. 2023), (Talsania, Pitroda et al. 2015)	The properties of concrete by partial replacement of cement with waste glass powder increases and peak was reached at 20% replacement.Then it decreases
Durability property (Water Absorption)	Decreases as % of WGP increases	(Neteti and Maheswari , Mageswari, Kareemullah et al. 2024), (Revathy, Yaswanth et al. 2023), (Zemenu 2021), (Kovalev, Abid et al. 2023)	These researchers declared that due to fineness of glass powder (>75micrometer) and their w/c water absorption of concrete decreases.A denser microstructure is crucial for enhanced durability as it reduces the ingress of aggressive substances like sulphate and chlorides, which can cause deterioration.

Property of concrete	% of replacement	Author name and citation	Remark
Microstructural Property	It become more compacted as amount of glass powder increased	(ONAIZI and MALAYSIA 2022), (Singh, Choudhury et al. 2024), (Guignone, Calmon et al. 2022)	Analyses conducted using Scanning Electron Microscopy (SEM) indicated a more compact arrangement and a more refined pore structure, which has a beneficial impact on the overall strength and long-term performance of the concrete matrix.
Sulphate attack resistance	As amount of glass waste become more fine Sulphate resistance increased	(Shi, Wu et al. 2005, Carsana, Frassoni et al. 2014, Olutoge and Strength 2016), (Kroviakov, Zavoloka et al. 2019), (Surendran and Akhas 2024).	Finer WGP exhibits higher pozzolanic activity and thus greater potential for sulphate resistance. Research indicates that replacing a portion of cement with properly processed WGP offers a sustainable and effective approach to producing concrete with improved long-term performance in sulphate-rich environments

2.14 Research Gap

The earlier researchers consider different cases of study related to mechanical and durability effect of waste glass powder on concrete with different amount of percentage in order to identify its optimization limit.

However these researchers can’t provide all required information like sulphate attack and its micro structural impact of replacing WGP to cement performance of the concrete.

This thesis focus on provide all required information for specified percentage replacement of WGP to cement which provide accurate information for the application of the WGP to real world. In addition to this research areas related to sulphate attack resistance of waste glass powder in concrete by earlier researchers can't made in detail and need further scientific experimental investigation.(Amin, Zeyad et al. 2024).

In order to overcome gap of the research this thesis aimed to provide scientific based investigations of sulphate resistance of concrete and its micro structural property using waste glass powder for future researchers. Further more WGP as supplementary Cementitious Material need detail research in our country context using locally available construction materials because earlier researchers can't provide detail scientific investigation researches related to WGP as pozzolanic material since its new scientific concept for our country researchers. Generally this experimental investigation focused on mechanical and durability property of the concrete using WGP to provide experimental solution for the work that can't performed before in detail.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Introduction

The study was carried out at Adama Science and Technology University within the construction materials laboratory. Its primary objective was to investigate the mechanical properties of concrete—including workability, compressive strength, flexural strength—and its durability, such as water absorption, sulfate resistance, in addition to this microstructure, specifically focusing on normal strength concrete (C-25) with partial cement replacement using Waste Glass Powder (WGP).

This research adopts an experimental approach, utilizing primary data gathered through laboratory tests and secondary data from existing literature that is more related to our thesis title. The experimental design examined the effects of replacing cement starting from 0%, 10%, 20% and 30% with WGP on the properties of C-25 concrete, aiming to identify the maximum replacement level that maintains mechanical strength and durability against sulfate attack. Material properties were tested in detailed including the chemical composition of WGP. Chemical analysis of WGP conducted were at the Ethiopian Geological Survey Laboratory.

In all mix designs, the quantities of aggregates, sand, and water remained constant, while the proportion of WGP as a cement substitute varied according to the replacement level. The methodology contains mixing procedures, material characteristics, mix proportions, and testing setups that mainly discussed in this chapter.

A total of 48 concrete cubes measuring 150 mm × 150 mm × 150 mm were cast and tested in accordance with ASTM standards: 24 cubes for compressive strength testing (following ASTM C-39 and ASTM C-172), 12 cubes for water absorption, and 12 cubes for sulfate resistance. Additionally, 24 beam molding measuring 100 mm × 100 mm × 500 mm were prepared for flexural strength testing following ASTM C78/C78M standards.These all prepared sample passes through preparation of the materials and made required testes to check either they fulfill the standard or not. For Coarse and Fine aggregate physical properties like Bulk density, specific gravity and Water absorption tests were conducted.In same manner Physical and Chemical property of waste glass powder made to check its condition to fulfill standard of pozzolanic material required. The testing included four different mix groups, including a control mix.

The workability of each fresh concrete mixture was assessed immediately after mixing. Compressive strength and flexural strength tests were conducted at 7 and 28 days and water absorption and sulfate resistance tests were conducted at 28 and 56 days, respectively.

3.2 Materials Used

All materials incorporated in this study were verified in accordance with standards set by the American Society for Testing Materials (ASTM) and the American Concrete Institute (ACI, 2009). The materials used include fine aggregate (sand), coarse aggregate, cement, waste glass powder, and water. Selection and testing of these materials followed the relevant ASTM guidelines: ASTM C33/C33M-11a for both fine and coarse aggregates, and ASTM C618-2000 for waste glass powder.

3.2.1 Coarse Aggregate

The coarse aggregate consisted of crushed rock that is clean, hard, and durable, free from dust, friable substances, organic matter, or other deleterious materials. The aggregates possess high compressive and shear strength, good interlocking properties, and suitable permeability. According to ASTM C33/C33M-11a, characterized by a particle size passing through a 20mm sieve and retained on a 14mm sieve, as specified in the standard. Coarse aggregate is the primary component of concrete, constituting approximately 70% to 80% of the total material for concrete production. In this thesis the coarse aggregate was sourced from a locally available and laboratory tests were performed to determine its physical properties, including , Bulk density specific gravity, water absorption capacity.

Table 3. 1 Summary of physical property of Coarse aggregates

Type of test	Test method	Test result	ASTM Requirement	Remark
Bulk Density	ASTM C29	1606.7Kg/m3	1280 to 1920	Ok
Specific gravity	ASTM C128	2.9	2.4 to 3.0	Ok
Water absorption	ASTM C128	0.76 %	0.2% to 4%	Ok

Here from the above table coarse aggregate that used for experiment respects the standard declared by ASTM and it used as composition of concrete in this study.

3.2.2 Fine Aggregate / Sand

The main aim of fine aggregate is to fill voids present in coarse aggregate and to provide Good workability(Ikotun, Sithole et al. 2024).

Natural river sand is characterized, and qualities such as water absorption, bulk density, specific gravity, and others are assessed using ASTM standards(Standard 2011).

In this study, locally available sand with particles smaller than 4.75mm was selected for use. The physical property of the fine aggregate following ASTM C33/C33M-11a was conducted and its summary included in this table

Table 3. 2 Summary of physical property of Fine aggregates

Type of test	Test method	Test result	ASTM Requirement	Remark
Bulk density of fine aggregate	ASTM C29	1629.5kg/m3	1280 to 1920 Kg/m3	Ok
Specific gravity	ASTM C128	2.5	2.4 to 3.0	Ok
Moisture content	ASTM C128	1.6%	0.2% to 4%	Ok

The above result shows that the Fine aggregate physical properties specified by ASTM. From the result fine aggregate can used for sample preparation for experimental investigation.

3.2.3 Quality of Water

For producing concrete with the desired strength, it is essential to use clean, potable water that is free from impurities, contaminants, or harmful substances.

Using such high-quality water ensures proper chemical reactions during curing, promotes strong bonding among the cement and aggregates, and ultimately results in durable, high-strength concrete. The water cement ration selected from physical tests of coarse and fine aggregate and earlier researcher recommendation for the application of wgp in aggressive environment(Fanache, Vasiliu et al. 2024).

3.2.4 Properties of Hydraulic Cement

For all of the sample mixes, the same type of cement was utilized, and the amount added every mix remained consistent. . The cement for the lab work was purchased in Adama local market. The cement used was Ordinary Portland Cement (OPC).

3.2.5 Waste Glass Powder (WGP)

Waste glass is material that used as supplementary Cementitious material due to its pozzolanic property. This material can replace as Concrete constituents like fine, coarse or cement while it grinded in different sizes. Here in this study Waste glass used as cement because different researchers declared that while we used as fine or coarse aggregate its more affected to Alkali-Silica reaction which affects the performance of concrete through its service time. Due to its amount of mineralogical find within it self while it used as cement it can fill gap between the concrete pores. This enhance the property of concrete.

I. Physical Property of Waste Glass Powder

It was essential to analyze the mineralogical composition of Waste Glass Powder (WGP) prior to its utilization in concrete applications. The Ethiopia Geological Survey conducted chemical testing of the WGP using established analytical procedures. The results of these chemical analyses were then compared against the ASTM C618 standards to determine compliance.

The waste glass was collected from Bahir Dar City, sourced from end-of-life glass containers and broken bottles. These included containers such as beer bottles, wine bottles, soft drink bottles, and other glass waste. The collected glass was initially shattered into small fragments to produce glass culets. These fragments were then ground further using a Jaw Crusher BB50 model to achieve finer particles. The crusher's gap width was precisely adjusted with a digital display to ensure optimal size reduction, targeting a setting of 75 µm.

The glass powder colour is white this is due its chemical composition and

The input material was fed through a non-rebound hopper into the crushing chamber, where size reduction occurred within the wedge-shaped space between the fixed jaw and the movable jaw driven by an eccentric shaft. The resulting Glass Waste Powder (GWP) was collected after grinding.

Figure 3. 1 Materials for production of Waste Glass Powder

As we can see from the figure above waste glass powder become more fine and contains white colour when milled into small particles. The reason for this is the process breaks down the glass into tiny particles that scatter light in all directions. Glass is originally made from silica and other materials that are usually transparent or colored. When the glass is ground into a very fine powder, the small particles reflect and scatter light more evenly, giving the powder a bright white appearance. Additionally, any impurities or colorants in the glass are less noticeable at such a fine scale, making the powder look uniformly white.

II. Chemical Property of Waste Glass Powder

Determining the chemical composition of Waste Glass Powder (WGP) is crucial prior to its application in concrete, as waste glass originates from various sources. This variability in source material can influence the chemical makeup of the powder, potentially affecting concrete performance. The analysis of WGP reveals a range of major and minor chemical compounds.

The primary oxides identified include Silicon Dioxide (SiO_2), Calcium Oxide (CaO), Aluminum Oxide (Al_2O_3), and Iron Oxide (Fe_2O_3). In addition, minor oxides such as Magnesium Oxide (MgO), Sodium Oxide (Na_2O), Potassium Oxide (K_2O), Sulfur Trioxide (SO_3), Manganese Oxide (MnO), Phosphorus Oxide (P_2O_3), and Titanium Dioxide (TiO_2) were also detected.

Based on the analysis done by the Ethiopian Geological laboratory the waste glass powder qualifies as a Class F pozzolanic, indicating its suitability for use in Cementitious applications. As shown in Table , the chemical analysis result conforms to ASTM C618 standard. Even, the chemical analysis result of waste glass powder does comply with some literature's mentioned before

Table 3. 3 Chemical Composition of waste glass powder

Material	SiO_2	Al_2O_2	Fe_2O_3	Cao	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Mass (%)	72.92	0.86	0.44	7.48	2.9	12.08	<0.01	<0.01	0.8	0.08	0.63	2.07
	Sum for pozzolanic property= (SiO2+Al2O3 + Fe2O3) =74.22 ≥70% class F (ASTM C618, 2000)											

According to the results noted in table and figure above, the chemical analysis result conforms to ASTM C618 standard and the waste glass powder can be used as a pozzolanic of Class F (fly ash), since the waste glass have CaO of 7.48 % by mass which is less than 10%(Standard 2000)

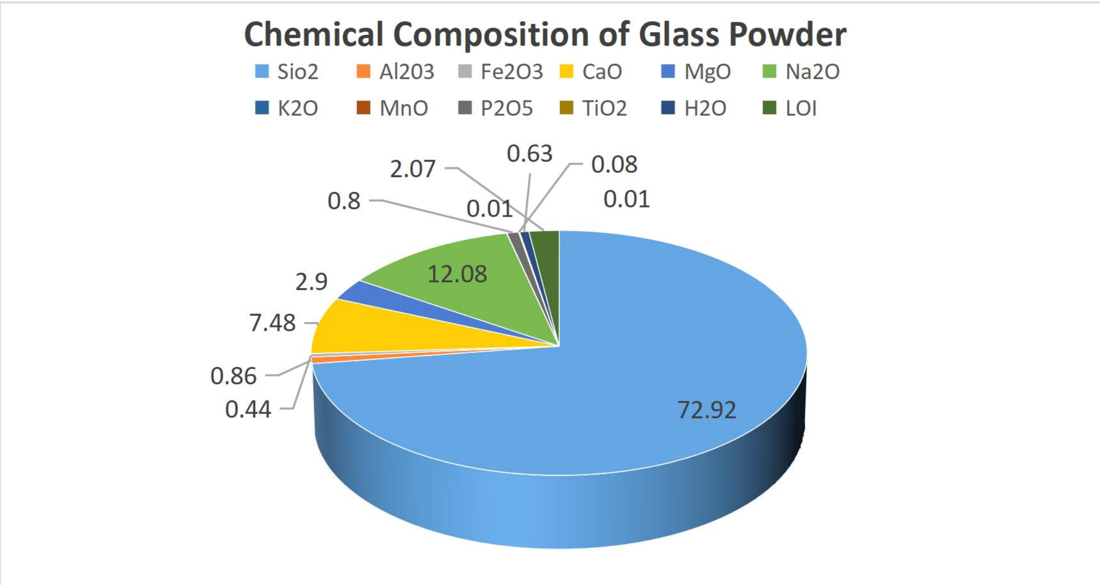


Figure 3. 2 Summary of chemical composition of glass powder

Waste glass powder mainly contains silica (SiO_2), along with small amounts of soda (Na_2O), lime (CaO), and other oxides. Its high silica content makes it similar to the main ingredient in cement and concrete. When added to concrete, waste glass powder can react with other materials and improve the strength and durability of the mixture. However, if not processed properly, the high silica content can cause a reaction called alkali-silica reaction (ASR), which may lead to cracking and damage in the concrete over time. Therefore, understanding the chemical composition of waste glass powder helps in using it effectively in construction and avoiding potential problems

Figure 3. 3 Summary of Material Used for Concrete Production (a) Coarse Aggregate (b) Cement (c) Waste glass Powder and (d) Fine aggregate

The figure above shows that material used for concrete production like waste glass powder, Cement, Fine aggregate and coarse aggregate

3.3 Experimental Setup

The study includes major tasks to accomplish the objectives.These tasks are clearly stipulated in the following Figure as shown below

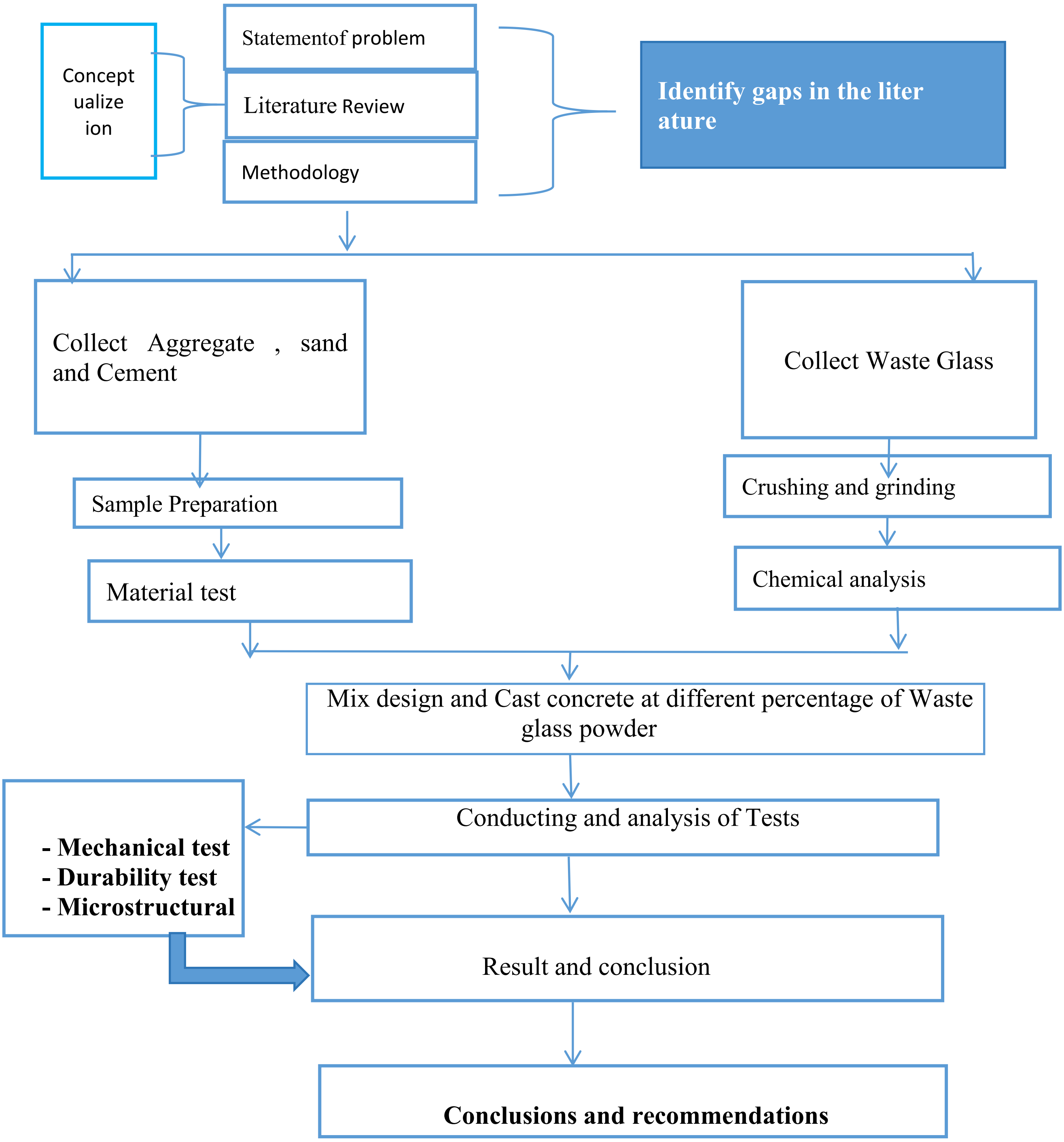


Figure 3. 4 Methodology flow chart of the Experiment

The above figure shows that all process that production of concrete passed through by using waste glass powder replacing cement in different amounts.

The process started with by observing the problem of waste glass powder on the environment and energy consumption when it appears as a waste. Then by bench marking the problem assessment of literature review had made and the gap from research performed before have been figure outed.In order to fill the gap material and methodology settled out from different literature and experimental investigation performed in the construction material laboratory. At last result and discussion of the experiment analyzed and recommendation made for future researchers.

3.4 Mix Design

Mix design is essentially the process of creating the ideal concrete mixture. However, accurately predicting the concrete's strength and properties isn't simply a matter of combining materials in fixed ratios; it often involves an experimental process with trial mixes to achieve the desired performance. The percentage of replacement selected from different literature that contains optimum and maximum amount of replacement. Besides this, the ratios of cement to aggregates and fine to coarse aggregates also sign from reviewing different optimum significantly impact the mix's quality. Since cement is the most expensive ingredient, the aim of mix design is to use the least amount possible without compromising quality, balancing cost-efficiency with performance in the final concrete

Table 3. 4 Mix proportion of the experiment

Sample code	Cement in (kg)	Glass Powder in (kg)	Fine Aggregate(Kg)	Coarse Aggregate (Kg)	Water Cement ratio
Control (0% WGP and 100 Cement	26.65	0	57.6	76.38	0.6
90C+10 WGP	23.76	2.88	57.6	76.38	0.6
80C+20WGP	21	5.65	57.6	76.38	0.6
70C +30 WGP	18.24	8.4	57.6	76.38	0.6

For concrete sample testing, it is essential to follow standard procedures to ensure accurate and reliable results. Typically, a minimum of three specimens are prepared for each test to account for variability and to provide a representative assessment of concrete properties. According to ASTM C39, three standard concrete cubic are used for compressive strength tests, with each specimen tested at specified ages such as 7 and 28 days. Similarly, for flexural tests, a similar number of samples are recommended to obtain consistent data.

In same way for water absorption, Sulphate three sample for each prepared for accurate of the data. These standard sample sizes and quantities help in assessing the overall quality and consistency of the concrete mix, ensuring that the results are statistically valid and reflective of the batch's performance.

Table 3. 5 Number of sample prepared for test

Sample code	Cement	Waste glass powder	Number of codes			
			At 7 days	At 28 days	At 56 days	Total
Control	100 %	0 %	6	9	3	18
90C+10 WGP	90 %	10%	6	9	3	18
80C+20WGP	80 %	20 %	6	9	3	18
70C +30 WGP	70 %	30 %	6	9	3	18
Total						72

From the above table at 7th day flexural and compressive strengthen investigated that is each test contains three samples. And in same way test on the 28th day done by adding the water absorption of concrete. For sulphate attack test at 56th day each three samples done for all samples.

3.5 Types of test

The concrete was prepared using a mixing machine in accordance with ASTM C-192, which outlines the standard procedures for making and curing laboratory test specimens. All ingredients were carefully loaded into the mixer, then combined for three minutes. Afterward, the mixture was allowed to rest for another three minutes, with the open top covered to prevent evaporation. It was then mixed again for an additional two minutes.

After we outed the concrete from the mixer the workability of fresh concrete is done using slump test materials.

Once the slump test was conducted, the freshly mixed concrete was poured into molds and compacted using electrical vibrator within specified time in order to avoid void present within the pores(Behera, Ghosh et al. 2019). The specimens were left in the molds for the first 24 hours to set. After this period, they were carefully removed from the molds and placed in a water bath maintained at 23 ± 1°C for curing until they reached the required testing age, as specified by ASTM standard.This process described here in below figure.

Figure 3. 5 Process of mixing sample,vibrating and curing

While we made mixing proportion, Sampling, Vibrating and curing consideration haven been taken because it have an impact on early concrete property and later on when concrete become hardened. Effects like segregation, opening pours ,loss in strengthen can be related to improper mixing proportion, vibrating and other. Therefore each step of sample preparation have been made through careful process.

3.5.1 Workability Test

The workability of fresh concrete is an essential property, reflecting how easily it can be placed and finished. To evaluate this, a standard slump test was conducted using a truncated metal cone mold filled with the fresh mix. The cone was filled in three equal layers, with each layer compacted by 25 rod strokes using a 5/8-inch tamping rod to ensure proper density. After filling, any excess concrete on top was leveled off, and the cone was carefully lifted vertically. The amount the concrete sank or "slumped" from the original height of the cone was then measured, producing the slump value, which indicates the concrete's workability. This procedure followed the guidelines specified in ASTM C 143/C, the "Standard Test Method for Slump of Hydraulic-Cement Concrete"(ASTM 2012).

Figure 3. 6 : Slump test process

3.5.2 Compressive Strength

Compressive strength is one the most critical property of hardened concrete. It depends on the age of the specimen, as strength increases over time due to ongoing cement hydration. The compressive strength was evaluated following the ASTM C-39 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens"(Habibul Ahsan 2018). Twelve samples were prepared by casting concrete into 150mm x 150mm x 150mm cubes and curing them in water.

The tests were performed at 7 and 28 days of curing using a suitable compression testing machine. During testing, each cube was placed in the machine, which applied a load at a rate of 20 N/mm² per minute until failure occurred. The maximum load sustained by the specimen was recorded.

The compressive strength was then calculated by dividing this maximum load by the cross-sectional area of the cube, providing the strength value in units of force per area.

Figure 3. 7 Machine and process of Compressive Strengthen

3.7.3 Flexural Strengthen test

The flexural strength of concrete was evaluated following the procedures outlined in ASTM C78/C78M, "Standard Test Method for Flexural Strength of Concrete (Using a Simple Beam with Third-Point Loading)(Wright and Garwood 1952)." The process involves preparing concrete beams, typically measuring 100 mm x 100 mm x 500 mm, which are then cured for periods of 7 and 28 days.

These beams are positioned on supports in a universal testing machine, with the supports spaced at two points, and load applied at the midpoint of the span, one-third of the length from each end. The load is increased gradually until the beam fails, with measurements taken for both the maximum load and the deflection at the center. The specimens are cast according to the dimensions specified in ASTM C78/C78M-17, and curing follows the guidelines set in ASTM C31/C31M-17a.

For this experiment, the ASTM C293 standard, "Test Method for Flexural Strength of Concrete (Using Simple Beam with Four-Point Loading)," was also used, as illustrated in the accompanying figure and the subsequent calculations.

$$\text{Flexural strength} = \frac{\text{Load at failure}}{\text{Beam width x Beam depth}}$$

Figure 3. 8 Machine test for Flexural Strengthen

3.7.4 Water Absorption of Concrete

ASTM C-642-13'standard test procedure for density, absorption, and voids for hardening concrete' is followed (ASTM C642 2013, ASTM 2013). The concrete with the respective replacement level of WGP 28th day water absorption tests. For the water absorption test, Four concrete samples (0%, 10%, 20% and 30%) each contains three samples applied to identify the water absorption of concrete.

First, the samples will be kept in an oven for 24 hours at 100-105° C., and the dry weight of the blocks will be determined.The wet weight of the sample was then measured after it was immersed in water for 24 hours. Water absorption was calculated as a percentage of the weight loss compared to the block's dry weight.

$$\textbf{Water Absorption} = \frac{\boldsymbol{Wet\ weight - dried\ weight}}{\boldsymbol{Wet\ weight}}$$

Figure 3. 9 Oven dry machine for water absorption test

3.7.5 Sulfate Attack of the Concrete

The method for testing concrete's resistance to sulphate attack is outlined in ASTM C1012. This procedure evaluates the chemical durability of concrete by immersing test specimens in acidic or alkaline solutions for a specified period, then comparing their measurements to those of control samples. The sulphate resistance is typically determined by observing changes in weight of the specimens after exposure to chemical solutions (kefelegn et al, 2022 McCarthy, M. J. and Thomas, D. D., 2019). In this study, 150mm x 150mm x 150mm concrete cubes were cast and cured in water for 28 days.

After curing, the specimens were carefully removed from the water, excess surface moisture was cleaned using a standard surface preparation process, and their initial weight was recorded. The specimens were then submerged in a 5% sodium sulphate solution and kept in this environment for another 28 days. After this period, the samples were taken out, and their final weights were measured to assess weight changes due to sulphate exposure. And Also the percentage of weight losses of the samples the sample calculated.

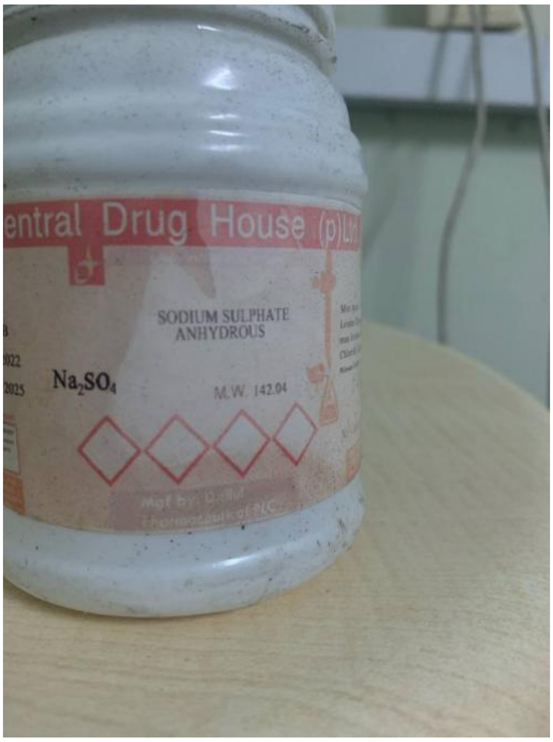


Figure 3. 10: Sample and material for sulphate attack test

3.7.6 Micro-structural investigation

Analyzing the micro structure of concrete is crucial for gaining insights into its properties and performance at a microscopic level. The morphological Structure of concrete observed in order to see the structure, porous and micro cracking of the concrete. A popular technique for this examination this morphological structure is by using Scanning Electron Microscopy (SEM), which is often conducted following standards such as ASTM C457, which evaluates air void systems in hardened concrete. The concrete sample is placed inside the SEM chamber, where it is scanned at various magnifications to unveil intricate details about hydration products, pore structures, and the organization of aggregate particles. During the SEM analysis, micro graphs are taken, enabling a thorough evaluation of characteristics like pore sizes and their distribution. This information is vital for assessing the durability and overall performance of the concrete. The internal concrete part of the fractured concrete used for the examination of SEM.

3.6 Standard For concrete Tests

The properties of the produced concrete at fresh and harden state are slump or workability test, compressive strength test, Flexural, water absorption, Sulphate attack and the micro structure of the cement paste are expected under this study.

Table 3. 6 : ASTM Test Standard Methods and Specifications for Concrete Properties

Laboratory tests types	Test method
Slump or workability test	ASTM C-136
Compressive strength of concrete after curing	ASTM C-29
Flexural strength of concrete after curing	ASTM C78/C78M
Water absorption of hardened concrete	ASTM C127
Sulfate attack test of hardened concrete	ASTM C-128
Microscopical Determination for hardened concrete	ASTM C457

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This Chapter discusses about the result obtained from experimental investigation of glass powder replacing the cement in production of concrete according to standard outlined. Different type of concrete test performed based on the objective of the study which states the overall experiment work in consideration of variability of the cement and glass powder amounts. Further more this part explains about the result through considering the material with respect to type of test .

4.2 Chemical Property of WGP and cement

The chemical Composition of materials indicate that what type of compound that material contains and in how much amount present in the material.These condition indicates or determine the property of the material which mainly have impact on there application. The compound percentage present in the material mainly affects the material application area.

The chemical composition of binding these material look likes different since the source of material they used is from different areas.

The main ingredient in glass is sand, which is rich in silicon dioxide (SiO2). Soda ash and limestone are also commonly added to help the glass melt at a lower temperature and make it easier to work with(Ikotun, Sithole et al. 2024). Other materials can be included to give the glass specific qualities like color, strength, or heat resistance.

Primarily produced OPC raw materials such as limestone and clay, which are crushed, blended, and heated in a kiln to form clinker. The clinker is then ground with gypsum to produce OPC cement. Major sources include limestone deposits rich in calcium carbonate and clay or shale rich in silica, alumina, and iron oxides.

The Below table shows that what type of compound find in the OPC and WGP and in how much percentage present within them. As the table shows the main difference between cement and WGP is amount of silica and Calcium they contains as constituent. The amount of these chemical composition have impact on the property of concrete in mechanical and durability enhancement.

Table 4. 1: Chemical Composition of OPC and Waste Glass Powder

No.	Compostion	OPC	Waste glass powder
1	Sio_2	20.8	72.92
2	Al_2O_3	4.60	0.86
3	Fe_2O_3	2.8	0.44
4	CaO	65.40	7.48
5	MgO	1.3	2.9
6	Na_2O	0.31	12.02
7	K_2O	0.44	<0.01
8	SO_3	-	-
9	MnO		0.01
10	P_2O_5	-	0.8
11	TiO_2	-	0.08
12	H_2O		0.36
12	LOI		2.07

The Silica amount in the OPC and WGP 20.8 % and 72.92 % respectively. The presence of silica mainly participate in enhancement of strength and durability by participating in the hydration process, forming compounds like calcium silicate hydrates (C-S-H) that contribute to the cement's overall strength (Anwar 2016).

Silica mainly acts as a filler material and contributes in the of resistance to chemical attack and helps control setting time(Anwar 2016, Amin, Zeyad et al. 2024, Ikotun, Sithole et al. 2024).The WGP mainly consists of this silica in high amount and it acts like filler that enhance strengthen and durability of concrete. The excess amount of this material in cement leads to incomplete reaction of hydration that affects the strengthen of concrete and made the mix harder for its workability.

The Calcium Oxide(CaO) amount in the Ordinary Portland Cement and Waste Glass Powder is 65.40 % and 7.48 % to total material percentage respectively.

As the result declared that amount of calcium oxide found in the cement mainly contributed to stability and hardening of concrete in the process of forming cement paste by combining and fusing the ingredients of cement together.This enhances the concrete property in hardening and setting through formation of Calcium silicate (Anwar 2016). In the meanwhile other Major pozzolanic material compounds like Aluminum oxide(Al_2O_3) and Iron Oxide(Fe_2O_3) present in cement 4.6% and 2.8% is greater in that of WGP 0.86 % and 0.44 % respectively .The presence of minor compound and loss of Ignition influence the property of the concrete indirectly.

4.3 Tests for Fresh Concrete

In this part of the thesis, the fresh concrete properties such as workability test are presented and analyzed relative to control concrete specimens and relevant ASTM standards(Daniel 2006). Those properties are studied under this categories as follows:

4.3.1 Workability Test

Workability describes certain traits of fresh concrete, such as its ease of handling and flow ability. The slump test is the simplest and most frequently used method to evaluate workability on construction sites. In this test, the depth to which a cone of concrete subsides after the cone is lifted is measured, providing an indication of the concrete's flow and consistency(Daniel 2006). The workability of each series mix is measured with slump test according to ASTM C143. The summary of slump test result is shown in Table below.

Table 4. 2 : Result of Workability test

Mix Design	W/c	Slump(mm)	% of decreasing
0% (control)	0.6	80	0(conventional)
10% WGP and 90 % cement	0.6	73	-8.75
20% WGP and 80% cement	0.6	70	-12.5
30% WGP and 70% cement	0.6	62	-22.5

The result above here is slump test of Concrete with different amount of WGP replacing cement.

The table and figure shows Workability of the concrete decreases as amount of WGP replaced increases. At conventional level slump value is 80mm, at 10% 73mm slump value and 8.75 % decrease in slump value relative to conventional value. At 20% ,70mm slump value and 12.5 % in decreasing slump value and at 30%, 62 slump value and 22.5 % decreasing slump value.

Figure 4. 1 : Graph of Slump test Result

As the figure above shows that amount of workability of fresh concrete decreases as amount of WGP replace the cement increases. The decrease in the workability of concrete is because the glass powder is finer in size compared to cement content which has more surface area than cement. Hence, required more water than cement, which indirectly reduced the workability of the produced concrete(Shubham , Zanwar and Patil 2021). In addition to this water cement ratio critical influences the workability of concrete because they are directly proportioned to each other (Neteti and Maheswari).

Reduction of fineness modulus of glass powder results quantity of cement paste available is less for providing lubricating effect per unit surface area of aggregate, as a result there is a restrain on the mobility (Raju and Kumar 2014). Another researcher declared that decreasing the value of slump test can be related to the bad shape of the glass powder, which results in decreasing the fluidity of the mixes as well as the decrease of fineness modulus(Ikotun, Sithole et al. 2024).

According to ASTM C143, adequately plastic and cohesive concrete is characterized by a slump measurement greater than 1/2 inch (12.7 mm) and less than 9 inches (228.6mm) . But it is important to note that concrete with slumps height greater than 9 inches may not be enough cohesive for the test to have significance (Daniel 2006).

In this study, the measured slump ranged from 62mm to 80mm, indicating that the concrete possesses plastic and cohesive characteristics. As the result there is drop in the slump values, but the WG concrete mixes were considered workable and this suggests that the concrete made of WGP is effective in reducing the segregation of fresh concrete during placement.

4.4 Tests for Harden Concrete

In this part of study hardened concrete properties such as , compressive strength, flexural strengthen, water absorption ,sulfate attack and micro-structural test are analyzed and discussed relative to control concrete specimens and relevant ASTM standards(Kovler and Roussel 2011). Those properties are studied under this categories as follows:

4.4.1 Compressive Strength Test Cured in Water

The compressive strength of concrete serves as a critical factor in structural and non-structural part the construction area and is done using a digital compression testing machine that implement speed of 20mm/sec at each second. This measurement indicates the concrete's ability to withstand compressive forces. In this analysis, Cubic sample size of 150mm *150mm *150mm of concrete tested with precise dimensions by crushing them in the machine. For particular experiment, we chose a cube specimen to evaluate its compressive strength. The results from this testing are crucial for ensuring that the concrete mix employed at the construction site aligns with the strength criteria outlined in the project specifications. As part of our quality control process, we carry out acceptance tests on cubic prepared and cured according to the guidelines of ASTM C-31, which sets the standard for fabricating and curing concrete test specimens in real-world conditions. Compressive strength assessments at different Percentage of waste glass powder replaced notably on the 7th and 28th days following the mixing process.

This study particularly focused on documenting and analyzing the compressive strength of concrete mixtures that incorporate waste glass powder, with specific attention to the time frames mentioned.

Table 4. 3 : Result of Average Compressive Strengthen

Sample Code	Average Compressive Strengthen			
	7^{th} day(Mpa)	% of increase /decrease	28 day(Mpa)	% of increase /decrease
0% (control)	17.8	0(control)	27.6	0(conventional)
10% WGP and 90 % cement	18	1.2	27.9	1.1
20% WGP and 80% cement	19.4	8.9	28.9	4.7
30% WGP and 70% cement	19	6.75	28.1	1.88

The table above shows the Compressive strength gain at different percentages of waste glass powder replaced cement on the 7th and 28th days of sample cured. The result shows that the optimal performance of concrete occurs at a 20% replacement of cement with waste glass powder. The Compressive Strengthen on the 7th and 28th were 19.4 and 28.9 respectively.

At conventional level(0% percentage) Compressive Strengthen on 7th and 28th were 17.8 and 27.6 respectively. When cement replaced at 10% it results 18 and 27.9 within 1.2% and 1.1% increasing value from conventional result respectively. At 20% and 30% replacement the compressive result at 7th and 28th day were 19.4 and 28.9 and 19 and 27.4 respectively with percentage of increment in 8.9% and 4.7% for 20% and 6.75% and 1.8 % for 30% respectively. The maximum compressive strength at 7 days is observed in the 30% WGP and 70% cement mix (19 MPa), while at 28 days, the highest strength is recorded in the 20% WGP and 80% cement mix (28.9 MPa). These points represent the maximum strengths achieved within the tested parameter range at each respective age.The distinction here is that the maximum points indicate the highest possible strength achieved in the test, but the optimum point considers overall performance, cost-effectiveness, and practical feasibility. For instance, the 20% WGP mix at 28 days provides a near-maximum strength with potentially better workability and material efficiency, which could be more desirable in real-world scenarios The amount of silica and calcium oxide present in the chemical composition plays vital rule in enhancement of the concrete up to its optimum value and decrease after that point. And also the percentage of other major compound have effect on the property of the concrete for the reason that they participate on the setting time of concrete produced.

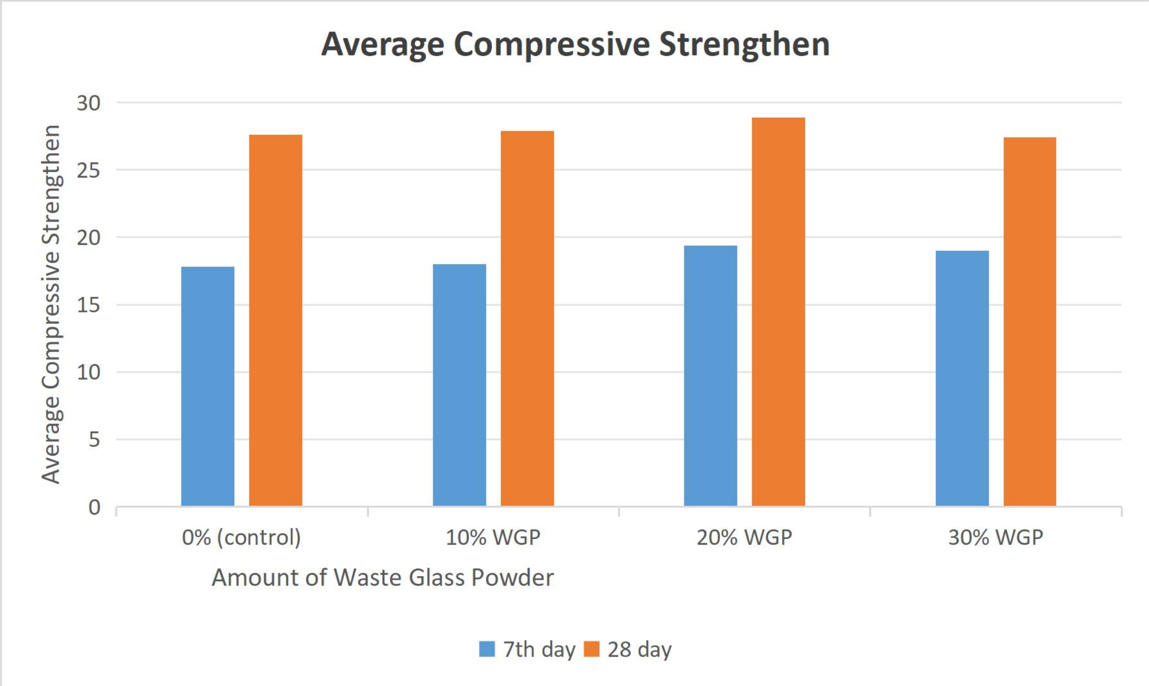


Figure 4. 2 : Graph of Average Compressive strengthen

As the figure above shows that amount of compressive strengthen increased until it reach its optimal replacement (20%) and then it decreases. There were different reasons for this condition, When waste glass grinded into finely powder material its primary component silica dioxide ($SiO2$), engages in chemical reactions with the alkalis present in cement, resulting in the formation of supplementary Cementitious compounds. As the result of this formation compressive strengthen of the sample enhanced due to the maturity at the curing periods of the samples(Sharifi, Houshiar et al. 2013).

The silica compound play a crucial role in the concrete by contributing to strength development over time (Neteti and Maheswari). Additionally, the fine glass powder serves to effectively fill voids within the concrete matrix, enhancing the overall density and reducing porosity.Which leads to increasing compressive Strengthen(Zemenu 2021). Nevertheless Vibration time, Vibration rate and mixing the concrete ingredients process have significant effect on the enhancing the compressive strengthen of concrete.

Calcium Oxide present in the mix plays vital role in producing Calcium Silicate Hydrate which is mainly responsible for the Compressive strengthen of the concrete. Proper amount of this compound exist in the mix participate in enhancement of the Concrete property but as amount of waste glass powder increased the amount of this compound relatively decreases and form low Calcium silicate which leads to lowering the Compressive Strengthen of concrete.Therefore as observed from the result the waste glass powder can enhance bond Strengthen of concrete at 20% which is very important for quality of concrete and improve compressive strengthen of the concrete.

4.4.2 Flexural strength test

This test method assesses the flexural strength of concrete through a basic beam that utilizes third-point loading. The process involves supporting a concrete prism at both ends and applying two loads positioned at one-third intervals along the beam's length. The loading continues to increase until the point of flexural failure is reached. From the highest load achieved, the maximum flexural stress within the beam is determined.

This test performed according to ASTM C78/C78M measures taken for the flexural strength of concrete, specifically to estimate resistance to bending or cracking under a load(Hamad and Sldozian 2019).

Table 4. 4 : Average Flexural Strengthen result

Sample Code	Average Flexural Strengthen			
	7th day	% of increasing/decreasing	28 day	% of increasing/decreasing
0% (control)	3.8	0 (control)	6.85	0
10% WGP and 90 % cement	3.93	3.4	7.07	3.21
20% WGP and 80% cement	4.21	10.79	8.1	9.93
30% WGP and 70% cement	3.95	3.9	7.4	5.69

The table above shows that replacement of WGP to cement enhances the flexural strengthen of the concrete until its replacement of glass powder reaches 20% to that of cement.

At conventional level Flexural Strengthen on 7th and 28th are 3.67 and 6.85 respectively. When cement replaced at 10% it results 3.94 and 7.07 within 3.4% and 3.21% increasing value from control result obtained on 7th and 28th day respectively. At 20% and 30% replacement the flexural result on 7th and 28th day are 4.21 and 7.53 and 3.95 and 7.24 respectively with increase in of 10.79 % and 9.93 % for 20% and 3.9% and 5.69 % for 30% respectively. The highest flexural strength at 7 days is observed in the 20% WGP and 80% cement mix (4.21 MPa). At 28 days, the maximum strength is also in the same mix, with a value of 8.1 MPa. These points can be regarded as the maximum flexural strength within the test range at each age. While the maximum flexural strength is observed in the 20% WGP mix at both ages, the optimum mix appears to be the same, given its consistent high performance and substantial percentage increase over time. This indicates that incorporating 20% WGP is effective in enhancing flexural strength, making it a suitable choice for practical applications

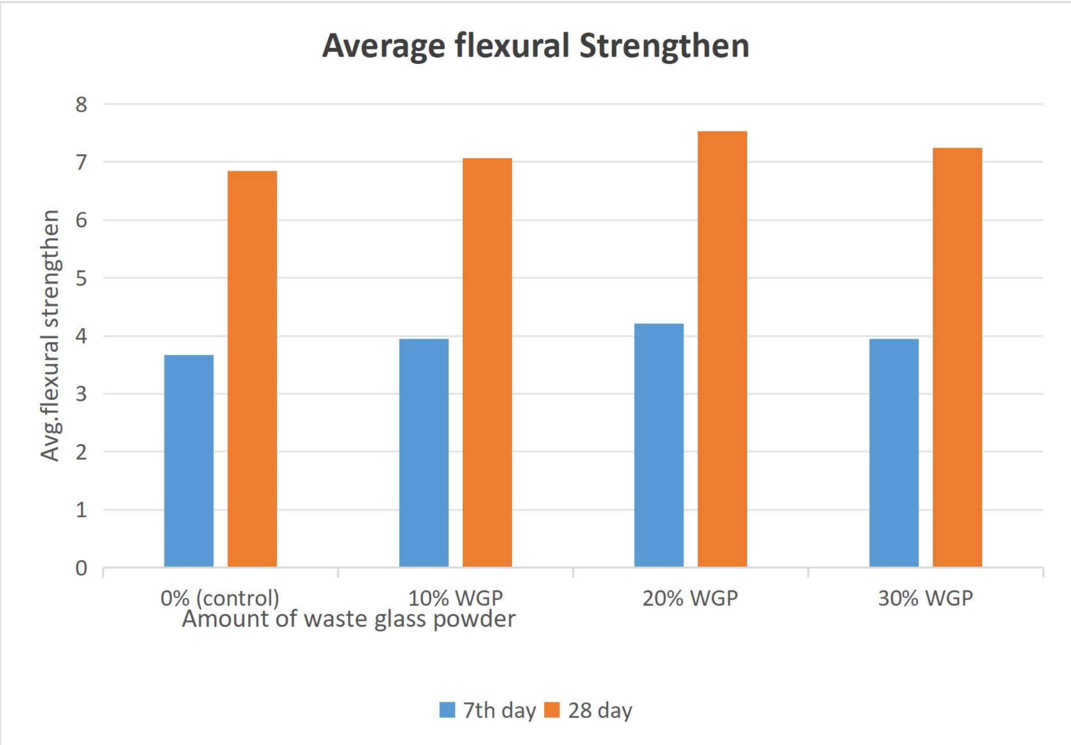


Figure 4. 3 : Graph of Average Flexural Strengthen

The results demonstrate a positive correlation between the partial replacement of cement with waste glass powder (WGP) and flexural strength of concrete, up to 20 % of percentage replacement. The fine particle size of WGP, acting as a pozzolanic, contributes to a denser microstructure within the hardened concrete. This increased density can restrict micro-cracks, leading to enhanced flexural properties of concrete (Neteti and Maheswari). And also the pozzolanic reaction of WGP with calcium hydroxide, a by-product of cement hydration, likely enhances the flexural strength-developing hydration products, increasing the overall strength. Maintaining an optimal w/c ratio is vital for concrete Flexural strength development and is important with WGP replacement.(Zemenu 2021).

Curing method , Vibration rate and mixing time of the ingredient of concrete plays crucial factor for the flexural property of concrete enhancement.

The formation of calcium silicate due to presence of silicate oxide and calcium oxide mainly enhance the flexural property of concrete. There combination can interlock the space between the cement paste and improve the concrete property. Since amount of Calcium Oxide present in the composition decreases as amount of waste glass powder increases it reduces the Flexural strengthen of concrete property beyond the optimum point(20%). Generally the pozzolanic property of WGP contribute for enhancement of flexural strengthen of concrete that provide advantageous for concrete property within limited amount of replacement.

4.4.3 The Water Absorption

Different mixes in the series, each incorporating various amounts of waste glass powder, were evaluated. A laboratory test, conducted in accordance with ASTM C-140— the "Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units"— was used to measure the water absorption of the concrete. For each percentage of material substitution three samples were tested, and the results are summarized in the corresponding table and graph for both time frames. The summary of Water Absorption test result is shown in Table.

Table 4. 5 : Water Absorption test result

Sample Code	Average wet weigth	Average dry weight	Average water absorption test(%) at 28th days
0% (control)	8.176	7.863	3.98
10% WGP and 90 % cement	7.916	7.623	3.845
20% WGP and 80% cement	8.234	7.934	3.785
30% WGP and 70% cement	7.604	7.33	3.74

The incorporation of waste glass powder (WGP) into concrete formulations, particularly at percentages of 10%, 20%, and 30% as a replacement for cement, has been shown to significantly reduce water absorption compared to Conventional sample of concrete(0% replacement) mixes. The result shows as decreasing in water absorption results from 3.98, 3.845, 3.785 and 3.74 for partial replacement of waste glass powder in 0%, 10% ,20% and 30% respectively.

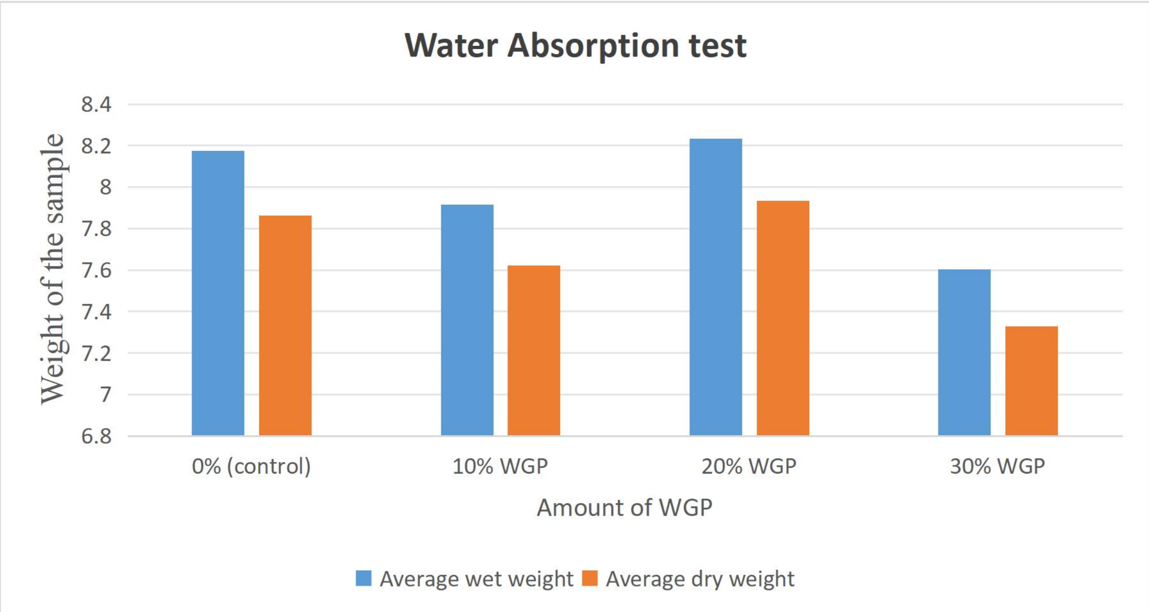


Figure 4. 4 : Graph of Average Water absorption test

From the figure above the amount of water absorption decreases as amount of waste glass powder that replace cement decreases. This notable decrease in water permeability can be attributed to pore filling within concrete Structure and the pozzolanic effects of glass powders. The fine particles of WGP effectively occupy the voids present in the concrete mix that leading to a denser and more compact structure of concrete mixes that minimizes the pathways available for water absorption (Neteti and Maheswari , Mageswari, Kareemullah et al. 2024).

And also during the curing process, the silica present in the Waste Glass Powder participate in pozzolanic reactions with the alkalis in cement, producing supplementary Cementitious compounds that further enhance the interlocking of the microstructure. More water absorption (conventional concrete) result contains more capillaries inside the concrete or more is the porous the concrete which will lead to higher absorption of water and less strength.

Since the calcium oxide in the waste glass powder decreases as amount of the amount of WGP increases it influences the water absorption property of concrete. Hence it relates to the hydration process of concrete. The enhanced performance in terms of reduced water absorption observed in concrete mixes containing WGP underscores the material's potential as a sustainable alternative that can elevate the longevity and durability of concrete structures.

4.4.4 Waste Glass powder against Sulphate Attack

Sulphate attack experimental investigation assesses the impact of Sodium Sulphate (for this thesis) to the concrete structure when the sample cured within the sulphate Solution for 28 days after the sample cured in water. The test result evaluated by calculating the weight loss of the concrete sample due to its curing in the sulphate solution with sample cured within water solution for 28 days.

The different mix samples cured within water for 28 days and weight of each sample recorded and then the sample kept within sodium sulphate solution's until the sample reaches 56 day, then the loss of weight of each sample calculated. The test follow the standard declared on ASTM C1012 in order to obtain the accurate and precious value.The waste glass powder performance against sulphate attack result declared here in below figure and tables.

Table 4. 6 : Average Suphate Attack Result

Sample Code	Average Sulphate attack result			
	28th day(weight)	56th day(weight)	Loss of weight	Percentage of weight loss
0% (control)	7.5	7.05	0.45	6.38
10% WGP and 90 % cement	7.372	6.965	0.407	5.84
20% WGP and 80% cement	7.62	7.27	0.351	4.81
30% WGP and 70% cement	7.695	7.42	0.275	3.4

Here the table above declared sulphate attack resistance of concrete against different mix samples. The result shows the weight loss of concrete structure against the sulphate attack decreases as the percentage of glass powder increases. For conventional mix weight loss and its weight loss percentage was 0.45 and 6.38% respectively. The weight loss and percentage of weight loss for 10%, 0.407 and 5.84%, for 20%, 0.351 and 4.81% and for 30%, 0.275 and 3.4% were tested respectively.

These results indicate as percentage replacement increases it had the best performance in minimizing both weight and weight loss percentage, suggesting improved material efficiency and durability.

Here the result above shows that when fine particle size of waste glass replaced the cement it fills and reduces the void space between the concrete constituents that result low entrance of sulphate chemical into the concrete. And also the pozzolanic reaction of waste glass powder on the pore solution and solid material compacted the cement paste that reduce permeability of the sulphate.

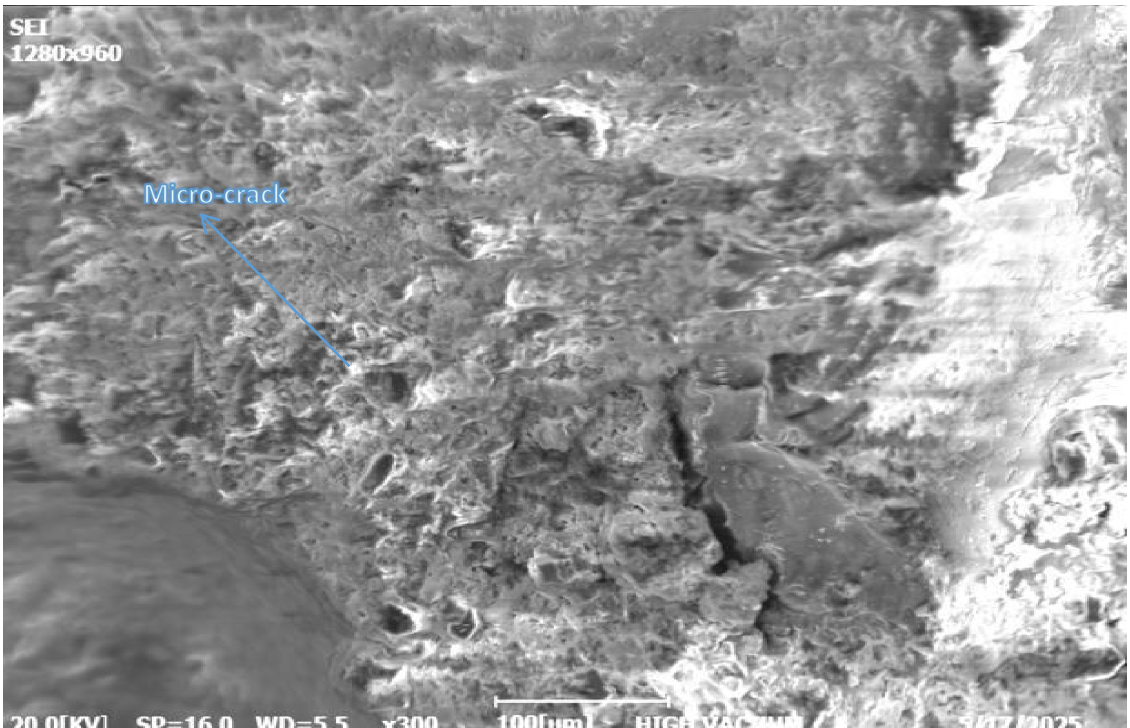
Figure 4. 5 : Sulphate attack

The decrease in weight of sulphate immersed sample and percentage of weight loss is a result that related to nature of glass waste which resist the decay of concrete (Mathur and Chhipa 2023). The reaction between waste glass and sulfate could produce a material with improved Cementitious characteristics relative to ettringite (Bajad, Modhera et al. 2012).
An increase in weight loss of concrete caused by sulfate attack leads to more hydration products, resulting in expansion. This expansion can create micro cracks between the pores, ultimately weakening the concrete (MN, CD et al. 2011).
The result Sulphate attack obtained from experimental investigation shows that Waste Glass Powder can reduces the impact of sulphate on the concrete structure due to reasons stated above.

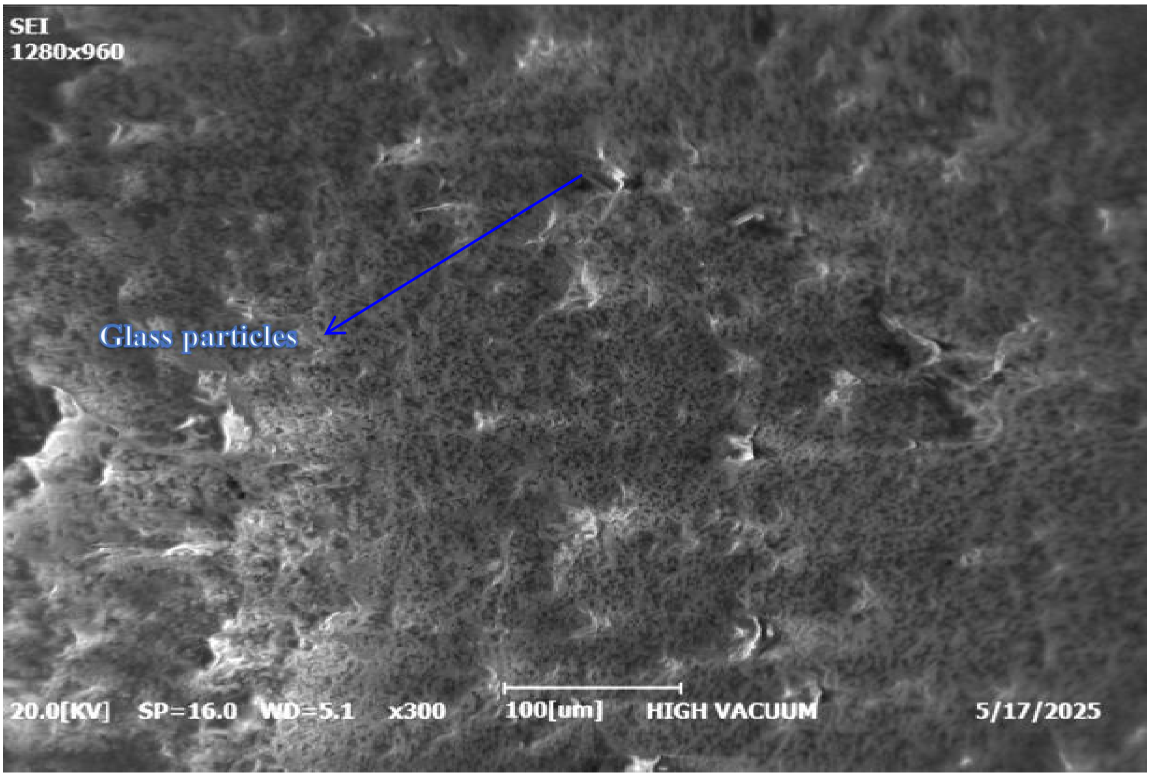
4.4.5 Microstructure of concrete with WGP

The micro-structural properties of concrete are vital in determining its strength and durability property of concrete over time. These microscopic features influence how well the concrete resists damage, water penetration, chemicals movement in the internal structure of concrete like chemicals that contains sulphate and other that have an environmental effects. Denser structure of the concrete can resist the penetration of water and other chemicals in to the internal section of the concrete and enhance the durability of concrete structure. But when the porous and micro-cracking happen on the concrete structure the penetration made easily and influences the durability property of the concrete

and long-time existence of the concrete structure. This microstructure impact happened on the concrete dependent on the binder (filler) material property of chemical composition exist in the pozzolanic material(Muhedin and Ibrahim 2023).
Cement has been used as the primary binder in concrete, producing a microstructure mainly composed of hydration products such as calcium silicate hydrate (C-S-H) gel. However, incorporating waste glass powder as a SCM can modify this microstructure, leading to improved durability by reducing porosity and filling microscopic gaps.
This micro-structural part of the concrete investigated by using Scanning Elector Microscope(SEM). A Scanning Electron Microscope (SEM) is a powerful analytical instrument characterized by its high-resolution imaging capability, allowing detailed visualization of surface topography at nanometer scales. Standard tests such as ASTM C457/C457M are commonly used to evaluate the Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.
The scanning Elector microscope of these sample have been made at Haramaya University department of Mechanical Engineering. These samples were then subjected to SEM image analysis at 20 kV by mounting small broken sections on brass stubs. The sample for this experimental investigation prepared from the fracture of sample made for compressive strengthen on the 28th days of curing.



(a) control concrete sample at 28th day



(b) 20% WGP replaced at 28th day

Figure 4. 6 : Micro-structural test

The figure above shows that micro-structural view of control sample (a) and (b) 20% replaced cement by WGP that is the optimal percentage of flexural and compressive strengthen at 7th and 28th day. This result was selected based on the test performed to identify its view like porous, micro crack and other that determines the water absorption and intrusion of sulphate solution within the concrete structure. As we see the figure (a) the concrete structure contains porous and micro cracking on the structure of the concrete. This indicates the concrete sample contains high water absorption capacity relatively the sample (b). This can show as the sulphate attack by the sulphate compound passes easily through the structure of concrete. Relative to figure (a), figure (b) contains less porous and microcracking surface due to filler material that present in waste glass powder compostion. When compared to conventional cement(a), waste glass powder containing concrete (b) reacts with calcium hydroxide during hydration to form additional C-S-H gel, which refines the microstructure and enhances the concrete's resistance to deterioration. This results in a denser and less porous microstructure, making the concrete more durable and long-lasting. The use of waste glass powder not only offers a sustainable alternative to concrete materials but also improves the micro-structural integrity of concrete, contributing to its overall performance and lifespan.

In concrete with no WGP replacement, large pores and cracks can be noticed while, when cement was replaced by WGP, a decrease in CH crystals, denser and more homogeneous structure can be seen. This phenomenon is due to the pozzolanic activity for the WGP which CH turned to C-S-H gel, beside the filler effect of the material in which the small particles of WGP fill the micro pores in the structure. As a result, the number of large pores is much less noticeable in the structure(Muhedin and Ibrahim 2023).

The Waste Glass Powder particles function as fillers, reducing porosity by filling spaces within the cement paste, thereby resulting in a denser microstructure. Furthermore, the waste glass powder particles exhibit pozzolanic behavior, reacting with calcium hydroxide in the cement matrix to form additional calcium silicate hydrates (C-S-H)(Sobuz, Kabbo et al. 2025). The formation of C-S-H mainly depends on the presence of silicate oxide present within composition of pozzolanic material because higher reactivity of silicate oxide results more denser and compacted structure which enhances durability of the concrete structure.

The result above shows the same thing, since the 20% replace of pozzolanic material contains high silica content within itself the morphological section of the concrete become more denser than the control (0%) of the sample. The presence of calcium oxide also have impact on the micro-structural property of concrete since it enhances the completion of hydration reaction and proper development of concrete structure.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

CONCLUSION

The analysis of concrete incorporating waste glass powder (WGP) as a partial substitute for cement leads to several critical conclusions:

1) WGP is suitable for use in concrete production and exhibits class F pozzolanic properties as outlined by ASTM standards.

2) The workability/ Slump test of the concrete mixes decreases as the percentage of glass powder increases this is because due to fineness of waste glass powder.

3) Due to binding property of glass powder, the amount of water absorption of concrete decreases as amount of waste glass powder present in mix increases.

4) The result of 7^{th} day concrete property declared that, compressive strength of the concrete improves with the increasing use of Waste glass powder and reach its peak at a combination of 20% of waste glass powder and 80% of cement in concrete mix. Although the mix designs showed a declining trend in compressive strength beyond this point. In same manner to this, compressive strengthen at 28^{th} shows increasing up to 20% replacement and decreases after that point. This is because of presence of different amount of Chemical composition in WGP and cement.

5) The flexural strength of the concrete increases with up to 20% replacement of glass powder , beyond which the strength starts to decrease.

6) The sulphate attack resistance of the concrete results show that weight loss of the concrete decreases as percentage replacement of waste glass powder increases.This happens as a result of glass powder fills the porous area of the concrete structure which prevents movement of water solution in the porous areas.

7) More pores and micro-cracking found in the control sample of the concrete rather than concrete sample with waste glass powder. This is due to the pozzolanic activity for the WGP which CH turned to C-S-H gel, beside the filler effect of the material in which the small particles of WGP fill the micro pores in the structure. As a result, the number of large pores is much less noticeable in the structure.

Overall, based on these concrete property tests, substituting cement with glass powder can enhance the flexural and compressive strengthen of concrete and also affects the Workability, water absorption, microstructure and sulphate attack resistance of concrete.

RECOMMENDATION

The experimental investigation performed using waste glass powder as Supplementary Cementitious Materials recommends as to use this WGP in structural and non-structural part of the concrete production for the following reasons:

- Due to the chemical composition of Waste Glass Powder it can be used as cement replacing material in concrete production because it can enhance Flexural and Compressive property of concrete.
- Using WGP in concrete production reduces the waste glass impact on the environment mostly around the city where waste of glass mostly available and reduces energy consumption for recycling the waste glass. This can reduce the global warming occurred due to these pozzolanic material.
- For supporting the reduction of environmental effect due to cement production,WGP can be used as SCM .
- Most percentage of this waste glass powder is silicate Oxide that mainly used as binder material that highly influences the water absorption and Sulphate attack of the concrete property.

This study provides experimental investigation on the property of concrete like Workability, water absorption, flexural strengthen , compressive strengthen ,Sulphate attack resistance and micro structural within different amount of replacement. However application of this WGP in real world is needed to be investigated. And also further study for the future is needed to be conducted by Using WGP as cement replacing material in aggressive environmental areas. Meanwhile experimental investigation need deep research on effect glass powder on concrete property in consideration of different cement types.

REFERENCE

Abdelli, H. E., et al. (2020). "Utilization of waste glass in the improvement of concrete performance: A mini review." Waste Management & Research **38**(11): 1204-1213.

Abdulazeez, A. S., et al. (2020). "Effect of waste glass powder as a pozzolanic material in concrete production." Int. J. Eng. Res **9**: 589-594.

Abreha, Y. B., et al. (2023). Engineering Properties of Concrete with Partial Replacement Cement and Coarse Aggregate by Waste Glass Powder and Steel Slag Aggregate. Advancement of Science and Technology: Materials and Energy, Springer**:** 103-125.

Agboola Shamsudeen Abdulazeez, D. N. U., et al. "Suitability of Waste Glass Powder as Partial Cement Replacement in Concrete Subject to Chemical Aggressive Environment."

Al-jburi Najad, A., et al. (2019). Waste glass as partial replacement in cement–A review. IOP Conference Series: Earth and Environmental Science, IOP Publishing.

Ali, H. A. (2023). "Use of waste glass in geopolymer based repairing materials."

Aliabdo, A. A., et al. (2016). "Utilization of waste glass powder in the production of cement and concrete." Construction and Building materials **124**: 866-877.

Almusaed, A., et al. (2024). "Assessing the impact of recycled building materials on environmental sustainability and energy efficiency: a comprehensive framework for reducing greenhouse gas emissions." Buildings **14**(6): 1566.

Amin, M., et al. (2023). "Investigation of the physical mechanical properties and durability of sustainable ultra-high performance concrete with recycled waste glass." Sustainability **15**(4): 3085.

Amin, M., et al. (2024). "Effect of industrial wastes on the properties of sustainable ultra-high-performance concrete: Ganite, ceramic, and glass." Construction and Building materials **428**: 136292.

Anwar, A. (2016). "The influence of waste glass powder as a pozzolanic material in concrete." Int. J. Civ. Eng. Technol **7**(6): 131-148.

Anwar, F. H., et al. "EFFECT OF COMBINED REPLACEMENT OF CEMENT AND AGGREGATES ON THE PERFORMANCE OF PERVIOUS CONCRETE."

Arora, R., et al. (2022). "Analyze the outcome of waste material as cement replacement agent in basic concrete." Materials Today: Proceedings **56**: 1877-1881.

ASTM C642, A. (2013). "Standard test method for density, absorption, and voids in hardened concrete." ASTM, ASTM International.

ASTM, C. (2012). "Standard test method for slump of hydraulic-cement concrete." ASTM International West Conshohocken, PA.

ASTM, C. (2013). "642-13 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete ASTM International." West Conshohocken, PA.

Bajad, M., et al. (2012). "Resistance of concrete containing waste glass powder against MgSO4 attack." NBM Media.

Bank, M. S., et al. (2020). "Microplastic's role in antibiotic resistance." Science **369**(6509): 1315-1315.

Behera, S., et al. (2019). "Slump test." Current Science **117**(2): 235-241.

Biyani, Y., et al. (2020). Engineered cementitious composites. International Conference on Emerging Trends in Engineering (ICETE) Emerging Trends in Smart Modelling Systems and Design, Springer.

Brwa, O. and J. Saeed (2020). "Long-Term effect of different particle size distributions of waste glass powder on the mechanical properties of concrete." Architecture, Civil Engineering, Environment **13**: 61-75.

Carsana, M., et al. (2014). "Comparison of ground waste glass with other supplementary cementitious materials." Cement and concrete composites **45**: 39-45.

Chandrasekaran, V., et al. (2018). "Experimental investigation of partial replacement of cement with glass powder and eggshell powder ash in concrete." Civ. Eng. Res. J **5**: 1-9.

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

Du, H. and K. H. Tan (2014). "Waste glass powder as cement replacement in concrete." Journal of Advanced Concrete Technology **12**(11): 468-477.

Du, H. and K. H. Tan (2015). "Transport properties of concrete with glass powder as supplementary cementitious material." ACI Materials Journal **112**(3): 429.

El-Didamony, H., et al. (2012). "Hydration mechanisms of calcium sulphoaluminate C4A3S, C4AS phase and active belite β-C2S." Ceram. Silikáty **56**: 389-395.

Eštokov, A., et al. (2012). "Study of the deterioration of concrete influenced by biogenic sulphate attack." Procedia Engineering **42**: 1731-1738.

Fanache, M., et al. (2024). "Composite materials with glass fiber waste and blast furnace slag." Journal of Composites Science **8**(7): 256.

Goa, E. and S. S. Sota (2017). "Generation rate and physical composition of solid waste in Wolaita Sodo Town, southern Ethiopia." Ethiopian Journal of Environmental Studies and Management **10**(3): 415-426.

Guignone, G., et al. (2022). "Life cycle assessment of waste glass powder incorporation on concrete: a bridge retrofit study case." Applied Sciences **12**(7): 3353.

Habibul Ahsan, S. (2018). "Effect of size and shape of test specimens on compressive strength of normal strength concrete."

Hamad, A. J. and R. J. A. Sldozian (2019). "Flexural and flexural toughness of fiber reinforced concrete-American standard specifications review." GRD Journals-Global Research and Development Journal for Engineering **4**(3): 5-13.

Idir, R., et al. (2011). "Pozzolanic properties of fine and coarse color-mixed glass cullet." Cement and concrete composites **33**(1): 19-29.

Ikotun, J., et al. (2024). Use of Waste Glass Powder in Concrete—A Review of Microstructure and Durability Properties. International Conference on Concrete Repair, Rehabilitation and Retrofitting, Springer.

Islam, G. S., et al. (2017). "Waste glass powder as partial replacement of cement for sustainable concrete practice." International Journal of Sustainable Built Environment **6**(1): 37-44.

Islam, M. H., et al. (2025). "Experimental investigation on fresh, hardened and durability characteristics of partially replaced E-waste plastic concrete: A sustainable concept with machine learning approaches." Heliyon **11**(2).

Ismaeel, A. M., et al. (2023). Analysis of Mechanical and Environmental Effects of Utilizing Waste Glass for the Creation of Sustainable Ultra-High Performance Concrete. Annales de Chimie Science des Matériaux.

Jena, A. and M. Paikaray (2018). "Strength Assessment and Feasibility Study on Waste Glass Powder as Partial Replacement of Cement in Concrete Production."

K Al-Chaar, G., et al. (2013). "Natural pozzolan as a partial substitute for cement in concrete."

Kedir, S. A. (2023). Investigating The Effect Of Partial Replacement Of Cement With Waste Glass Powder, Waste Marble Powder And Scoria Powder In Quaternary Blended Cement Mortar.

Kovalev, A., et al. (2023). "Acknowledgment to the Reviewers of Sustainability in 2022."

Kovler, K. and N. Roussel (2011). "Properties of fresh and hardened concrete." Cement and concrete research **41**(7): 775-792.

Kroviakov, S., et al. (2019). "Comparison of strength and durability of concretes made with sulfate-resistant portland cement and portland cement with pozzolana additive." Electronic Journal of the faculty of civil engineering Osijek-e-GFOS **10**(19): 81-86.

Kumar, S. and B. Nagar (2017). "Effects of waste glass powder on compressive strength of concrete." Int. J. Trend Sci. Res. Dev **1**: 289-298.

Leza, S. (2020). Innovations in Green Building: Why Sustainable Construction Should Include Localized Knowledge, Worcester Polytechnic Institute Worcester, MA, USA.

Mageswari, D. U., et al. (2024). "Experimental investigation of mechanical properties and multi-objective optimization of electronic, glass, and ceramic waste–mixed concrete." Environmental Science and Pollution Research **31**(46): 57158-57176.

Mandal, A. K., et al. (2023). Waste incorporation in glass: A potential alternative and safe utilization. Advanced materials from recycled waste, Elsevier**:** 133-154.

Martina, N., et al. (2022). "The use of glass powder waste as a partial substitute for cement on the compressive strength of concrete." GEOMATE Journal **23**(98): 197-204.

Más-López, M. I., et al. (2021). "Application of concretes made with glass powder binder at high replacement rates." Materials **14**(14): 3796.

Mathur, M. and R. Chhipa (2023). "Experimental study on durability of glass modified concrete: resistance to acid and sulphate attack." International Journal of Advanced Technology and Engineering Exploration **10**(107): 1353.

Mathur, S., et al. (2022). "Annals of NAGI."

Matos, A. M. and J. Sousa-Coutinho (2012). "Durability of mortar using waste glass powder as cement replacement." Construction and Building materials **36**: 205-215.

Meena, M. K., et al. (2018). "Performance of concrete by using glass powder." Int. Res. J. Eng. Technol **5**: 840-844.

Melaku, H. (2020). Investigation of Properties of Concrete Containing Recycled Concrete Coarse Aggregate and Waste Glass Powder.

MN, B., et al. (2011). "Effect of glass on strength of concrete subjected to sulphate attack." International Journal of Civil Engineering Research and Development (IJCERD) **1**(2).

Mohamad, N., et al. (2022). "Environmental impact of cement production and Solutions: A review." Materials Today: Proceedings **48**: 741-746.

Muhedin, D. A. and R. K. Ibrahim (2023). "Effect of waste glass powder as partial replacement of cement & sand in concrete." Case studies in construction materials **19**: e02512.

Mulatu, D., et al. (2018). "The cement industry in Ethiopia." Journal of Energy Engineering **27**(3): 68-73.

Nadir, H. M. and A. Ahmed (2022). "Elucidating chemo-mechanical synthesis and microstructural study on the performance of partial cement-based concrete composites against sulphate attack–a review." Research & Development in Material Science **18**(2): 2065-2078.

Nadir, H. M. and A. Ahmed (2022). "The mechanisms of sulphate attack in concrete–a review." Modern Approaches on Material Science **5**(2): 658-670.

Nassar, N. E. and M. Abo (2020). Effects of Waste Marble and Glass Powders on Concrete Properties and Performance, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ).

Neteti, S. and A. U. Maheswari "Strength and Durability Analysis of Concrete Replacing Cement by Glass Powder."

Nwaubani, S. O. and I. Konstatinos (2013). Poutos:"The Influence of waste glass powder fineness on the properties of cement mortars", Vol-2.

Olii, M. R., et al. (2023). "ENVIRONMENTALLY FRIENDLY CONCRETE USING WASTE GLASS POWDER (WGP) AS A PARTIAL SUBSTITUTE OF CEMENT." Jurnal Teknik Sipil **12**(2): 140-146.

Olutoge, F. and C. Strength (2016). "Effect of waste glass powder (WGP) on the mechanical properties of concrete." Am. J. Eng. Res **38**(511): 2320-2847.

Omopariola, S. (2024). "Evaluation of the Outcome of the Variation of Constituent Ingredients on the Compressive Strength of Concrete." International Journal of Women in Technical Education and Employment **5**(1): 231-238.

ONAIZI, A. M. A. S. and U. T. MALAYSIA (2022). ENHANCEMENT OF MECHANICAL PROPERTIES OF HIGH− VOLUME FLY ASH CONCRETE USING GLASS NANO POWDER AND EFFECTIVE MICROORGANISMS, Universiti Teknologi Malaysia.

Otunyo, A. and B. Okechukwu (2017). "Performance of concrete with partial replacement of fine aggregates with crushed waste glass." Nigerian journal of technology **36**(2): 403-410.

Pan, Z., et al. (2017). "High temperature performance of mortars containing fine glass powders." Journal of Cleaner Production **162**: 16-26.

Panesar, D. K. (2019). Supplementary cementing materials. Developments in the Formulation and Reinforcement of Concrete, Elsevier**:** 55-85.

Paul, S. C., et al. (2018). "A comprehensive review on mechanical and durability properties of cement-based materials containing waste recycled glass." Journal of Cleaner Production **198**: 891-906.

Pourkhorshidi, A., et al. (2010). "Applicability of the standard specifications of ASTM C618 for evaluation of natural pozzolans." Cement and concrete composites **32**(10): 794-800.

Raju, S. and P. Kumar (2014). "Effect of using glass powder in concrete." International Journal of Innovative Research in Science, Engineering and Technology **31**: 21-427.

Ramakrishnan, K., et al. (2017). "Experimental study on the mechanical and durability properties of concrete with waste glass powder and ground granulated blast furnace slag as supplementary cementitious materials." Construction and Building materials **156**: 739-749.

Raman, S. and R. Nateriya (2024). "Synthesizing sustainable construction paradigms: A comprehensive review and bibliometric analysis of granite waste powder utilization and moisture correction in concrete." Reviews on Advanced Materials Science **63**(1): 20240084.

Rashad, A. M. (2014). "Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement." Construction and Building materials **72**: 340-357.

Revathy, J., et al. (2023). "Flexural performance of GGBS-based EGC layered reinforced cement concrete and geopolymer concrete beams: A retrofit perspective." Innovative Infrastructure Solutions **8**(10): 263.

ROSLAN, M. L. F. M. and S. S. MOHD (2024). "OPTIMIZING SUSTAINABLE CONCRETE STRENGTH WITH LAMINATED WASTE GLASS (LWG): INSIGHTS FROM WATER-TO-CEMENT RATIOS AND SLUMP VALUES (0.35-0.5)." Journal of Engineering Science and Technology **19**(3): 977-995.

Saidat, F., et al. (2021). "Effect of sodium sulfate in a mortar incorporating metakaolin." Algerian Journal of Environmental Science and Technology **7**(3).

Sakale, R., et al. (2015). "Experimental investigation on strength of glass powder replacement by cement in concrete with different dosages." International Journal of Advanced Research in Computer Science and Software Engineering **5**(12): 386-390.

Sayeeduddin, M. S. and M. F. Chavan (2016). "Use of waste glass powder as a partial replacement of cement in fibre reinforced concrete." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684.

Schmitz, A., et al. (2011). "Energy consumption and CO2 emissions of the European glass industry." Energy policy **39**(1): 142-155.

Sharifi, Y., et al. (2013). "Recycled glass replacement as fine aggregate in self-compacting concrete." Frontiers of Structural and Civil Engineering **7**: 419-428.

Shi, C., et al. (2005). "Characteristics and pozzolanic reactivity of glass powders." Cement and concrete research **35**(5): 987-993.

SHIRVANI DASTGERDI, A. (2023). "Developing a Framework for Improving Climate Resilience in Cultural Landscapes."

Shubham, A. "Experimental Study on Partial Replacement of Cement with Waste Glass Powder." Journal of Progress in Civil Engineering ISSN **2322**: 0856.

Siddika, A., et al. (2021). "Roles of waste glass and the effect of process parameters on the properties of sustainable cement and geopolymer concrete—A state-of-the-art review." Polymers **13**(22): 3935.

Singh, N., et al. (2024). "Optimizing Waste Glass Powder Content in the Development of Sustainable Concrete for High-Temperature Resistance." Iranian Journal of Science and Technology, Transactions of Civil Engineering: 1-15.

Sobuz, M. H. R., et al. (2025). "Microstructural behavior and explainable machine learning aided mechanical strength prediction and optimization of recycled glass-based solid waste concrete." Case studies in construction materials: e04305.

Standard, A. (2000). "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete1." ASTM C618-2000.

Standard, A. (2011). "C33/C33M-11a."." Specification for Concrete Aggregates." ASTM International.

Suganthi, M., et al. (2024). Investigation on Flexural Performance of Concrete Beam with Replaced of Cement using WGP. E3S Web of Conferences, EDP Sciences.

Surendran, H. and P. K. Akhas (2024). Properties of high-performance concrete incorporating toughened glass waste coarse aggregate: An experimental study. Structures, Elsevier.

Szudek, W., et al. (2022). "Influence of waste glass powder addition on the microstructure and mechanical properties of autoclaved building materials." Materials **15**(2): 434.

Talsania, S., et al. (2015). Experimental investigation for partial replacement of cement with waste glass powder on pervious concrete. International Conference on:"Engineering: Issues, opportunities and Challenges for Development.

Tamanna, N. and R. Tuladhar (2020). "Sustainable use of recycled glass powder as cement replacement in concrete." The Open Waste Management Journal **13**: 1-13.

Ubeid, H. S., et al. (2020). Mechanical Properties, Energy Impact Capacity and Bond Resistance of concrete incorporating waste glass powder. IOP conference series: Materials science and engineering, IOP Publishing.

Vasudevan, G. and S. G. K. Pillay (2013). "Performance of using waste glass powder in concrete as replacement of cement." Am. J. Eng. Res **2**(12): 175-181.

Venkatesan, B., et al. (2022). "Utilization of granite powder and glass powder in reactive powder concrete: assessment of strength and long-term durability properties." Canadian Journal of Civil Engineering **49**(6): 885-898.

Venkatesan, S., et al. (2023). An IoT Based Mitigation of Occupational Dust Risks in Glass Manufacturing Plants. 2023 3rd International Conference on Pervasive Computing and Social Networking (ICPCSN), IEEE.

Wright, P. and F. Garwood (1952). "The effect of the method of test on the flexural strength of concrete." Magazine of Concrete Research **4**(11): 67-76.

Yohannes, B. A. (2022). InvestigationofPropertiesof Concrete Containing Waste Glass Powder and Steel Slag Aggregate.

Yuan, Q., et al. (2021). Civil Engineering Materials: From Theory to Practice, Elsevier.

Zanwar, A. B. and Y. D. Patil (2021). Utilization of waste glass powder as a cementitious material in concrete. IOP Conference Series: Materials Science and Engineering, IOP Publishing.

Zemenu, N. (2021). Partial replacement of cement by waste glass for concrete production.

Zeybek, Ö., et al. (2022). "Influence of replacing cement with waste glass on mechanical properties of concrete." Materials **15**(21): 7513.

Zhang, T., et al. (2014). "Formation of magnesium silicate hydrate (MSH) cement pastes using sodium hexametaphosphate." Cement and concrete research **65**: 8-14.

Zhu, J., et al. (2023). "Experimental Study on Long-Term Mechanical Properties and Durability of Waste Glass Added to OPC Concrete." Materials **16**(17): 5921.

LIST OF APPENDICES

APPENDIX I : MATERIAL CHARACTERIZATION

Aggregate Quality Tests

Appendices A : Fine Aggregate Quality Test Results

Physical Tests of Fine Aggregate

Aggregates are available naturally on the earth surface or in the sea as sand, gravel, or clay. Since doing a simple visual test is inadequate different lab tests were conducted to determine the quality of the sand used in this work

a) Gradation and Fineness Modulus of Fine Aggregate Test

According to ASTM C 136, particle size distribution (sieve analysis) of sand can be done based on different sieve size less than 4.75mm. This test performs the determination of particle size and its gradation using sieve analysis .

b) Specific Gravity Test and Absorption Capacity Test

According to ASTM C 128, the measurement of aggregate weight gain caused by water within its pores and the calculation of the ratio between the mass of a given volume of material and that of an equivalent water volume are performed to evaluate the absorption and specific gravity of fine aggregate. Specific gravity may be identified as either the ratio of a substance's density to that of a reference substance (water), or as the mass ratio of a substance to a reference substance for the same volume. Absorption can be described either as the process by which a liquid is drawn into and fills the permeable pores of a porous solid or as the increase in mass of a porous solid resulting from liquid infiltration into its permeable pores. The total water content within the internal pores and on the surface of the sand is referred to as its moisture content. The moisture level can influence the workability and compressive strength of concrete. The procedure outlined was used to determine the specific gravity and absorption of the sand.

Procedure

1) The pycnometer was partially filled with water, and 500 gm. of saturated surface dry sand was introduced into the pycnometer prepared.

2) The pycnometer was rolled manually to eliminate visible air bubbles.

3) Brought the water level in the pycnometer to its calibrated capacity. And the total mass of the pycnometer, sample, and water was recorded.

4) After removing of the sand from the pycnometer it was dried in the oven to constant mass at a

temperature of 110±5 and cooled in air for 1 ± 1⁄2 h, and the mass was recorded.

5) The mass of the pycnometer filled to its calibrated capacity with water was recorded.

Table 1.2: Specific Gravity and Water Absorption

No.	Sample	Result
1	Weight of sample (A)	500
2	Weight of sand, water and pycnometer (B)	1944.5
3	Weight of water and pycnometer (C)	1643.6
4	Oven dry weight (D)	492

I. Specific Gravity

According to ASTM C128 Relative density specific gravity shall be calculated as follow.

1. Density specific gravity (SSD) $=\frac{A}{A+C-B} = \frac{500}{500+1643.6-1944.5} =$ **2.5**

ii. Absorption Capacity

According to ASTM C128 absorption shall be calculated as follow.

Absorption, % = (S-O/O)*100 $\frac{A-D}{D} = \frac{500-492}{492}$ *100 = **1.6%**

Where;

A= Weight of SSD sample

B=Weight of water and pycnometer

C=Weight of sand, water and pycnometer

D= Weight of sample after oven Dry

Discussion

Here the Fine aggregate relative density should be between 2.4 and 2.9 with corresponding particle density of 2400 and 2900 kg/m3.

Generally at saturated surface dry (SSD) fine aggregate have absorption levels between 0.2% and 2%.

C) **Bulk Density of Fine Aggregate (ASTMC C 29M)**

According to ASTM C 29, bulk density helps to determine the weight of sand in a given volume of graded sand. It is a density measurement. It includes the aggregate and the void between the aggregate

To determine the bulk density (unit weight) of the sand in a compacted or loose condition the following procedures was followed.

Procedure

1) First the weight of container was recorded.

2) After filling of the container with one-third full its surface was leveled with the fingers and was rod the layer of sand with 25 strokes of the tamping rod evenly distributed over the surface.

3) The container was filled again two-thirds full and again leveled and rod as previous.

4) Finally the container was filled to overflowing and rod again in the previous manner.

5) The weight of the container with the sand was recorded,

Table I.4: Bulk Density Test Result

No. Sample Result(gm.)

1. Weight of equipment= 2962g

2. Weight of fine aggregate and equipment= 7871.5g

3. Equipment Volume= 0.003 m

No.	**Sample**	**Result**
1	Weight of equipment(A)	2880
2	Weight of fine aggregate and equipment(B)	7768.4
3	Volume of equipment(C)	0.003 m3

Bulk Density (M) $=\frac{B-A}{C}=\frac{7.7684-2.88}{0.003m3}$ =**1629.5kg/m3**

Where:

M = bulk density of the fine aggregate, kg/m3.

B = mass of the fine aggregate plus equipment, kg.

A = mass of the equipment, kg

C = volume of the equipment, m3

Discussion

Aggregate usually used in normal weight concrete have Bulk density between 1200 and 1750 kg/m3 (75 to 110 lb. /ft3).

D) **Silt Content of Fine Aggregate (IS 2386-2)**

This test investigates the size of fine material than a 75-µm sieve in the sand.To determine silt content of the sand the following procedures was followed.

Procedure

1) After a jar was filled up to 50 ml mark with the sand and up to 100 ml with water 1% of salt was added.

2) Then the jar was shaken vigorously for one minute and the last few shakes being in a side wise direction to level off the sand.

3) The thickness of the silt on the top of the sand was recorded after the jar was allowed to stand for three hours

Table: Silt Content Test Result

No.	Sample	Result
1	volume deposited above the sand (A)	4.5ml
2	Volume of clean sand (B)	98ml

Silt content $= \frac{\text{Volume deposited above the sand (A)}}{\text{Volume of clean sand (B)}} = \frac{4.5}{98} = 4.5\ \%$

Appendices B : Coarse Aggregate QualityTests

The following tests are done for natural aggregate based on respective ASTM standards.

a) Gradation Test

According to ASTM C-136, coarse aggregate is described as material larger than 4.75mm sieve size (sieve No. 4) Or that passed 20mm and retained on 4.75mm.

c) Bulk density Test

According to ASTM C29-07, bulk density is the weight of aggregate in a given volume of graded aggregate. It includes the aggregate and the void space between the aggregate.

The following data are the results of the test.

No	Sample	Result
1	The weight of coarse aggregate and equipment (Kg)- A	25.5
2	The weight of Equipment (Kg) B	1.4
3	Volume of Equipment (m3) C	0.015

Bulk density (Kg/m3) = $\frac{\text{The weight of coarse aggregate and Equipment (A)} - \text{The weight of Euipment (Kg) B}}{\text{Volume of Equipment (m3) C}} = \frac{4.5}{98}$

=1606.7 kg/m3

Discussion of Result:

The approximate bulk density of aggregates commonly used in normal-weight concrete ranges from about 1120 to 1920 kg/m3. Hence, the sample falls in the range and is suitable for concreting practice.

d) Specific Gravity and Absorption Test

According to ASTM C 127-07, specific gravity is defined the ratio of the mass of a unit volume of material to the mass of the same volume of water at stated temperature while water absorption is the increase in the weight of aggregate due to water in the pore of the materials.

Observations and Calculations:The following data were found from the test.

Table : Specific gravity and absorption test results

No.	Sample	Result (gm)
1	The weight of oven dry sample (A)	3970
2	The weight of saturated-surface dry (B)	4000
3	The weight of saturated-surface dry sample in Water (C)	2620

specific gravity = $\frac{\text{The weight of saturated}-\text{surface dry (B)}}{\text{The weight of saturated}-\text{surface dry (B)} - \text{The weight of saturated}-\text{surface dry sample (C)}}$

specific gravity = $\frac{\mathbf{4000}}{\mathbf{4000-2620}}$ **= 2.9**

Absorption, % =

$$\frac{\text{The weight of saturated}-\text{surface dry (B)} - \text{The weight of oven dry sample (A)}}{\text{The weight of saturated}-\text{surface dry (B)}} * 1000$$

= 0.76%

Discussion of Results:

The specific gravity range in between 2.4 to 3.0 and the absorption is 0.5% to 4%. The sample absorption and specific gravity are all with the range and can be used for concrete production.

d) Moisture Content Test

According to ASTM C 566-13, moisture content test is the test that shows the amount of water or moisture in coarse aggregate.

Observation and Calculation:

The following data were found from the test

No	Sample	Result (gm)
1	Weight of original sample (A)	4000
2	Weight of the oven dried sample (B)	3840.8

Moisture content =

$$\frac{\text{Weight of original sample (A)} - \text{Weight of the oven dried sample(B)}}{\text{Weight of original sample(A)}}$$

$= \frac{4000-3840.8}{4000}$ = **3.98 %**

Discussion of Results:

Here, the moisture content is smaller than the absorption of the coarse aggregate. Accordingly, the aggregate will absorb the mixing water without adjusting. As result, the mixing water needs to be increased to account for absorption of aggregate.

Appendices C: Glass Powder Chemical Compostion

	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;- Megersa Lamessa

Sample type ;- Powder

Sample Preparation:-200 Mesh

Date Submitted ;- 10/03/2025

Issue Date:- 20/03/2025

Request No:- GLD/RQ/1065/25

Report No:- GLD/RN/4574/25

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'scode	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
Megersa-1	72.92	0.86	0.44	7.48	2.90	12.08	< 0.01	< 0.01	0.8	0.08	0.63	2.07	700gm

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

- LOI = Loss on Ignition

Analysts	Checked By	Approved By	Quality Control
Fasika Dereje Abdisa Yohannes Wedajo Gudisa Tensae Tarekegn Bane Abera Shashe Haile	Kindie Kasahun	Lidet Endeshaw	Yohannes Getachew

Geochemical Laboratory Desk

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APPENDIX II: RESULT OF CONCRETE TESTS

Taking the average of concrete test samples as a result is fundamental because concrete's contains different variability in materials and production means individual tests differ; averaging multiple specimen strengths provides a reliable, statistically representative value crucial for accurate structural design, quality control, mix proportioning, and ensuring the concrete meets specified performance requirements for mechanical and durability of concrete.

Table : Result of Compressive Strengthen sample tests

Sample Code	7^{th} day Compressive Strengthen result	Average Compressive Strengthen	28^{th} day Compressive Strengthen result	Average Compressive Strengthen
Conventional	17.1	17.8	27.1	27.6
	18.6		27.2	
	17.7		28.5	
10 percent	17.6	18	28.8	28
	17.9		28.1	
	18.5		27.1	
20 percent	20.1	19.4	30.9	28.9
	19		27.7	
	19.1		28.1	
30 percent	19.25	19	28.3	27.4
	18.4		26.8	
	19.35		27.1	

Table : Result of Flexural Strengthen sample Tests

Sample Code	7^{th} day Flexural Strengthen result	Average Flexural Strengthen	28^{th} Flexural Strengthen result	Average Flexural Strengthen
conventional	3.22	3.8	7.85	6.85
	4.65		6.25	
	3.45		6.45	
10 percent	4.62	3.93	6.2	7.07
	3.22		7.76	
	3.95		7.25	
20percent	5.01	4.65	8.75	8.1
	4.05		7.5	
	4.89		8.05	
30 percent	3.60	3.95	8.8	7.4
	4.90		6.8	
	3.35		6.6	

Table : Result of Water absorption of concrete sample tests

Sample Code	weight	oven dry	percentage of water absorption	Average Result	Percentage (%)
Conventional	8.153	7.9	0.034819792		
	8.255	7.965	0.035130224	0.03980898	**3.98**
	8.125	7.723	0.049476923		
10 percent	7.975	7.739	0.032020013		
	7.935	7.53	0.051039698	0.03845664	**3.845**
	7.834	7.600	0.032340209		
20 percent	8.424	7.997	0.032130209		
	8.19	7.89	0.036630037	0.037847364	**3.785**
	8.125	7.763	0.044553846		
30 percent	7.844	7.525	0.041889483		
	7.956	7.565	0.049145299	0.037437126	**3.74**
	7.05	6.9	0.021276596		

Table: result of water absorption test

Sample Code	weight	oven dry	percentage of water absorption	Average Result	Percentage (%)
Conventional	8.153	7.9	0.034819792		
	8.255	7.965	0.035130224	0.03980898	**3.98**
	8.125	7.723	0.049476923		
10 percent	7.975	7.739	0.032020013		
	7.935	7.53	0.051039698	0.03845664	**3.845**
	7.834	7.600	0.032340209		
20 percent	8.424	7.997	0.032130209		
	8.19	7.89	0.036630037	0.037847364	**3.785**
	8.125	7.763	0.044553846		
30 percent	7.844	7.525	0.041889483		
	7.956	7.565	0.049145299	0.037437126	**3.74**
	7.05	6.9	0.021276596		

APPENDIX III: PHOTOGRAPHY

SG 57.