ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

EGGSHELL POWDER AND WASTE SODA-LIME GLASS POWDER AS A PARTIAL CEMENT REPLACEMENT MATERIAL IN MORTAR

A Thesis in Structural Engineering

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Eggshell Powder and Waste Soda-Lime Glass Powder as a Partial Cement Replacement Material in Mortar**' presented by Faiza Yasin, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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I certify that research work titled "**Eggshell Powder and Waste Soda-Lime Glass Powder as a Partial Cement Replacement Material in Mortar**" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Faiza Yasin

Date: February 04, 2026

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ABSTRACT

In current situation where the need for cement is scaling up and the world is wisely using waste materials in to useful products, this research proposes potential poultry and domestic waste (Eggshell) and industrial and domestic waste (Soda-lime glass) as a partial cement replacing material for the construction industry.

The eggshell samples were collected from Mojo and the soda-lime glass where collected from households then grinded until all the particles passed 150 µm sieve and then their chemical properties were investigated. From the complete silicate analysis test result it is found that eggshell is reach in calcium oxide or lime and soda-lime glass is reach in silica. And the XRD test result showed, the eggshell has 47.87% crystalline and 52.13% amorphous property and the soda-lime glass has pure amorphous property.

For the flow and compressive strength test a total of 414 mortar cubes were utilized. The mortar cubes were done by replacing OPC with eggshell powder and soda-lime glass powder in 23 different mixes according to the ASTM using 0.485 water to cement ratio and 1:2.75 cement to sand content.

The property of mixes at fresh state showed that, workability increases as ESP and SLGP increases. The results of mortar at hardened state also showed that, 2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP replacement with OPC have applicable compressive strength value relative to the control sample throughout the tests period i.e. 7, 28 and 56 days curing in 20°c. The result also shows 2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP replacement with OPC have applicable compressive strength value relative to the control sample throughout the tests period i.e. 7 and 28 days curing in 60°c. However the control still shows higher value at 56 days curing in 60°c. Even if the control tends to have a higher compressive strength at later age, 2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP replacements could be used as an optimum mix.

Key words**: -** Eggshell powder, soda-lime glass powder, mortar, workability, compressive strength

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
SCM	Supplementary cementitious material
XRD	X-Ray Diffraction
ESP	Eggshell powder
SLGP	Soda-lime Glass powder
$CaCO_3$	Calcium Carbonate
C_2S	Dicalcium Silicate
C_3S	Tricalcium Silicate
C_4AF	Tetra Calcium Alumino Ferite
C_3A	Tricalcium Aluminate
CaO	Calcium Oxide
SiO_2	Silicon dioxide
CaO	Calcium Oxide
MgO	Magnesium Oxide
Al_2O_3	Alumina
$Ca(OH)_2$	Calcium Hydroxide
SO_3	Sulpher Trioxide
CO_2	Carbon dioxide
C–S–H	Calcium Silicate Hydrate
CSH_2	Calcium Sulfate dehydrate
cm^2	Centimeter square
ES	Ethiopian Standard
Fig.	Figure
Fe_20_3	Ferrite
Gm	Gram
Kg	kilo gram
kJ	kilo Joule
kN	kilo Newton
kg/m^3	kilo gram per meter cube
Km	Kilometer
L.O.I	Loss On Ignition
M	Meter
m^3	meter cube
mm	Millimeter

mm^2	Millimeter square
MPa	Mega Pascal
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
OD	Oven Dry
SD	Saturated Surface Dry
W/B	Water to Binder ratio
%	Percent
°C	Degree Centigrade
µm	Micrometer

1. INTRODUCTION

1.1 General

Cement is one the most important constituent in concrete production which acts as a binder in holding the fine and the coarse aggregate together and give a concrete structure and concrete blocks high strength. It has been used for decorative purposes (for patios, stairways, floors, driveways, and pool decks) as well as for objects like tables, sculptures, and bookcases in addition to its great strength. The drastic increase in production of cement lead to global pollution from continuous CO_2 emission to the environment during burning of raw material. To balance the production of cement with the environment, replacing it with waste materials become a wise way in the production of supplementary cementitious material. From the waste materials eggshell powder and soda-lime glass powder seems to be a good material to be used as a partial cement replacement due to their high calcium (Ca) and Silica (Si) content respectively.

From the data that's been gathered on the availability of this alternative materials, Ethiopian egg production for the year 2020, included 6.555 billion table eggs, and 126.5 million hatching eggs which means 40,089 tons of eggshell is thrown to the environment each year [17]. And from total solid waste in Ethiopia 1% is bottle glass (soda-lime glass) material which means that, there is around 147,752 ton/year of glass is thrown to the land fill [32].

In general this research investigates eggshells and waste soda-lime glasses to be recycled in order to make use of partial cement replacement to reduce solid waste disposal to landfills and CO_2 emissions to the environment owing to cement manufacture.

1.2 Statement of the Problem

In Ethiopia, where the construction industry is expanding quickly, concrete is frequently employed in the construction of industries, dams, buildings and bridges.

As a result, the need for concrete in the construction industry is increasing. As a result, in order to achieve long-term development, more attention must be paid to construction materials in terms of energy efficiency and environmental preservation.

Eggshell and Waste soda-lime glass being one of the solid waste materials causing pollution to the environment, giving them a purpose is one way to minimize waste materials thrown to the land fill and may also be a good way to minimize CO2 emission to the environment due to the production of cement.

1.3 Objectives

1.3.1General Objectives

The general objective of this research is to experimentally study the characteristics of soda-lime glass powder and eggshell powder to determine whether or not they may be utilized to partially replace cement in the creation of green concrete.

1.3.2 Specific objectives

- Investigate the foundational materials of eggshell powder and soda-lime glass powder.
- Examine the chemical and physical characteristics of eggshell powder, soda-lime glass powder, cement, and fine aggregate (sand) to assess the potential for substituting cement with eggshell powder and soda-lime glass powder.
- Conduct experiments on the mixture of eggshell powder, soda-lime glass powder, and cement to identify their chemical and mechanical properties.
- Evaluate the experimental outcomes to ascertain the mechanical properties when varying percentages of cement are replaced with eggshell powder and soda-lime glass powder.
- As part of goal of this study, this research will also make recommendations and draw conclusions based on the findings, as well as identify areas that require more research.

1.4 Scope of the study

This research scope is limited to finding the optimum percentage of replacement of cement by eggshell and soda-lime glass powder in mortar.

1.5 Methodology

In order to achieve the study's objectives, the following methodology has been applied:

- A review of the literature on concrete, cement, cement replacement materials, eggshell and waste soda-lime glass as cement replacement materials, Ethiopia's potential for eggshell and waste soda-lime glass, and tests on fresh and hardened mortar and concrete. Textbooks, periodicals, academic journals, seminars, and research papers are also included in the review.
- Different percentages of eggshell and soda-lime glass were used to partially replace cement in the samples.
- Different tests on the eggshell powder, soda-lime glass powder and fine aggregates were performed
- Flow and compressive strength tests were performed on mortars made of various proportions of eggshell and soda-lime glass powder partially replacing cement components at 7, 28, and 56 days in 20°c and 60°c curing temperatures.
- After the test results were examined, the findings were interpreted and discussed, and the results were displayed graphically.
- Finally, conclusions and recommendations are developed based on the laboratory findings.

2. LITERATURE REVIEW

2.1 Introduction

Waste materials have long been used effectively in the making of concrete. Waste materials have frequently been used as additional cementitious materials to improve the qualities of concrete, lower costs, and lessen environmental impact [18].

In their brief discussion of the advantages of using additional binding elements in the manufacturing of concrete divided into three categories: engineering, ecological, and economic [20]. Alternative materials have several positive environmental effects, such as:

(1) Keeping non-recycled waste out of landfills for useful purposes;

(2) Minimizing the negative effects of cement production, like the use of non-renewable natural resources;

(3) Consuming less energy during the cement-making process; and

(4) Reducing gas emissions.

When alternative materials are less expensive than cement while providing comparable performance, their economic benefits become most noticeable. In addition to savings from diversion, such as landfill management and tipping fees expenses, this cost should take into consideration the alternative material's source, processing and transportation. When a specific use for these materials is created, the engineering or technological advantages become apparent, making the use of alternative materials more appealing than concrete manufactured exclusively with OPC. Thus, there is a chance to capitalize on the potential advantages of using waste glass or other alternative cementitious materials [20].

One of the earliest materials ever created by humans, glass is used for a variety of applications, including flat, container glass and light bulb. Glass items are recycled or landfilled to lessen environmental contamination because of their short lifespan. In the construction business nowadays, waste materials including waste glass are widely utilized to partially substitute cement. Glass garbage production and disposal have surged along with modern industry, causing environmental problems and the depletion of natural resources [22].

As a result, recycling glass into concrete improves concrete's qualities, saves landfill space, and uses less virgin material to make cement.

2.2 Cement

Cement is a fine gray powder that solidifies upon mixing with water, forming a rigid chemical mineral structure that serves as an adhesive to bind particles together, thereby imparting strength to concrete. The Romans are acknowledged for discovering it, as they combined lime ($CaCO_3$) with volcanic ash to produce a cement mortar used in constructing impressive edifices like the Colosseum

The use of cement is linked to a nation's economic growth, serving as a foundation for new buildings, factories, and infrastructure, which are essential for development. Consequently, cement production has surged significantly in developing nations.

As depicted in Figure 2.1 below, the global cement production reached an estimated 4.4 billion tons in 2021. In contrast, in 1995, Production of cement worldwide was only 1.39 billion tons, highlighting the substantial growth of the construction industry since then.[31].

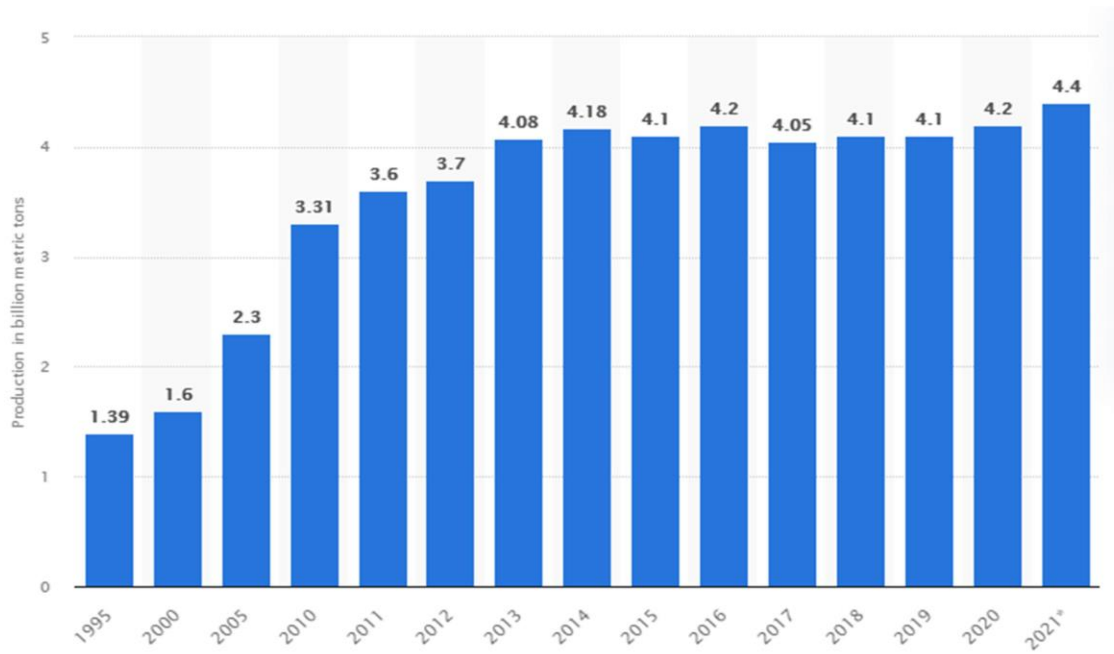

Figure 2. 1 Cement production worldwide from 1995 to 2021

2.2.1 Types of cement

Cement comes in various forms, distinguished by their composition, manufacturing process (such as grinding and burning), and the relative amounts of different compounds. Among these, Portland cement is the most prevalent and is further categorized into several types. Another widely used variety is Portland pozzolana cement, which includes a certain quantity of pozzolanic materials.

2.2.1.1 Portland cement

One of the most widely used cements, Portland cement is regarded as the most important hydraulic cement. Plaster and mortar are also made with it. Many structural concrete applications, such as walls, floors, bridges, and tunnels, call for this form of cement. It is also utilized in many masonry projects, including pavements, dams, retaining walls, and foundations. Portland cement serves as mortar for laying bricks and stones when combined with sand and lime; concrete is created when it is combined with fine and coarse aggregates and the right amount of water to reach the proper consistency.

Joseph Aspdin, an English bricklayer, is usually given credit for coining the term "Portland cement" after he invented a process in 1824 for turning hard limestone and finely divided clay into a powder. After forming into a slurry, this combination is calcined in a furnace until the CO_2 is released. Because the solidified mortar resembled the stone quarried near Portland, England, he called the resultant substance Portland cement [8]. Since then, cement production techniques have improved, but the basic procedure has not altered.

The ingredients used to make modern Portland cement must include the proper amounts of iron (Fe_2O_3), silica (SiO_2), alumina (Al_2O_3), and lime (CaO), with trace amounts of sulfur trioxide and magnesia. Table 2.1 below displays a typical general-purpose OPC composition:

Table 2. 1 Typical composition of ordinary Portland cement [7]

Symbols	Chemical formula	Chemical Name	Weight percentage
C_3S	$3CaO.SiO_2$	Tricalcium silicate	55
C_2S	$2CaO.SiO_2$	Dicalcium silicate	18
C_3A	$3CaO.Al_2O_3$	Tricalcium aluminate	10
C_4AF	$4CaO.Al_2O_3.FeO_3$	Tetracalcium aluminoferrite	8
CSH_2	$CaSO_4.2H_2O$	Calcium sulfate dehydrate (gypsum)	6

Among these compounds, C3S and C3A are primarily responsible for the initial strength of concrete. A high concentration of C3S (and low C2S) leads to significant early strength but also results in considerable heat production as the concrete cures. Conversely, a low C3S and high C2S combination results in slower strength development and reduced heat generation. C3A contributes to unwanted heat and rapid reaction characteristics, which can be mitigated by incorporating CaSO4 into the final product.

According to the relative proportions of the compounds and the degree of fineness, ASTM classifies Portland cement into five main types (non-air entrained): ASTM type I, ASTM type II, ASTM type III, ASTM type IV, and ASTM type V. This is the most widely accepted classification system for Portland cement and they are used for different purposes and type of work as listed below

- When no special qualities are needed for the concrete, ASTM type I cement, a general-purpose Portland cement, is utilized.
- Moderate Portland cement, commonly known as ASTM type II cement, is a general-purpose cement that is utilized when moderate heat of hydration or sulfate resistance are required.
- High early strength Portland cement, or ASTM type III cement, is used when quick early strength is needed, usually within a week, and is frequently utilized when a structure needs to be operational right away.
- Low-Heat of Hydration Portland cement, or ASTM type IV cement, is utilized in mass concrete applications and other situations where a low heat of hydration is required.

- Lastly, ASTM type V, or sulfate-resisting Portland cement, is utilized when sulfate resistance is required.

2.2.1.2 Portland Pozzolana cement

Portland pozzolana cement is the result of OPC clinker grinded with 15–35% pozzolanic ingredients [8]. Pozzolanic materials are alumina or siliceous substances that have little to no cementitious qualities on their own. However, when water is present, they react with calcium hydroxide, which is released when cement hydrates, to create a compound having cementitious properties.

PPC has numerous advantages over OPC as a result of the reaction between the pozzolanic ingredients and calcium hydroxide. The presence of free calcium hydroxide in the concrete would have increased its permeability and made it more vulnerable to further attacks if these pozzolanic elements had not interacted with the calcium hydroxide. By creating a cementitious compound, the pozzolanic reaction lowers the concrete's porosity. Because its reaction is slower than OPC's, it also lowers the heat of hydration. This suggests that it has a slower rate of strength than OPC, which makes it appropriate for mass concrete production.

Apart from these cement varieties, there are more cement varieties that are made by either incorporating additional materials into the clinker or by creating new compounds while burning. The term "modified Portland cements" refers to them all. This can be demonstrated by masonry cement, oil well cement, white cement, calcium sulfoaluminate cement, expansive cement, etc. Inorganic cements that are not Portland are also utilized to a certain degree.

2.2.2 Hydration Reaction of Cement

Cement and water react during the concrete-making process to create calcium-silicate hydrate (C-S-H) gel, a solid phase. By penetrating the crevices between particles, this gel binds them together and gives the cement strength. The cement becomes comparatively impermeable to water and dissolved ions as hydration advances because the volume of water-filled pores is reduced by the development of C-S-H gel. The microstructure is the arrangement of pore spaces and solid phases. These microstructural characteristics, which are typically too small to be seen without a microscope, are much smaller than the atoms or molecules that comprise the fundamental chemical structure. In general, a material's qualities are determined by both its chemical structure and microstructure [21].

The main components of cement that undergo reactions with water are tetra calcium aluminoferrite (C4AF), tricalcium silicate (C3S), dicalcium silicate (C2S), and tricalcium aluminate (C3A). C3S and C2S are the two main hydration processes that support the development of strength. Typical hydration reactions are as shown on the equations below [23].

$$\text{For } C_3S : S_2C_3S + 6H \text{ (water)} \rightarrow C_3S_2H_2(\text{CSH gel}) + 3CH \text{ (hydrated lime)} \qquad \text{Equation 2-1}$$

$$\text{For } C_2S : 2C_2S + 4H \text{ (water)} \rightarrow C_3S_2H_3 + CH \qquad \text{Equation 2-2}$$

In addition to being the most common reaction product making up over 50% of the paste volume the C-S-H gel is also responsible for the majority of cement paste's technical qualities. Calcium hydroxide, commonly referred to as portlandite, makes up around 15% of the volume of a typical Portland cement paste and is formed from C3S and, to a lesser extent, C2S. In this sense, calcium hydroxide is far less important than C-S-H, even if it marginally improves the paste's strength and impermeability by turning some liquid water into solid. The table 2.1 provides an overview of the standard ordinary Portland cement's chemical makeup

2.3 Pozzolanic Reaction

The term "pozzolanic reaction" refers to the interaction between pozzolanic substance and CH. Because the CH generated during cement hydration is consumed together with mineral admixtures to make further C-S-H gel, CH is either negligible or nonexistent in blended cement pastes. Since CH is the most soluble hydration product, its durability in cement and concrete is compromised. CH can dissolve in fresh water, increasing porosity and leaving the paste vulnerable to further leaching and chemical attacks.

Free lime is also undesirable in hardened concrete because it can leach out unsightly and increases the surface's chemical reactivity, even along cracks. Any pozzolans applied to the cement or concrete mix might react with it, improving permeability and strength [23].

$$\text{Pozzolan + Calcium Hydroxide + water} \rightarrow \text{Calcium Silicate hydrate (gel)} \qquad \text{Equation 2-3}$$

$$S + CH + H \rightarrow C - S - H$$

By combining with the alkalis in the paste, the active silica in pozzolans lowers the amount of alkalis available to react with aggregates and considerably lowers the porosity of cured concrete.

There is a consensus that the total amount of combined lime depends on [29]

1. The nature of their active phases;
2. Their pozzolanic material content;
3. Their SiO_2 content;
4. The lime/pozzolanic material ratio;
5. The length of curing;

whereas the combination rate depends on

6. The specific surface area of the pozzolanic material;
7. The water/solids mix ratio;
8. Temperature.

2.4 Curing

Controlling moisture loss from previously laid concrete is known as curing. It guarantees the cement's hydration, increasing its strength and resilience. Concrete must be kept at the proper temperature and moisture content for a certain period of time during the curing process, which starts as soon as the concrete is placed [43].

2.4.1 Curing length

Several elements, such as the weather, the size and shape of the concrete material, the combination proportions, and the mixture's strength, affect the length of curing period.
There are three main methods to achieve concrete curing:

1. Maintaining mixing water in concrete during the early hardening process.
2. Reducing the loss of mixing water from the surface of the concrete.
3. Accelerating strength gain using heat and additional moisture [43].

2.4.2 Curing temperature

The rate of the pozzolanic reaction increases with temperature but tends to halt beyond a certain point. Between 50°C and 90°C, 1:3 ratio of lime/natural pozzolana mixes, compacted with 10% water under a compressive load of 130 N/mm^2, react rapidly, with most lime fixed after just one day. However, above 70°C, the amount of combined lime tends to stabilize or decrease due to changes in the composition of the hydrated phases at higher temperatures [43].

2.5 Mortar

The composite material known as mortar is composed of inert materials of different sizes that are joined by a binding agent. It is composed of fine aggregate, cement, water, and air. The paste made of cement, water, and air keeps the particles together. Therefore, aggregate matrix bond strength is a determinant of mortar strength [16].

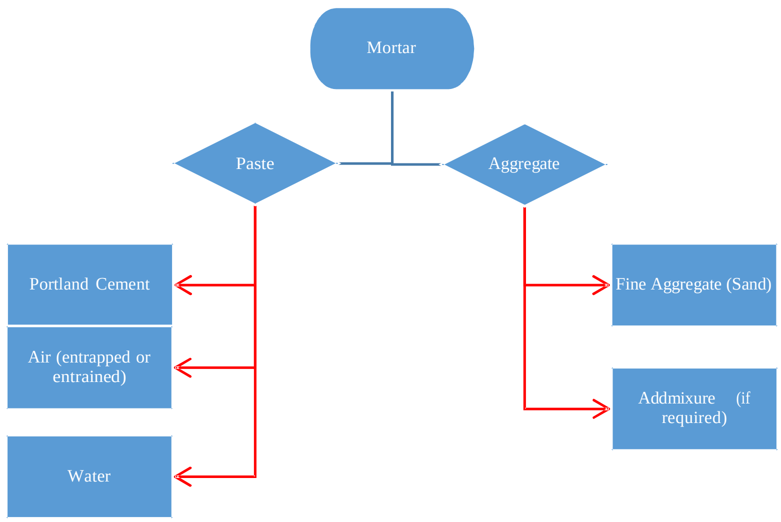

Figure 2. 2 Flow Chart of mortar

The entire mass of mortar is placed in a plastic state and begins to harden almost immediately, a process that, with proper curing, can continue for years.

2.6 Concrete

In essence, concrete is a mixture of gravel and sand that is held together by cement paste. It serves as the foundation for infrastructure, including buildings, bridges, roads, and other structures, making it the most frequently utilized man-made material in the world. Concrete is made in a very complicated process at the microscopic level, and scientists are still unsure of some aspects of its chemistry and microscopic structure. Concrete has a lot of room to be improved in order to produce stronger and more resilient constructions [24].

2.7 Supplementary Cementitious Materials

New supplementary cementitious materials with purported pozzolanic properties are continually being developed, driven by economic and environmental pressures. To compare the properties of these new materials with established ones like fly ash, silica fume, metakaolin, glass, and rice husk ash, which have been used to supplement or replace Portland cement for the past 40 years, testing of newly discovered cementitious materials and their mixing effects is a major focus of modern cement research [27].

It is now possible for cements to contain up to 5% of extra ingredients, including fly ash, slag, or limestone, and still be categorized as Portland cement. These elements can now be used in greater amounts to standardize up to 27 common cements [27].

The cementitious system includes the incorporation of additional cementitious ingredients into concrete. Depending on the properties of the materials and the intended use of the concrete, SCMs can be used in addition to or in place of Portland cement or mixed cement in concrete. They can also be used to enhance certain properties of concrete, such as resistance to alkali-aggregate reactivity. To ascertain whether the material is truly improving the property, tests should be conducted to determine the right amount of SCMs to use. Additionally, the ideal percentage should be controlled to avoid an overuse or underuse, which could be harmful or not have the desired effect. Different cements react differently with the extra cementitious materials. In the past, concrete was made using fly ash, slag, calcined clay, calcined shale, and silica fume separately. With the increased availability of these materials, concrete producers can now combine two or more of them to enhance the concrete's properties.

2.7.1 Egg

The egg is highly valued for its biological worth due to its rich protein content. The protein quality in eggs is often used as a benchmark for evaluating the protein quality in other foods. Eggs also contain essential unsaturated fatty acids like linoleic and oleic acid, along with iron, phosphate, trace minerals, and fat-soluble vitamins.

An egg is composed of three primary components: the egg white, the yolk, and the shell. The shell is made up of calcite crystals within a matrix of proteins and polysaccharides. The egg white, a thick, colorless liquid inside the shell, makes up about 58% of the egg's total weight.

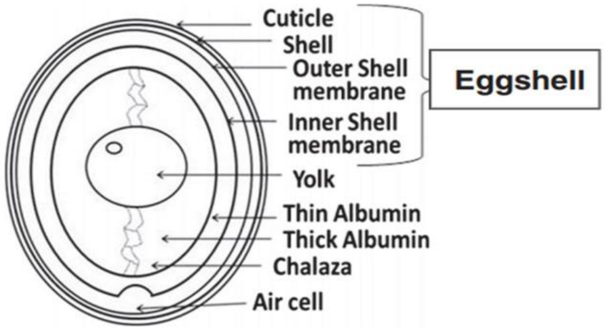

Figure 2. 3 Egg and Egg shell structure

2.7.1.1 Structure of Egg

A typical egg weighs around 57 grams, with the shell making up 11%, the white 58%, and the yolk 31% of this weight. These proportions generally remain consistent across different egg sizes. Eggs are particularly valuable for their protein content, with one egg providing approximately 6 to 7 grams of protein. They are also rich in minerals such as iron and phosphorus.

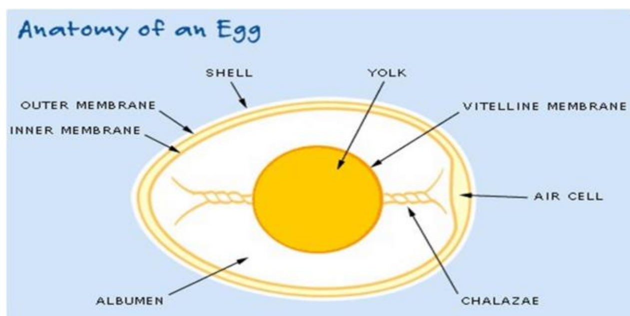

Figure 2. 4 Anatomy of an egg

2.7.1.2 Egg Albumin

The albumin, or egg white, is the clear or slightly cloudy substance surrounding the yolk, providing nourishment for the developing embryo. While whole eggs have long been recognized as a valuable protein source, modern understanding highlights that the yolk is primarily fat, whereas the albumin consists of protein and water.

Table 2. 2 Proteins found in egg White

Proteins	Percentage
Ovalbumin	54.00
Ovotransferrin	12.00
Ovomucoid	11.00
Ovoglobulin G2	4.00
Ovoglobulin G3	4.00
Ovomucin	3.50
Lysozyme	3.40
Ovolinbitor	1.50
Ovoglycoprotien	1.00
Flavoprotien	0.80
Ovomacroglobulin	0.50
Avidin	0.05
Crystatin	0.05

Due to its high protein concentration, egg albumin serves as an effective binding agent in food. Proteins are naturally somewhat elastic and tend to bind together.

Eggs have a high protein content, mainly composed of amino acids, which can affect cement properties.

Numerous experimental investigations have demonstrated that test specimens' ultimate strength decreases with an increase in cement's alkali content. After 14 days, concrete specimens with a higher alkali content statistically had a higher dynamic modulus of elasticity, according to a study that included 199 commercial Portland cement samples. Additionally, it was discovered that a larger alkali concentration in cement decreases ultimate strength while speeding up the growth of short-term strength.

2.7.1.3 Egg Shell

Ten to eleven percent of the egg's weight is made up by the eggshell, which serves as its exterior coating. The eggshell is 300-350 micrometers thick, weighs 5-6 grams on average, and has remarkable mechanical strength (over 30N). This structure is essential for controlling the flow of gasses and water as well as shielding the egg's contents from physical and microbiological dangers. The eggshell contains between 1.7 and 2.5 grams of calcium.

Table 2. 3 Contents of Egg shell in %

Content	Percentage
Calcium carbonate (CaCO3)	94 – 97%
Phosphorus (P)	0.3%
Magnesium (Mg)	11.00
Manganese (Mn), Sodium (Na), Iron (Fe), Copper (Cu), Potassium (K), - traces	4.00
Organic Matter	<2%

Table 2. 4 Specific Gravity of Egg content in %

Content	Percentage
Shell	2.3250
Yolk	1.0320
Albumin	1.0380
Shell membranes	1.0750

Table 2. 5 Percentage Composition of egg white and yolk

Nutrients	Egg yolk	Egg White
Water	48.00	88.0
Proteins	17.50	11.00
Fat	32.50	0.20
Minerals	2.00	0.80

Table 2. 6 Percentage distribution of weight

Part	Weight (%)
White	57-61
Yolk	27-32
Shell	8-11

2.7.2 Glass

2.7.2.1 General

One of the oldest materials used in many different industries, especially in building and construction, is glass. It comes in a variety of hues and chemical makeups. Glass is usually a clear, amorphous substance that is created by cooling molten glass. Its composition is similar to that of igneous rocks, in which the eruption gives the energy to form naturally occurring glass and the hollow volcanic space acts as a furnace.

Glass waste needs to be completely recycled or landfilled because it is not biodegradable. It is a chemically resistant, inert, and inorganic material that acts as an efficient heat insulator and provides good resistance to environmental influences.

Consequently, recycling this waste by converting it into powder for partial cement replacement can conserve landfill space and decrease the need for extracting natural raw materials for construction.

Glass types include silicate, borosilicate, sodium borosilicate, soda-lime, alumino silicate, lead oxide, and germanium oxide, depending on their chemical composition. To develop unique glass kinds, ZnO and MgO are also added. Glasses are often categorized according to their production process, use, and function.

2.7.2.2 Types of glass

Based on chemical composition, nearly all commercial glasses belong to one of six primary categories. These include:

Soda-lime glass

The most economical and commonly used kind of glass is soda-lime, which makes up 90% of industrial glass manufacturing. It is used to make windows, jars and light bulbs. It is resistant to high temperatures and corrosive substances.

Because of its smooth, fine-pored surface and ability to let light through, it is simple to clean. Pouring hot water into a soda-lime glass bottle or container, however, requires caution because it expands quickly when heated. Although it has little resilience to heat shock, it can tolerate temperatures as high as 200 °C. The chemical composition of soda-lime silica glass is shown in Table 2.8 below.

Table 2. 7 Composition of soda lime silica glass

Type of Glass	**Composition (by weight)**
Soda Lime Silica	73% Silica – 14% Soda – 9% Lime – 4% Magnesia – 0.1% Alumina

1. Lead glass

Lead oxide makes up a significant portion of this type of glass—at least 20%. It costs more than soda-lime glass, is comparatively soft, and is perfect for electrical applications because of its superior insulating qualities. Art glass, thermometer tubing, and lead crystal tableware are common uses for lead glass. It is unable to withstand abrupt temperature changes, though. The chemical composition of lead glass is displayed in Table 2.9 below.

Table 2. 8 Chemical Composition of lead glass.

Type of glass	**Composition (by weight)**
Lead (Crystal)	57% Silica – 31% lead Oxide – 12% Potassium Oxide

2. Boro silicate glass

Is known for its exceptional resistance to temperature changes and chemical corrosion. This makes it ideal for use in laboratory apparatus, heat-resistant kitchenware, and durable lamp covers. It can endure temperatures as high as 1700°C. Table 2.10 below details the chemical composition of borosilicate glass.

Table 2. 9 Chemical Composition of Boro silicate glass.

Type of glass	Composition (by weight)
Boro-silicate	81% Silica – 13 % Boron Oxide – 4% Soda -2%Alumina.

3. Alumino-silicate glass

Contains aluminum oxide, which gives it the ability to resist heat shock and high temperatures. It is frequently found in halogen tungsten lights and high-pressure steam boilers, which can function at temperatures of up to 750°C. Table 2.11 below outlines the chemical composition of alumino-silicate glass.

Table 2. 10 Chemical composition of alumino silicate glass

Type of Glass	Composition (by weight)
Alumino Silicate	64.5% Silica – 24.5% Alumina – 10.5% Magnesia – 0.5% Soda

4. Ninety-six percent silica glass

Is a type of borosilicate glass that undergoes a melting process to eliminate nearly all non-silicate elements, resulting in a glass resistant to heat shock up to 900°C. The pores in this glass are consolidated by reheating to 1200°C.

5. Fused silica glass

It is made entirely of silicon dioxide in its non-crystalline form. Because it is difficult to produce, it is the most expensive kind of glass. For brief periods of time, it can tolerate temperatures as high as 1200°C. There are numerous uses for these six varieties of glass.

2.7.3 Eggshell and glass as cement replacing material

Many researches are done on egg shell powder and waste soda-lime glass powder as cement replacement material separately and with other materials [1], [2], [3], [4], [5], [6], [7], [8], [9], [10] and [11].

Based on this experimental investigation and my opinion using egg shell powder and fine glass powder in order to partially replace cement can enhance the strength of concrete, and also minimize CO_2 emission and solid waste disposal to the environment.

2.8 Availability of egg shells and soda-lime glass

To evaluate the potential of waste soda-lime glass and eggshells in Ethiopia, it is essential to examine the glass manufacturing and poultry industries, as well as solid waste disposal data. In Ethiopia, numerous poultry businesses exist, and in 2020, approximately 6,681,520,000 eggs were produced annually, resulting in 40,089 tons of eggshell waste each year [39].

Data gathered in Ethiopia indicates that bottled glasses, or soda-lime glasses, make up 1% of solid trash. At 0.32 kg per person per day on average, solid waste generation is within low-income countries' waste generation restrictions. Nonetheless, garbage generation has increased by 5% year [32]. According to this data, Ethiopia wastes an average of 147,752 tons of soda-lime glass annually.

3. MATERIALS AND METHODS

3.1 Introduction

This chapter explains the experimental setup and component materials used to investigate the potential application of using eggshell and soda-lime glass powder in mortar mixtures as cement substitutes. For this study, all of the experiments are conducted in Material Laboratory at the Addis Ababa Institute of Technology.

In this experiment, varying amounts of eggshell and soda-lime glass powder will be added to the mortar to observe their influence on various mortar mix qualities. The test program took into account a number of factors, including the method used to cure the sample and the proportions of eggshell and soda-lime glass powder in mortar mixtures. The test protocol, specifics, and tools utilized to evaluate the qualities of mortar are presented in this paper. The material qualities and testing were examined using the criteria outlined in ASTM standards and specifications.

3.2 Materials

OPC, Sand, water, eggshell powder and waste soda-lime glass powder were among the materials employed in the test program. These materials will be described in detail in the next pages:

3.2.1 Binding materials:

- Cement

Dangote ordinary portland cement (Dangote OPC 42.5 R) was used throughout the investigation.

- Eggshell and Soda-lime glass

In this study, eggshell was collected from Abdi poultry in mojo and soda-lime glass from house hold. Below there is illustrates and chemical properties of samples of eggshell and waste soda-lime glass used for replacement of cement.

Figure 3. 1 Samples of egg shell and waste soda lime glass used for cement replacement

3.2.1.1 Chemical properties of binding material

3.2.1.1.1 Chemical composition of cement, eggshell and soda-lime glass from complete silicate analysis

Table 3. 1 Chemical composition of Dangote cement, eggshell and soda-lime glass

Chemical Composition (%)	Dangote OPC Cement	Eggshell	Soda-lime Glass
SiO_2	22.82	2.66	66.60
Al_2O_3	5.41	0.56	7.77
Fe_2O_3	3.37	0.70	0.66
CaO	66.32	52.20	8.96
MgO	1.46	0.58	2.28
Na_2O	-	0.36	10.72
K_2O	-	< 0.01	< 0.01
MnO	-	0.1	0.1
TiO_2	-	< 0.01	0.04
P_2O_5	-	0.35	0.27
H_2O	-	0.89	0.14
SO_3	2.16	< 0.01	0.95
LOI	-	41.60	0.90

Cl	-	< 0.01	< 0.01
SiO_2+ Al_2O_3+ Fe_2O_3	31.6	3.92	75.03

3.2.1.1.2 X-ray diffraction (XRD) output

In this thesis paper XRD test is used to determine the chemical composition of soda-lime glass and eggshell in atomic arrangement level and to show if the two materials can be mixed with cement in giving useful blended cement. To retrieve information from XRD output, the following methods can be used.

- Basic XRD Data Analysis using High Score Plus
- Profile Fitting and Crystallite Size Determination
- Rietveld Refinement

From the XRD test result it has been found that the soda-lime glass is 100% Amorphous and the eggshell is 47.87% Crystalline and 52.13% Amorphous, which can be concluded that both materials are suitable for binding with cement to form blended cement.

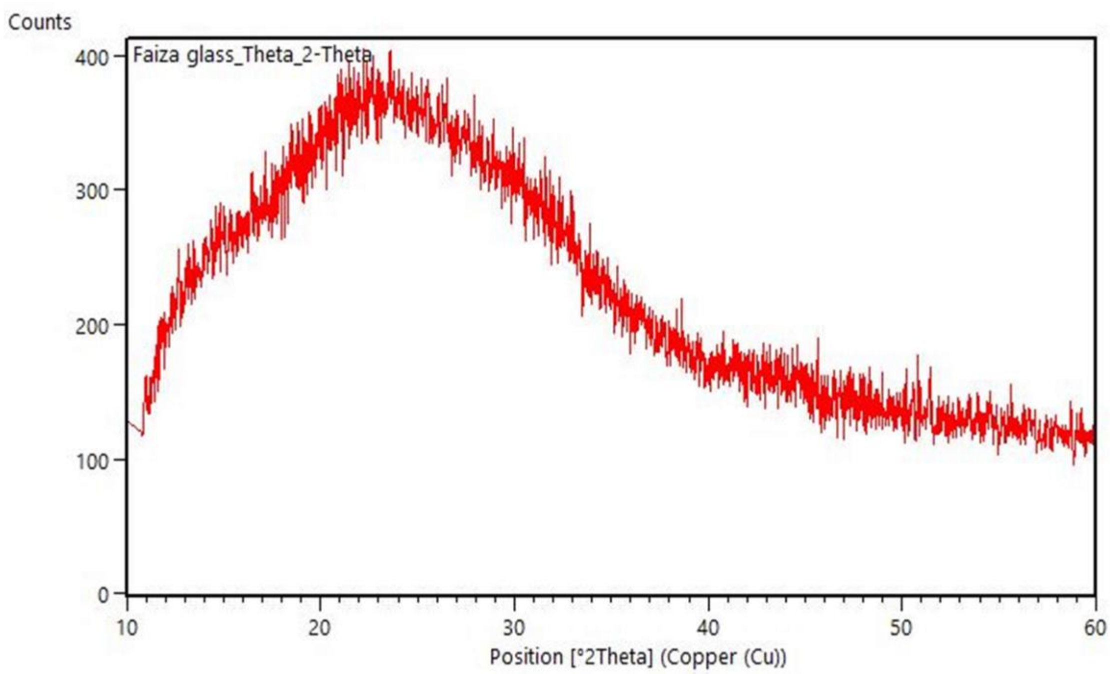

Figure 3. 2 XRD patterns of Soda-lime glass

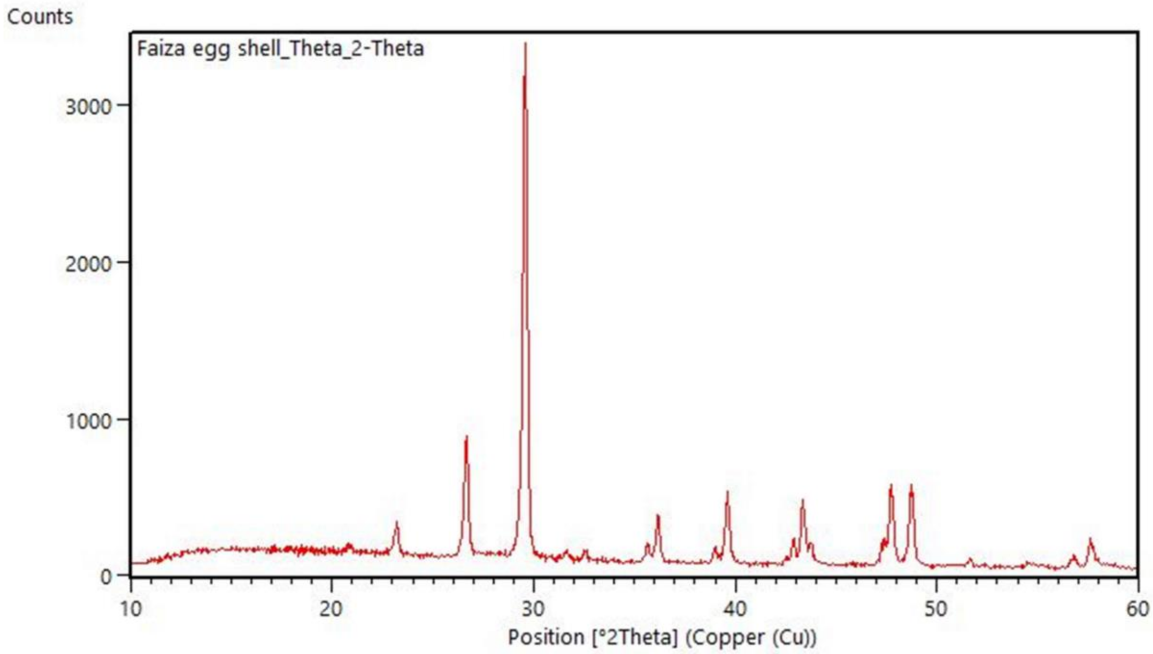

Figure 3. 3 XRD patterns of eggshell

3.2.1.2 Physical properties of cement, eggshell and soda-lime glass

3.2.1.2.1 Density

The mass per volume of the binding material in this researcher are as follows:

ρ = mass (g)/displaced volume

ρ of Dangote OPC cement = 50/16 = 3.13g/cm^3

ρ of eggshell = 45.5/19.2 = 2.37g/cm^3

ρ of soda-lime glass = 43.6/17.3 = 2.52g/cm^3

3.2.1.2.2 Blain's Air Permeability

The Blaine air permeability test is a recognized technique for determining cement's fineness, which is essential for comprehending how well it works in building applications. Cement particle size and distribution are intimately correlated with the test's measurement of the particles' specific surface area. The higher the specific surface is, the finer cement will be.

Table 3. 2 blain air finesse of cement, eggshell and soda-lime glass

Material	**Blain air in cm^2/gm**
Dangote OPC	2910
Eggshell	4770.15
Soda-lime glass	1303.58

3.2.2 Water

All mortar formulations and specimen curing processes used potable tap water free of chemicals and salts.

3.2.3 Fine Aggregates

Relevant experiments were conducted to determine the properties of the aggregates used in this investigation. Remedial actions were then carried out prior to the proportioning of the mix, including washing the aggregates to fulfill the silt content criterion and blending them to meet the grading requirement. Aggregates ought to be strong, durable, contaminant-free, and generally chemically stable. During mixing, soft, porous rock can break down and raise particles, which can lead to workability issues. It can also decrease strength and resistance to wear. Aggregates should not contain organic ingredients, silt, clay, or dirt.

3.2.3.1 Silt content

Silt is typically defined as material in fine aggregates that are finer than 75μm. The quality of the concrete is significantly impacted by this silt in the sand. It mostly impacts the concrete's workability and causes its strength to decrease. In order to reduce the amount of silt in the fine aggregate, it was cleaned. According to the results of the silt content test conducted on the sand, the initial silt content was 9%. The silt content is limited to 6% per the Ethiopian standard. Washing or rejecting the sand is advised by the standard if it over this upper limit. Therefore, the sand was washed and its final silt content became 2.56%.

Fine aggregates should, in general, be chemically stable and devoid of unwanted materials such as silt, clay, dirt, or organic matter. Physical property of the mixed sand was tested as shown in Table 3.4

Silt content (%) = 2.56% as seen in Appendix B-5

Figure 3. 4 sand sample used and tested

3.2.3.2 Sieve Analysis and fineness modules

This process is used to ascertain the aggregate's particle size distribution. The fineness modulus, a measure of aggregates' fineness, coarseness, and homogeneity, is also ascertained using this method. These aggregate characteristics have a significant impact on the concrete's characteristics. According to ASTME 33, fine aggregate must be graded, and Table 3.3 and Figure 3.5 display the fine aggregate's grain size distribution.

Table 3. 3 Standard for fine aggregate and sieve analysis results

Sieve size	Percentage passing Limits	Percentage passing of original sand	Mass retained (gm)	Cumulative Mass retained (gm)	Cumulative % Retained
9.50mm	100	100	0	0	0
4.75mm	95-100	99.8	1	1	0.2
2.36mm	80-100	93.08	33.6	34.6	6.92
1.18mm	50-85	75.48	88	122.6	24.52
600μm	25-60	29.08	232	354.6	70.92
300μm	5-30	5.12	119.8	474.4	94.88
150μm	0-10	1.3	19.1	493.5	98.7
pan			6.5	500	Sum=296.14

$$\text{Fineness modulus} = \frac{\text{sum of cumulative retained \%}}{100}$$

$$\text{Fineness modulus} = \frac{296.14}{100} = 2.96$$

The graph for the sieve analysis of the sand and ASTM C33 standard is as follows;

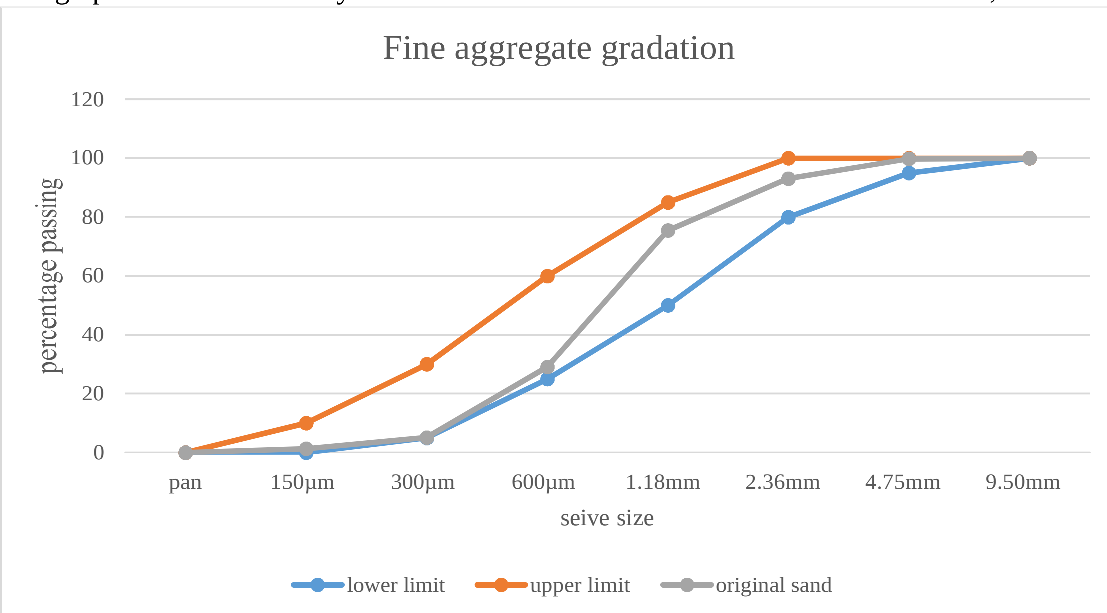

Figure 3. 5 Gradation curve of fine aggregate

3.2.3.3 Specific gravity and absorption capacity

The specific gravity of an aggregate is a measure of its density. It is calculated by dividing a substance's weight by the weight of an equivalent volume of water. Because aggregates have pores in their structure, the inclusion or exclusion of the pores in the measurement determines the specific gravity. While bulk specific gravity refers to the aggregate's whole volume, including pores, apparent specific gravity refers to the solid materials excluding pores.

The following results are found for the fine aggregate:

Bulk specific gravity = 2.52

Bulk specific gravity (SSD basis) = 2.53

Apparent specific gravity = 2.534

Absorption capacity = 0.2%

3.2.3.4 Moisture content

The ratio of cement to water has an impact on the workability and strength of concrete. The concrete becomes more workable and loses strength as the water-to-cement ratio rises. It is believed that concrete aggregates are harmless substances. However, the majority of aggregates either release water (wet aggregates) or absorb it (dry aggregates) in order to fail to meet this requirement. This aggregate characteristic causes a change in the mix's design water to cement ratio. As a result, both the absorption capacity and the moisture content of the aggregate must be determined.

The moisture content of fine aggregates was evaluated by oven drying a 500g sample of fine aggregate for 24 hours at 110°C and dividing the weight change by the oven dry weight 0.58 percent moisture content was discovered.

3.2.3.5 Unit weight

The unit weight of a given volume of graded aggregate is its weight. It is hence a density measurement that is also known as bulk density. But it might not be the greatest choice because this alternative phrase is similar to bulk specific gravity, which is a whole other figure.

The unit weight, which accounts for both the solid aggregate particles and the spaces between them, accurately calculates the volume that the graded aggregate will occupy in concrete. By simply filling a container with a known volume and weighing it, the unit weight can be determined.

The quantity of empty space and, hence, the unit weight will obviously vary depending on the degree of compaction. Since the aggregate's weight is reliant on its moisture content, a consistent moisture content is necessary. In this test, an oven-dried aggregate sample is used. The fine aggregate sample's unit weight was determined to be 1.487 g/cm3.

The above test results are summarized in Table 3.4 below and the detail data is presented in Appendix B:

Table 3. 4 Summary of test results for fine aggregate

No	Test Description		Test Result
1	Silt Content		2.56%
2	Moisture Content		0.58%
3	Unit wt.		1.487g/cm3
4	Absorption Cap.		0.2%
5	Specific	Bulk	2.52

	gravity	Bulk(SSD)	2.53
		Apparent	2.534
6	Fineness Modulus		2.96

3.3 Sample preparation for Mix

The primary goal of this study is to conduct an experiment to see if eggshell and soda lime glass may be used as cement substitutes. Before moving on to the final mix design, multiple trial pastes were made in a cup with varied mixing ratios of cement, eggshell, and soda-lime glass paste at different temperatures. From the trial mixes 1:1 and 1:1.5 ratios of eggshell to soda-lime glass has showed better results at room temperature (20°C). The trail mixes also showed that the mixed sample needs some time or heat in order to start the hydration process. Finally adding heat on the sample showed a better result for 1:1 and 1.5:1 ratio of eggshell to soda-lime glass mixes. Figure 3.5 shows the trial mixes that has been done at different ratio in cups.

Figure 3. 6 Trial mixes in a cup

For the final mortar samples twenty-three mixes were prepared in this study one is the control mix containing only cement, four mixes containing only soda-lime glass, four mixes containing only eggshell as a reference and the other fourteen mixes contain egg shell and waste soda lime glass with different proportion in mass of cement.

For each mix, three samples were prepared for compressive strength testing at 7, 28, and 56 days after curing at 20°C and 60°C. The 7 × 7 × 7 mortar cubes are used for all compressive strength tests.

Table 3. 5 Mortar samples made of different proportion of cement, eggshell and soda-lime glass at different curing temperature

Percentage of cement replacement	Days for test curing temperature and number of specimens used					
	7 day		28 day		56 day	
	20°c	60°c	20°c	60°c	20°c	60°c
0%	3	3	3	3	3	3
2.5%G, 7.5%ES	3	3	3	3	3	3
5%G, 5%ES	3	3	3	3	3	3
7.5%G, 2.5%ES	3	3	3	3	3	3
10%G	3	3	3	3	3	3
10%ES	3	3	3	3	3	3
5%G, 10%ES	3	3	3	3	3	3
7.5%G, 7.5%ES	3	3	3	3	3	3
10%G, 5%ES	3	3	3	3	3	3
15%G	3	3	3	3	3	3
15%ES	3	3	3	3	3	3
5%G, 15%ES	3	3	3	3	3	3
10%G, 10%ES	3	3	3	3	3	3
15%G, 5%ES	3	3	3	3	3	3
20%G	3	3	3	3	3	3
20%ES	3	3	3	3	3	3
5%G, 25%ES	3	3	3	3	3	3
10%G, 20%ES	3	3	3	3	3	3
15%G, 15%ES	3	3	3	3	3	3
20%G, 10%ES	3	3	3	3	3	3
25%G, 5%ES	3	3	3	3	3	3
30%G	3	3	3	3	3	3
30%ES	3	3	3	3	3	3

Figure 3. 7 shows the mixing, vibrating, moulding and demoulding of the specimen

Figure 3. 8 Curing place of the sample at 20°c and 60°c

3.4 Equipment and testing procedure

The laboratory work consists of fresh and hardened tests. The fresh sample was tested for flow test and the hardened sample was tested for compressive strength.

3.4.1 Fresh concrete test

- Flow test

The horizontal spread that a cement mortar undergoes as a result of many dynamic impacts is measured by the flow test. The flow table process (ASTM C 109) and the cone penetration procedure (ASTM C 780) are the two standard techniques that ASTM has created for determining the consistency of unhardened mortar. The flow table method is applied in this thesis.

Figure 3. 9 Flow test conducted for the given sample

3.4.2 Hardened concrete test

- Compressive strength test

Four hundred fourteen cubic specimens, three for each percentage of replacement, measuring $7cm \times 7cm \times 7cm$, were cast in order to perform a compressive strength test. The cubes were taken out of the mold after a day and kept in water (the curing phase) at 20°C and 60°C until the test time. Specimens were allowed to air dry for 10 to 15 minutes prior to testing.

The test for compressive strength, which was based on ASTM C109, was conducted after 7, 28, and 56 days of curing. Any mix's compressive strength was calculated by averaging the strengths of three cubes.

By dividing the greatest load, the cube specimen could support during the test by its cross-sectional area, the specimen's compressive strength, σ comp (in MPa), is determined.

Figure 3. 10 Machine and material setup for cubic compression test

4. TEST RESULTS AND DISCUSSION

4.1 Introduction

This section presents and analyzes laboratory test findings for eggshell powder and soda-lime glass powder mortar to determine whether they are suitable as cement substitutes. Investigations are also conducted into the workability and compressive strength of mortar that contains eggshell powder and soda-lime glass powder at various substitutions.

4.2 Test results and discussion on Experiment

This section presents and analyzes several test findings for the blended mortars. These include the OPC-ESP-SLGP blended mortar's workability based on flow table values in its fresh state and its compressive strength in its hardened condition.

4.2.1 Workability of mortar

The flow table test is used to determine the mortar's workability right before it is poured into the mold. These workability values for the blended and control mortars are shown in Table 4.1 below.

Table 4. 1 Flow table values of OPC-ESP-SLGP blended mortar

No	Percentage of cement replacement	Flow(mm)
1	0%	113.94
2	2.5% SLGP,7.5%ESP	136.88
3	5% SLGP,5%ESP	131.25
4	7.5% SLGP,2.5%ESP	130.83
5	10% SLGP	129.10
6	10%ESP	143.05
7	5% SLGP,10%ESP	146.67
8	7.5% SLGP,7.5%ESP	145.28
9	10% SLGP,5%ESP	140.92
10	15% SLGP	141.21
11	15%ESP	155.30
12	5% SLGP,15%ESP	146.22
13	10% SLGP,10%ESP	144.00

14	15% SLGP,5%ESP	139.20
15	20% SLGP	139.15
16	20%ESP	153.53
17	5% SLGP,25%ESP	141.05
18	10% SLGP,20%ESP	144.33
19	15% SLGP,15%ESP	145.35
20	20% SLGP,10%ESP	144.15
21	25% SLGP,5%ESP	143.67
22	30% SLGP	128.82
23	30%ESP	132.42

As can be seen above Table 4.1 shows an increase in flow value as the eggshell powder and soda-lime glass powder content increases. This can be attributed to the low specific surface area of ESP and SLGP that required less water to wet the surface as compared to the OPC in the control specimen.

4.2.2 Compressive strength of OPC-ESP-SLGP mortars

Here this research has evaluated and examined the compressive strength of mortar composed of Dangote OPC, ESP, and SLGP. Appendix G provides a full breakdown of the laboratory test results. In Table 4.2 and Table 4.3, the average outcomes for OPC-ESP-SLGP mortars cured at 20°C and 60°C are displayed, respectively:

Table 4. 2 Compressive strength of OPC-ESP-SLGP mortar curing at 20°c

S. No	% Replacement	Average compressive strength					
		7 days		28 days		56 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	0%	92.13	18.80	117.67	24.01	160.43	32.74
2	2.5%SLGP,7.5%ESP	96.16	19.62	116.63	23.80	141.32	28.84
3	5% SLGP,5%ESP	67.25	13.73	116.61	23.80	135.83	27.72
4	7.5% SLGP,2.5%ESP	102.21	20.86	119.34	24.35	149.57	30.53
5	10% SLGP	78.92	16.11	114.33	23.33	147.77	30.16
6	10%ESP	60.64	12.38	115.60	23.59	116.80	23.84
7	5% SLGP,10%ESP	52.31	10.67	96.30	19.65	107.46	21.93
8	7.5% SLGP,7.5%ESP	67.70	13.82	88.42	18.05	112.18	22.89
9	10% SLGP,5%ESP	68.08	13.89	95.43	19.47	114.27	23.32

10	15% SLGP	78.92	16.11	111.58	22.77	138.32	28.23
11	15%ESP	63.10	12.88	100.90	20.59	119.42	24.37
12	5% SLGP,15%ESP	33.83	6.90	94.17	19.22	104.38	21.30
13	10% SLGP,10%ESP	59.80	12.20	85.93	17.54	107.12	21.86
14	15% SLGP,5%ESP	62.12	12.68	83.65	17.07	101.18	20.65
15	20% SLGP	62.15	12.68	104.77	21.38	134.19	27.39
16	20%ESP	55.76	11.38	94.30	19.25	109.62	22.37
17	5% SLGP,25%ESP	50.24	10.25	78.30	15.98	99.20	20.24
18	10% SLGP,20%ESP	44.73	9.13	77.99	15.92	99.14	20.23
19	15% SLGP,15%ESP	49.12	10.02	79.38	16.20	96.98	19.79
20	20% SLGP,10%ESP	52.68	10.75	86.46	17.65	95.57	19.50
21	25% SLGP,5%ESP	54.19	11.06	103.49	21.12	106.35	21.70
22	30% SLGP	49.65	10.13	94.85	19.36	111.92	22.84
23	30%ESP	50.91	10.39	80.24	16.38	93.43	19.07

Table 4. 3 Compressive strength of OPC-ESP-SLGP mortar curing at 60°c

S. No	% Replacement	Average compressive strength					
		7 days		28 days		56 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	0%	117.01	23.88	135.88	27.73	222.63	45.43
2	2.5%SLGP,7.5%ESP	119.74	24.44	137.06	27.97	140.35	28.64
3	5% SLGP,5%ESP	120.06	24.50	139.19	28.41	142.39	29.06
4	7.5% SLGP,2.5%ESP	123.91	25.29	145.00	29.59	147.60	30.12
5	10% SLGP	109.46	22.34	163.20	33.31	173.26	35.36
6	10%ESP	119.68	24.42	129.27	26.38	124.40	25.39
7	5% SLGP,10%ESP	103.57	21.14	101.95	20.81	144.20	29.43
8	7.5% SLGP,7.5%ESP	94.28	19.24	103.20	21.06	118.25	24.13
9	10% SLGP,5%ESP	115.61	23.59	114.54	23.38	153.72	31.37
10	15% SLGP	121.74	24.84	122.38	24.98	166.34	33.95
11	15%ESP	82.35	16.81	114.09	23.28	124.30	25.37
12	5% SLGP,15%ESP	96.61	19.72	97.75	19.95	141.65	28.91
13	10% SLGP,10%ESP	88.92	18.15	106.08	21.65	119.89	24.47

14	15% SLGP,5%ESP	113.41	23.14	103.08	21.04	150.91	30.80
15	20% SLGP	115.42	23.56	153.35	31.30	161.57	32.97
16	20%ESP	70.07	14.30	104.76	21.38	121.01	24.70
17	5% SLGP,25%ESP	83.36	17.01	93.65	19.11	109.27	22.30
18	10% SLGP,20%ESP	91.18	18.61	86.48	17.65	106.80	21.80
19	15% SLGP,15%ESP	92.41	18.86	103.64	21.15	119.13	24.31
20	20% SLGP,10%ESP	61.26	12.50	102.51	20.92	124.25	25.36
21	25% SLGP,5%ESP	96.84	19.76	96.82	19.76	131.06	26.75
22	30% SLGP	102.18	20.85	113.05	23.07	115.11	23.49
23	30%ESP	76.99	15.71	81.21	16.57	99.62	20.33

As shown in the above tables, mortar specimens were prepared for OPC, OPC-ESP, OPC-SLGP and OPC-ESP-SLGP separately. This is done in order to investigate how each acts together and independently in the OPC cement.

Finally the result showed that the 2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP replacement with OPC have applicable compressive strength value relative to the control sample throughout the tests period i.e. 7, 28 and 56 days curing in 20°c. The result also shows 2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP replacement with OPC have applicable compressive strength value relative to the control sample throughout the tests period i.e. 7 and 28 days curing in 60°c. However the control still shows higher value at 56 days curing in 60°c. Table 4.3 also shows that the mortar with 10%, 15% and 20% SLGP has higher compressive strength at 28 days curing in 60°c or curing at 20°c for a long time than the control. And better result showed for 10%, 15% and 20% SLGP than other mixes, except the control at 56 days of curing in 60°c which tells us that soda-lime glass powder is highly pozzolanic material which gives higher strength in high temperature curing or after a long period of time.

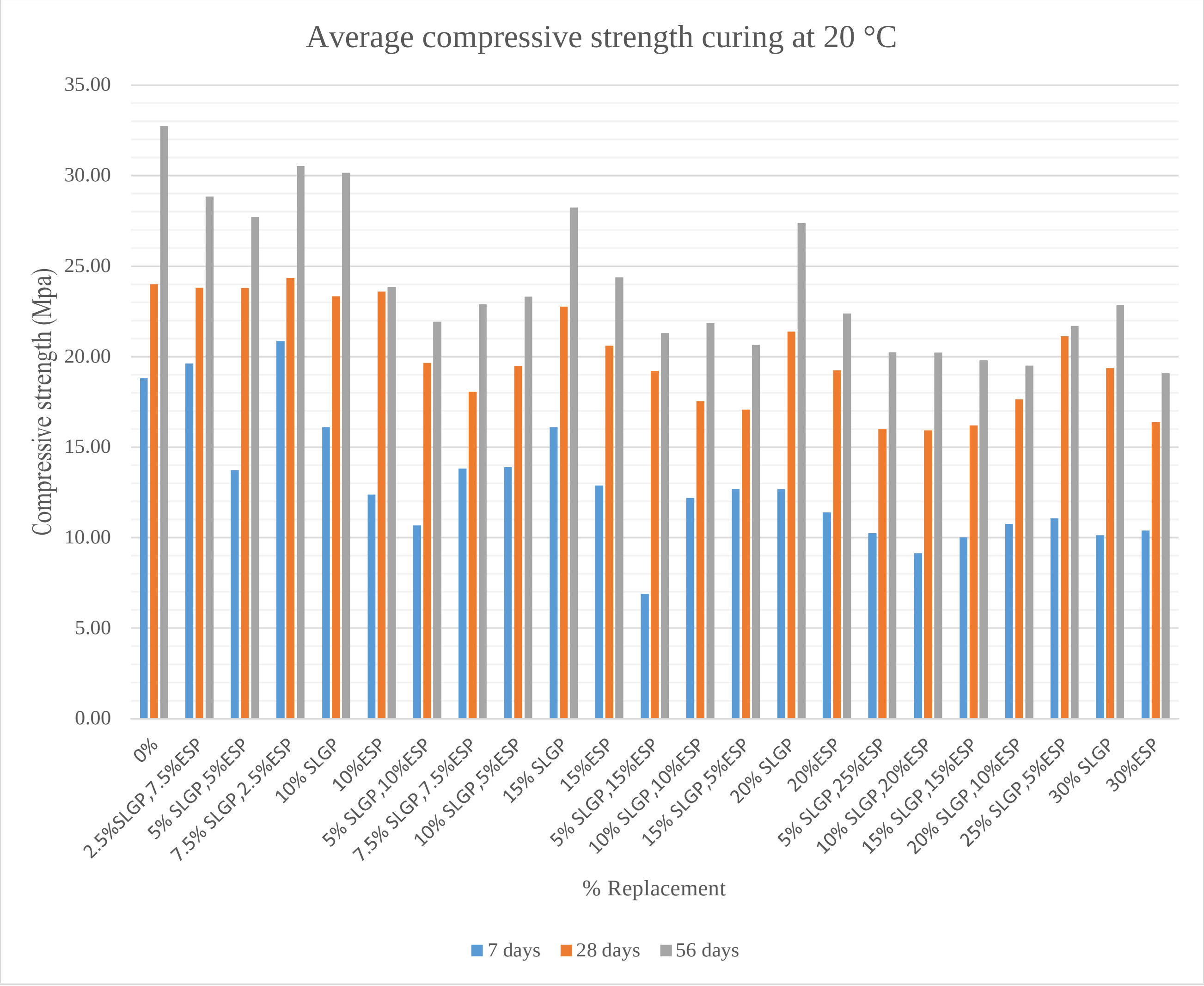

Figure 4. 1 7th day, 28th day and 56th day Compressive strength of OPC-ESP-SLGP mortar curing at 20°c

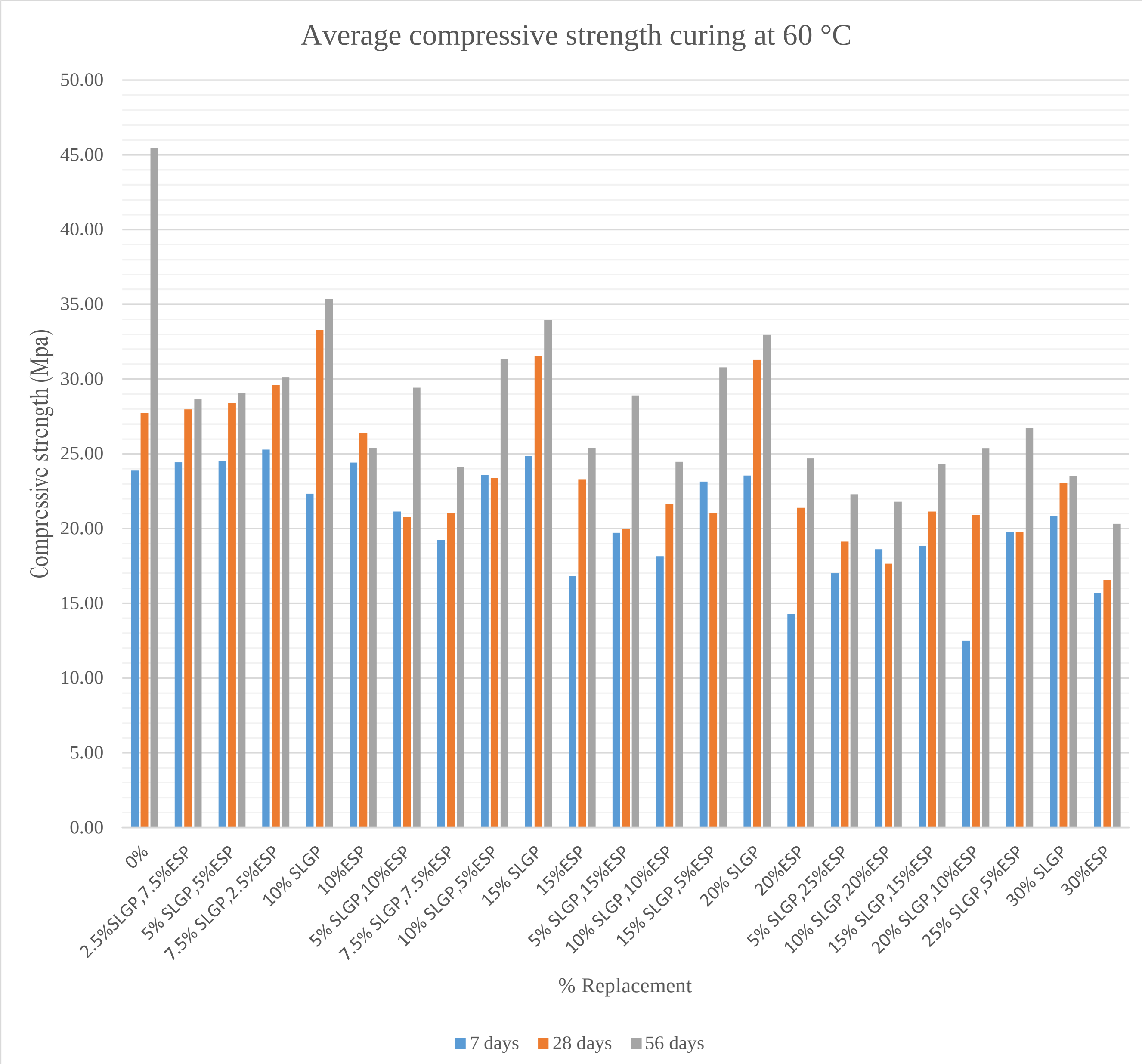

Figure 4. 2 7th day, 28th day and 56th day Compressive strength of OPC-ESP-SLGP mortar curing at 60°c

From Figures 4.1 and 4.2 and Tables 4.2 and 4.3 it is clear that the soda-lime glass is a pozolanic material which contains a higher amount of silica, i.e. it under goes a secondary chemical reaction by itself. The addition of Soda-lime glass (reach in silica) after a certain amount in this cement will not result in compressive strength improvement because there will be a high amount of unhydrated silica due to the competition for the $Ca(OH)_2$ released from the hydration of the cement particles. As a result of this, the compressive strength of the OPC-ESP-SLGP mortars has shown decrement after a certain percentage increment of SLGP, in most mixes after 7.5%SLGP if ESP is added to the mix and 20%SLGP if ESP is not added to the mix.

The result also showed that ESP slightly increase CH at early age but ESP has low impact on converting CH to C-S-H during hydration since it is lime. In conclusion addition of SLGP in this cement had resulted in a higher compressive strength while creating more C-S-H when curing for a long time or curing at a high temperature while ESP acted as filler.

5. ENVIRONMENTAL AND ECONOMICAL ANALYSIS

5.1 Introduction

In today's world, sustainability is a pressing issue, with its development largely focused on the legacy we leave for future generations. The primary areas of concern are our social, environmental, and economic activities.

Cement is a key component in concrete production. However, the manufacturing of cement is both environmentally and economically disadvantageous compared to other concrete components, highlighting sustainability challenges within the cement industry. Various methods have been devised to address these challenges, particularly in developed nations. One such method involves using alternative materials to replace cement, which have lower production costs, reduced CO2 emissions, and decreased energy usage, leading to a more sustainable and cost-effective material.

Due to the lack of the requisite data, a detailed cost breakdown and economic analysis of the cost benefits of employing eggshell and soda lime glass was not conducted. Further studies are needed on this matter.

5.2 Environmental advantages

As highlighted in the literature review, the cement industry emits approximately 0.6-0.7 tons of CO2 for every ton of Portland cement produced, even with modern clinker kiln technology. Additionally, concrete production requires a significant amount of natural resources. By substituting a portion of Portland cement with eggshell and soda-lime glass, the environmental impact of cement production can be significantly reduced. The most critical environmental considerations are the use of virgin materials and emissions.

5.2.1 Virgin material saving

The use of eggshell and soda-lime glass, which are waste and recycled materials, can significantly conserve virgin materials. This is because, in the inventory of materials used for cement production, only virgin materials are included in comparative calculations, not recovered materials like eggshell and soda-lime glass, as these already exist and would otherwise be discarded if not utilized productively. Table 5.1 presents the comparative calculation of virgin materials.

Various assumptions were made to determine the savings in virgin materials. These include:

- The mass of the raw materials used to make Portland cement is thought to be 1.6

times that of the final product [29].

- Assuming 5% wastage for the eggshell and soda-lime production, even though only transportation and grinding is involved,
- Eggshell and soda-lime glass is not included as a virgin material, because it is a recycled material.

Table 5. 1 Raw material input for one cubic meter of mortar

% Replacement	OPC (kg/m^3)	SLGP (kg/m^3)	ESP (kg/m^3)	Saving (%)
0%	657.8	0	0	0.00
2.5%SLGP,7.5%ESP	592	16.4	49.3	10
5% SLGP,5%ESP	592	32.9	32.9	10
7.5% SLGP,2.5%ESP	592	49.3	16.4	10
10% SLGP	592	65.8	0	10
10%ESP	592	0	65.8	10
5% SLGP,10%ESP	559.1	32.9	65.8	15
7.5% SLGP,7.5%ESP	559.1	49.3	49.3	15
10% SLGP,5%ESP	559.1	65.8	32.9	15
15% SLGP	559.1	98.7	0	15
15%ESP	559.1	0	98.7	15
5% SLGP,15%ESP	526.2	32.9	98.7	20
10% SLGP,10%ESP	526.2	65.8	65.8	20
15% SLGP,5%ESP	526.2	98.7	32.9	20
20% SLGP	526.2	131.6	0	20
20%ESP	526.2	0	131.6	20
5% SLGP,25%ESP	460.4	32.9	164.4	30
10% SLGP,20%ESP	460.4	65.8	131.6	30
15% SLGP,15%ESP	460.4	98.7	98.7	30
20% SLGP,10%ESP	460.4	131.6	65.8	30
25% SLGP,5%ESP	460.4	164.4	32.9	30
30% SLGP	460.4	197.3	0	30
30%ESP	460.4	0	197.3	30

As can be seen from Table 5.1, using eggshell and soda-lime glass as a cement replacement has resulted in saving of virgin materials. From the annual 4.4 billion tons of cement produced, the optimum 10% replacement saves about 440 million tons of virgin material, which is 110 million tons from eggshell powder and 330 million tons from soda-lime glass powder production.

5.2.2 CO_2 emission

When Portland cement is manufactured, many gases are released. When discussing environmental concerns, CO2 is the most significant gas and the most abundant gas. Beginning with the specific gross (e.g., kg of CO2 emitted per ton of cement produced), the CO2 emission can be estimated by multiplying entire cement production, which yields an absolute amount (e.g., kg of CO2 emitted). According to the IEA, 0.5–0.6 tons of CO2 are released for every ton of cement; however, cement companies' reports suggest that the actual amount is closer to 0.6–0.7 tons of CO2/t cement (the GNR average is 0.654 tons of CO2/t cement). The total CO2 emissions from the cement industry are 2.64 Gt, or almost 7% of global CO2 emissions, calculated by multiplying the average value (0.6) by the total cement production (4.4 Gt) [30].

Table 5.2 estimated the CO2 emission savings. Assuming that:

- One ton of ordinary Portland cement production releases 600 kg of CO2 when a modern clinker kiln technology is taken into consideration;
- Energy usage percentages being 0% (burning of eggshell and soda lime glass), 90.34% (burning of cement), 4.33% (milling), 0.67% (crushing), 0% (agitation), 3.9% (grinding), and 0.75% (bagging);

Table 5. 2 Approximate CO_2 emission for different ESP and SLGP replacements

% replacement	CO_2 (Kg)/ton of cement	Saving (Kg)	CO_2 (Gton/year)	Saving (Gton/year)
0%	600	0	2.64	0
2.5%SLGP,7.5%ESP	545.796	54.204	2.402	0.238
5% SLGP,5%ESP	545.796	54.204	2.402	0.238
7.5% SLGP,2.5%ESP	545.796	54.204	2.402	0.238
10% SLGP	545.796	54.204	2.402	0.238
10%ESP	545.796	54.204	2.402	0.238
5% SLGP,10%ESP	518.694	81.306	2.283	0.357

7.5% SLGP,7.5%ESP	518.694	81.306	2.283	0.357
10% SLGP,5%ESP	518.694	81.306	2.283	0.357
15% SLGP	518.694	81.306	2.283	0.357
15%ESP	518.694	81.306	2.283	0.357
5% SLGP,15%ESP	491.592	108.408	2.164	0.476
10% SLGP,10%ESP	491.592	108.408	2.164	0.476
15% SLGP,5%ESP	491.592	108.408	2.164	0.476
20% SLGP	491.592	108.408	2.164	0.476
20%ESP	491.592	108.408	2.164	0.476
5% SLGP,25%ESP	437.388	162.612	1.925	0.715
10% SLGP,20%ESP	437.388	162.612	1.925	0.715
15% SLGP,15%ESP	437.388	162.612	1.925	0.715
20% SLGP,10%ESP	437.388	162.612	1.925	0.715
25% SLGP,5%ESP	437.388	162.612	1.925	0.715
30% SLGP	437.388	162.612	1.925	0.715
30%ESP	437.388	180	1.925	0.715

As can be seen from the simple calculations performed, using eggshell and soda-lime glass powder saves a great deal of CO_2 emission to the environment, using the optimum 7.5% soda-lime glass and 2.5% eggshell powder saves about 264Mton/year of CO_2 when compared to using ordinary Portland cement.

5.3 Economical advantages

A detailed cost breakdown and economic analysis of the cost benefits of using eggshells and waste soda-lime glass were not conducted due to the variability and lack of necessary data from cement factories. However, the economic benefits of using eggshells and waste soda-lime glass as a cement substitute can be assessed qualitatively. Successfully reusing waste soda-lime glass and eggshells could significantly reduce mining and production energy costs directly and decrease solid waste disposal expenses indirectly.

Quantitatively, previous research indicates that cement production energy consumption is attributed to burning, milling, crushing, agitation, grinding, and bagging, with energy usage percentages being 93.68 and 90.34% (burning), 2.11 and 4.33% (milling), 0.43 and 0.67% (crushing), 1.39 and 0% (agitation), 2.12 and 3.9% (grinding), and 0.27 and 0.75% (bagging) for the wet and dry processes, respectively [28]. From this date utilizing eggshells and soda-lime glass as supplementary cementitious materials (SCM) will reduce the burning costs.

However using these waste materials increases cost of collecting and transporting the materials to the factory. As this has been placed as an idea, further studies are needed on this matter.

6. CONCLUSIONS AND RECOMMENDATIONS

The following is a summary of the conclusions and recommendations that may be made in light of the findings of this study and its experiments:

6.1 Conclusions

Following an investigation into the usage of eggshell and soda-lime glass as cement substitutes in the manufacturing of concrete, the following findings were reached:

1. According to the results of the chemical composition test, the eggshell can be categorized as a lime and the soda-lime glass as class N pozzolana, which is defined by ASTM C 618 as SiO_2+ Al_2O_3+ Fe_2O_3 being greater than 70%.
2. The workability of mortar and concrete containing eggshell and soda-lime glass increase slightly as the eggshell and soda-lime glass content increases which is due to the less water demand of eggshell and soda-lime glass.
3. The investigation has showed that replacement of OPC with 2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP replacement with OPC have applicable compressive strength value relative to the control sample throughout the tests period i.e. 7, 28 and 56 days curing in 20°c. The result also shows 2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP replacement with OPC have applicable compressive strength value relative to the control sample throughout the tests period i.e. 7 and 28 days curing in 60°c. However the control still shows higher value at 56 days curing in 60°c.
4. The investigation showed that the mortar with 10%, 15% and 20% SLGP has higher compressive strength at 28 days curing in 60°c or curing at 20°c for a long time than the control.
5. The investigation also showed that adding additional ESP on OPC and SLGP will slightly increase strength at early ages due it high production of CH during hydration, the strength is less at later ages of curing as compared to the samples that only contain OPC and SLGP.
6. Since eggshell and soda-lime glass are by-products, using them to replace cement lowers CO_2 emissions from the cement sector while also saving a significant amount of raw materials. Additionally, using it fixes the issues with landfill disposal.
7. Lastly, the findings of this study showed that eggshell and soda-lime glass might be used as an advantageous substitute for cement up to 10%. (2.5%SLGP + 7.5%ESP, 5% SLGP + 5%ESP, 7.5%SLGP + 2.5%ESP and 10% SLGP).

6.2 Recommendations

Based on the findings of this research, the following recommendations are forwarded:

1. This study examined some of the fundamental chemical and physical characteristics of soda-lime glass and eggshell as substitutes for cement. However, more research is needed on the following topics:
   - The effects of different fineness of eggshell and soda-lime glass should be studied as well.
   - Using more sophisticated techniques such X-ray diffraction (XRD) analysis, thermal analysis (TGA), and scanning electron microscopy (SEM), studies should be conducted to verify the pozzolanic interaction of eggshell and soda-lime glass.
2. Higher education organizations in the country should further study the durability of Eggshell and soda-lime glass as a cement replacing material.

3. Eggshell and soda-lime glass as investigated in this research work can be used as a cement replacing material with technical and environmental benefits. Therefore, concerned bodies should be made aware about this potential cement replacing material and promote its standardized production and usage.

REFERENCES

[1] V. C. Vijayvenkatesh, M. Vasanth, S. Thirunavukkarasu, and T. M. Prabu, "Experimental investigation of partial replacement of cement with glass powder and eggshell powder ash in concrete," Civil Engineering Journal, vol. 4, no. 8, pp. 1–6, 2018, ISSN 2575-8950.

[2] A. Khmiri, M. Chaabouni, and B. Samet, "Chemical behaviour of ground waste glass when used as partial cement replacement in mortars," Construction and Building Materials, vol. 44, pp. 74–80, 2013.

[3] G. Shakhmenko, A. Korjakins, and G. Bumanis, "Experiment on concrete with microfiller obtained from recycled lamp glass," 2015.

[4] N. Parthasarathi, M. Prakash, and K. S. Satyanarayanan, "Experimental study on partial replacement of cement with egg shell powder and silica fume," Rasayan Journal of Chemistry, vol. 10, no. 2, pp. 442–449, 2017.

[5] S. Sharma and O. Netula, "Experimental investigation of partial replacement of OPC (43 grade) cement by egg shell powder for M-35 concrete grade," Proc. Int. Conf. Recent Research and Innovations in Social Science, Humanities (ICRRISH-2018), 2018.

[6] A. A. Jhatial, W. I. Goh, K. H. Mo, S. Sohu, and I. A. Bhatti, "Green and sustainable concrete – the potential utilization of rice husk ash and egg shells," Civil Engineering Journal, vol. 5, no. 1, Jan. 2019.

[7] S. Sehgal and A. Kaur, "The effect of egg shell powder and silica fumes on properties of concrete," International Journal of Advanced Research in Science, Engineering and Technology, ISSN 2350-0328, 2018.

[8] K. Basit, N. K. Sharma, and B. Kishor, "Fractional substitute of cement with egg shell particles, India," International Journal of Innovative Technology and Exploring Engineering (IJITEE), ISSN 2278-3075, 2019.

[9] N. A. A. Al-Jburi, J. K. Hasan, N. Azline, and N. Ostovar, "Waste glass as partial replacement in cement – a review," IOP Conference Series: Earth and Environmental Science, vol. 357, p. 012023, 2019.

[10] A. A. Jhatial, W. I. Goh, N. Mohamad, K. H. Mo, and S. Sohu, "Incorporation of palm

oil fuel ash and egg shell powder as supplementary cementitious materials in sustainable foamed concrete," Technical Gazette, ISSN 1330-3651 (Print), ISSN 1848-6339 (Online), 2020.

[11] A. S. Agboola, N. Usman, M. A. Idi, and G. Ushie, "Suitability of waste glass powder as partial cement replacement in concrete subject to chemical aggressive environment," International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), ISSN 2278-2540, 2020.

[12] L. Rodger, "Climate change: The massive CO_2 emitter you may not know about," BBC News, Dec. 17, 2018. [Online]. Available: https://www.bbc.com/news/science-environment-46455844

[13] R. Olson, "Sight and life study: Ethiopia egg value chain analysis," AgriLinks – Achieving Agriculture-led Food Security through Knowledge Sharing, 2020. [Online]. Available: https://agrilinks.org

[14] ACI Committee 211, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91), American Concrete Institute, 2002.

[15] ASTM International, Standard Specification for Concrete Aggregates (ASTM C33), West Conshohocken, PA, USA, 2010.

[16] A. Dinku, Construction Materials Laboratory Manual, Addis Ababa: Addis Ababa Printing Press, June 2002.

[17] Anonymous, "Poultry egg postharvest technology," Agritech – Tamil Nadu Agricultural University, 2015. [Online]. Available: http://agritech.tnau.ac.in/postharvest/pht_anifoods_poul_egg.html

[18] A. Goyal, A. A. M. Anwar, K. Hattori, and H. Ogata, "Properties of sugarcane bagasse ash and its potential as cement-pozzolana binder," Ain Shams University, Dec. 2007.

[19] Wondimu, H. Yohannes, et al., "Experimental investigation of waste glass powder as partial replacement of cement in concrete production," B.Sc. thesis, Addis Ababa Institute of Technology (AAiT), 2015.

[20] V. M. Malhotra and P. K. Mehta, Pozzolanic and Cementitious Materials, in Advances in Concrete Technology, New York, NY, USA: Gordon and Breach Publishers, 1996.

[21] J. Maso, Interfacial Transition Zone in Concrete, J. Maso, Ed. New York, NY, USA: E

& FN Spon, an imprint of Chapman & Hall, 1996.

[22] R. Nigatu, D. S. Rajan, and B. B. Seboka, “Challenges and opportunities in municipal solid waste management: The case of Addis Ababa City, Central Ethiopia,” Institute of Environment, Gender and Development, Hawassa University, 2011.

[23] H. G. Oss, Background Facts and Issues Concerning Cement and Cement Data, U.S. Geological Survey, U.S. Department of the Interior, U.S. Science of Changing World, 2005. [Online]. Available: http://www.usgs.gov/pubprod

[24] R. J. Detwiler and J. I. Bhatty, Supplementary Cementing Materials for Use in Blended Cements, Research and Development Bulletin RD112T, Portland Cement Association, Illinois, USA, 1996.

[25] W. J. Stadelman, D. Newkirk, and L. Newby, Egg Science and Technology, 4th ed. Boca Raton, FL, USA: CRC Press, 2017. [Online]. Available: https://www.perlego.com/book/1499649/egg-science-and-technology-pdf

[26] M. S. Eusebio, “Did our church builders use egg whites as mortar ingredients?: The biomolecular reason behind collecting mortars from historical sites,” Proceedings of the Society of Philippine Archaeologists, vol. 7, 2009.

[27] M. Waheed, M. Yousaf, A. Shehzad, M. Inam-Ur-Raheem, and R. M. Aadil, “Channeling eggshell waste to valuable and utilizable products: A comprehensive review,” Trends in Food Science and Technology, vol. 106, pp. 78–90, Dec. 2020.

[28] O. S. Ohunakin, O. R. Leramo, O. A. Abidakun, M. K. Odunfa, and O. B. Bafuwa, “Energy and cost analysis of cement production using wet and dry processes in Nigeria,” Energy and Power Engineering, vol. 5, no. 9, 2013.

[29] J. R. Prusinski, M. L. Marceau, and M. G. VanGeem, Life Cycle Inventory of Slag Cement, Portland Cement Association, Skokie, IL, USA, 2006.

[30] International Energy Agency (IEA), Energy Technology Perspectives 2020, 2020. [Online]. Available: https://www.iea.org/reports/energy-technology-perspectives-2020

[31] M. Garside, “Global cement production 1995–2021,” Apr. 1, 2022. [Online]. Available: https://www.statista.com/statistics/1087115/global-cement-production-volume/

[32] F. Bekele, “Municipal solid waste management in Ethiopia: The gaps and ways for

improvement," Journal of Material Recycles and Waste Management, vol. 23, pp. 18–31, 2021.

[33] ASTM International, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory (ASTM C192/C192M–02), West Conshohocken, PA, USA, 2002.

[34] ASTM International, Standard Test Method for Slump of Hydraulic-Cement Concrete (ASTM C143/C143M), West Conshohocken, PA, USA, 2000.

[35] ASTM International, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39/C39M–03), West Conshohocken, PA, USA, 2003.

[36] ASTM International, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496), West Conshohocken, PA, USA, 1996.

[37] ASTM International, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (ASTM C78–94), Philadelphia, PA, USA: American Society for Testing and Materials, 2000.

[38] ASTM International, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens) (ASTM C109/C109M–02), West Conshohocken, PA, USA.

[39] A. G. Sime, "Review on poultry production, processing, and utilization in Ethiopia," Agricultural Science and Food Technology, vol. 8, no. 2, pp. 147–152, 2022.

[40] S. Kaza, L. C. Yao, P. Bhada-Tata, and F. Van Woerden, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, Washington, DC, USA: World Bank, 2018.

[41] F. Massazza and U. Costa, "Aspects of the pozzolanic activity and properties of pozzolanic cement," Informal Seminar on Cement Chemistry, 1979.

[42] N. Yesuf, "The effect of egg and lime on the compressive strength of mortar," M.Sc. thesis, Addis Ababa Institute of Technology (AAiT), 2014.

[43] P. Hewlett and M. Liska, Eds., Lea's Chemistry of Cement and Concrete, 5th ed. Oxford, UK: Butterworth-Heinemann, 2019.

[44] H. F. Taylor, Cement Chemistry, vol. 2. London, UK: Thomas Telford, 1997.

APPENDIX

Appendix A- Tests for Cement

Item No.	Description		Test result
1	Fineness of cement (cm^2/gm)		2910
2	Specific gravity (gm/cm^3)		3.13
3	Cement consistency test	Water to cement ratio (%)	27
		Water (gm)	135
		Penetration (mm)	10
4	Setting time	Initial setting time (min)	75
		Final setting time (min)	255

Appendix B- Tests for Fine Aggregate

B-1: Sieve analysis results of fine aggregate

Sieve size	Percentage passing Limits	Percentage passing of original sand	Mass retained (gm)	Cumulative Mass retained (gm)	Cumulative % Retained
9.50mm	100	100	0	0	0
4.75mm	95-100	99.8	1	1	0.2
2.36mm	80-100	93.08	33.6	34.6	6.92
1.18mm	50-85	75.48	88	122.6	24.52
600µm	25-60	29.08	232	354.6	70.92
300µm	10-30	5.12	119.8	474.4	94.88
150µm	2-10	1.3	19.1	493.5	98.7
pan			6.5	500	Sum=296.14

FM (Fineness modulus) $= \mathcal{E} cummulative\ caorser(\%)\ /100$

$$\text{Fineness modulus} = \frac{296.14}{100} = 2.96$$

B-2: Moisture content of the fine aggregate

Weight of original sample= 500g

Weight of original Sample+ weight of container = 537g

Weight of container= 37g

Weight of oven-dry sample = 497.1g

Moisture content

$$=\frac{original\ sample\ weight - weight\ of\ oven\ dry\ sample}{weight\ of\ oven\ dry\ weight} * 100\%$$

$$\text{Moisture content} = \frac{500-497.1}{497.1} * 100$$

Moisture content = 0.58%

B-3: Unit weight of fine aggregate

Weight of measure + content = 15.395Kg

Weight of measure = 4.66 Kg

Net weight of aggregate = (weight of measure + content) – weight of measure

$$= 15.395 - 4.66 = 10.735Kg$$

Volume of measure= $\frac{\pi d^2}{4} * h$

d=0.205m and h=0.217m

Volume of measure = $\pi * \frac{0.205^2}{4} * 0.217 = 0.0072m^3$

Unit weight of fine aggregate = $\frac{net\ weight\ of\ aggregate}{volume\ of\ measure} = \frac{10.735Kg}{0.0072m^3} = 1490.97\ Kg/m^3$

B-4: Specific gravity and absorption capacity for fine aggregate

Weight of original sample = 500g

Weight of water + weight of pycnometer = 706.6g

Weight of sample + water + pycnometer = 1008.7g

Weight of oven dry sample = 499g

Bulk specific gravity = $\frac{499}{706.6+500-1008.7}$ =2.52g/cm^3

Bulk specific gravity (SSD basis) = $\frac{500}{706.6+500-1008.7}$ =2.53g/cm^3

Apparent specific gravity = $\frac{499}{706.6+499-1008.7}$ =2.534g/cm^3

Absorption capacity = $\frac{500-499}{499}$ * 100 =0.2%

B-5: Silt content of the fine aggregate

Silt content (%) $= \frac{amount\ of\ slit\ content}{clean\ sand} * 100$

Silt content (%) = $\frac{7.5mm}{292.5mm}$ * 100 =2.56%

Appendix D- Tests for Eggshell powder

Item No.	Description	Test result
1	Fineness of Eggshell powder (cm^2/gm)	4770.15
2	Specific gravity(gm/cm^3)	2.37

D-1 Fineness of Eggshell powder

Fineness is measured as a specific surface.

$$S = (Ss * \sqrt{T})/\sqrt{T}s$$

Where, S- Sample's specific surface area (m2/Kg)

Ss: The sample's specific surface area (m2/kg) utilized for the calibration apparatus

Ts: The measurement of the manometer drop time in seconds for the calibration apparatus's standard sample.

T- Measured time interval in second of manometer drop for test sample

By employing Baline's air permeability device, the following time intervals are obtained.

T_1=97.96 sec

$T_{2=}$ 95.5 sec

T_3= 95.9 sec

$$Tavg = \frac{T1+T2+T3}{3} = \frac{97.96+95.5+95.9}{3} = 96.45 \text{ sec}$$

$$\square = \frac{* \sqrt{\quad}}{\sqrt{\quad}} = \frac{* \sqrt{\quad .}}{\sqrt{\quad}} = 4770.15 cm^2/g$$

D-2 Specific gravity of eggshell powder

$$\rho = \frac{\text{□□□□ □□ □□□□□□ □□ □□□□ □□□ □□□□□□ □} \quad (\;)}{\text{□□□□□□□□□ □□□□□□ □□3} \quad (\quad)}$$

Using Le Chatelier's Flask and either kerosene or naphtha, a laboratory test is conducted to determine the displaced volume. These outcomes were attained.

Trial No.	Displaced volume (cm^3)
1	19.3
2	19.1
3	19.2

Mass of sample (eggshell powder) = 45.5g

$$\rho 1 = \frac{45.5 \ \text{□}(\;)}{19.3 \ \text{□}(\text{□}3 \;)} = 2.36\text{□}/cm3$$

$$\rho 1 = \frac{45.5 \ \text{□}(\;)}{19.1 \ \text{□}(\text{□}3 \;)} = 2.38\text{□}/cm3$$

$$\rho 1 = \frac{45.5 \ \text{□}(\;)}{19.2 \ \text{□}(\text{□}3 \;)} = 2.37\text{□}/cm3$$

1 $$\frac{(\rho \;\; + \rho 2 + \rho 3)}{3} = \frac{(2.36 + 2.38 + 2.37)}{3} = 2.37\text{□}/cm3$$

Appendix E-Tests for Waste Soda-lime glass Powder

Item No.	Description	Test result
1	Fineness of waste soda-lime glass powder (cm^2/gm)	1303.58
2	Specific gravity(gm/cm^3)	2.52

E-1 Fineness of soda-lime glass powder

By employing Baline's air permeability device, the following time intervals are obtained.

T_1= 7.66 sec

T_{2}= 7.15 sec

T_3= 6.8 sec

$$Tavg = \frac{T1+T2+T3}{3} = \frac{7.66+7.15+6.8}{3} = 7.203 \text{ sec}$$

$$= \frac{* \sqrt{\ }}{\sqrt{\ }} = \frac{* \sqrt{\ .\ }}{\sqrt{\ }} = 1303.58 cm^2/g$$

E-2 Specific gravity of waste soda-lime glass powder

Using Le Chatelier's Flask and either kerosene or naphtha, a laboratory test is conducted to determine the displaced volume. These outcomes were attained.

$$\rho = \frac{(\ )}{3\ (\ )}$$

Trial No.	Displaced volume (cm^3)
1	17.3
2	17.3
3	17.2

Mass of sample (soda-lime glass powder) = 43.6g

$$\rho 1 = \frac{43.6\ (\ )}{17.3\ (3\ )} = 2.52 /cm3$$

$$\rho 1 = \frac{43.6\ (\ )}{17.3\ (3\ )} = 2.52 /cm3$$

$$\rho 1 = \frac{43.6\ (\ )}{17.2\ (3\ )} = 2.53 /cm3$$

$$\rho = \frac{(\rho 1 + \rho 2 + \rho 3)}{3} = \frac{(2.52 + 2.52 + 2.53)}{3} = 2.52 /cm3$$

Chemical properties of Eggshell powder and soda-lime glass powder

	GEOLOGICAL SURVEY OF ETHIOPIA	**Doc.Number: GLD/F5.10.2**	**Version No: 1**
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of **1**
Document Title:	**Complete Silicate Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: -02/06/2021

Customer Name:-Faiza Yasin Ahmed

Request No:- GLD/RQ/898/21

Report No:- GLD/RN/495/21

Sample type :-Egg Shell& Glass

Sample Preparation: - 200 Mesh

Date Submitted :-13/04/2021

Number of Sample:- Two (02)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	SO3	Cl-1
Eggs	2.66	0.56	0.70	52.20	0.58	0.36	<0.01	0.10	0.35	<0.01	0.89	41.60	<0.01	<0.01
Glass	66.60	7.77	0.66	8.96	2.28	10.72	<0.01	0.10	0.27	0.04	0.14	0.90	0.95	<0.01

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

Analysts	Checked By	Approved By	Quality Control
Lidet Endeshaw			
Yirgalem Abreham	Tizita Zemene	Yohannes Getachew	Gosa Haile
Nigist Fikadu			

Appendix F: Mix Design for Mortar according to ASTM C-109

By weight, the standard mortar's ingredient ratios must be one part cement to 2.75 parts graded standard sand. All Portland cements should have a water-to-cement ratio of 0.485.

% Replacement	Composition of mortar					
	Cement (g)	Soda-lime glass (g)	Egg shell (g)	Sand (g)	Water (g)	w/c or w/scm
0%	740	0	0	2035	359	0.485
2.5%SLGP,7.5%ESP	666	18.5	55.5	2035	359	0.485
5% SLGP,5%ESP	666	37	37	2035	359	0.485
7.5% SLGP,2.5%ESP	666	55.5	18.5	2035	359	0.485
10% SLGP	666	74	0	2035	359	0.485
10%ESP	666	0	74	2035	359	0.485
5% SLGP,10%ESP	629	37	74	2035	359	0.485
7.5% SLGP,7.5%ESP	629	55.5	55.5	2035	359	0.485
10% SLGP,5%ESP	629	74	37	2035	359	0.485
15% SLGP	629	111	0	2035	359	0.485
15%ESP	629	0	111	2035	359	0.485
5% SLGP,15%ESP	592	37	111	2035	359	0.485
10% SLGP,10%ESP	592	74	74	2035	359	0.485
15% SLGP,5%ESP	592	111	37	2035	359	0.485
20% SLGP	592	148	0	2035	359	0.485
20%ESP	592	0	148	2035	359	0.485
5% SLGP,25%ESP	518	37	185	2035	359	0.485
10% SLGP,20%ESP	518	74	148	2035	359	0.485
15% SLGP,15%ESP	518	111	111	2035	359	0.485
20% SLGP,10%ESP	518	148	74	2035	359	0.485
25% SLGP,5%ESP	518	185	37	2035	359	0.485
30% SLGP	518	222	0	2035	359	0.485
30%ESP	518	0	222	2035	359	0.485

Appendix G: Test Results for Weight, Load and Compressive Strength of Mortar
Weight and Load of 7th day Mortar, curing at 20°c

% Replacement	Weight for sample 1 (g)	Weight for sample 2 (g)	Weight for sample 3 (g)	Load for sample 1 (KN)	Load for sample 2 (KN)	Load for sample 3 (KN)	Avg Load (KN)
0%	759.4	761.8	750.8	91.65	94.43	90.32	92.13
2.5%SLGP,7.5%ESP	736.1	737.9	737.1	94.51	97.14	96.82	96.16
5% SLGP,5%ESP	736.5	736.3	742.5	65.11	66.45	70.21	67.26
7.5% SLGP,2.5%ESP	739.4	742.6	740.2	94.39	104.66	99.77	99.61
10% SLGP	744.5	742.9	750.7	78.36	79.22	79.18	78.92
10%ESP	740	727.3	728.2	67.86	59.15	62.14	63.05
5% SLGP,10%ESP	713.4	719.3	718.1	51.00	53.78	52.14	52.31
7.5% SLGP,7.5%ESP	722.8	721.9	724.3	66.60	66.29	70.21	67.70
10% SLGP,5%ESP	734.3	730.1	727.5	69.74	67.42	67.07	68.08
15% SLGP	744.6	743.4	739.9	79.22	79.18	78.36	78.92
15%ESP	727.3	723.5	720.4	64.06	62.76	62.49	63.10
5% SLGP,15%ESP	712.4	717	716.3	50.69	50.80		33.83
10% SLGP,10%ESP	722.3	715.9	720.5	59.62	55.58	60.80	58.67
15% SLGP,5%ESP	734.3	730.1	727.5	63.46	64.02	58.88	62.12
20% SLGP	744.3	740	739.3	64.84	61.78	59.82	62.14
20%ESP	726.3	720.5	716.4	59.98	56.76	54.76	57.17
5% SLGP,25%ESP	711.9	713.6	718.7	50.77	49.16	50.80	50.24
10% SLGP,20%ESP	710.3	717.8	708.8	44.96	48.84	44.50	46.10
15% SLGP,15%ESP	708.9	710.3	709.3	49.36	48.88	53.86	50.70
20% SLGP,10%ESP	714.6	708.8	710.3	53.86	50.34	53.86	52.69
25% SLGP,5%ESP	723.8	734.5	728.3	49.31	56.06	52.34	52.57
30% SLGP	728.5	731.9	738	49.66	49.62	56.02	51.77
30%ESP	709.7	712.2	713.9	51.55	50.69	50.49	50.91

Compressive Strength of 7th day Mortar, curing at 20°c

% Replacement	compressive strength for sample 1 (MPa)	compressive strength for sample 2 (MPa)	compressive strength for sample 3 (MPa)	Avg compressive strength (MPa)
0%	18.70	19.27	18.43	18.80
2.5%SLGP,7.5%ESP	19.29	19.82	19.76	19.62
5% SLGP,5%ESP	13.29	13.56	14.33	13.73
7.5% SLGP,2.5%ESP	19.26	21.36	20.36	20.33
10% SLGP	15.99	16.17	16.16	16.11
10%ESP	13.85	12.07	12.68	12.87
5% SLGP,10%ESP	10.41	10.98	10.64	10.67
7.5% SLGP,7.5%ESP	13.59	13.53	14.33	13.82
10% SLGP,5%ESP	14.23	13.76	13.69	13.89
15% SLGP	16.17	16.16	15.99	16.11
15%ESP	13.07	12.81	12.75	12.88
5% SLGP,15%ESP	10.34	10.37		6.90
10% SLGP,10%ESP	12.00	11.34	12.41	11.92
15% SLGP,5%ESP	12.95	13.06	12.02	12.68
20% SLGP	13.23	12.61	12.21	12.68
20%ESP	12.24	11.58	11.18	11.67
5% SLGP,25%ESP	10.36	10.03	10.37	10.25
10% SLGP,20%ESP	9.18	9.97	9.08	9.41
15% SLGP,15%ESP	10.07	9.98	10.99	10.35
20% SLGP,10%ESP	10.99	10.27	10.99	10.75
25% SLGP,5%ESP	10.06	11.44	10.68	10.73
30% SLGP	10.14	10.13	11.43	10.57
30%ESP	10.52	10.34	10.30	10.39

Note: the one in red colors are faulty samples

Faulty samples check for Compressive Strength of 7th day Mortar, curing at 20°c

Factor for 3 samples	(0.087* avg)	min	max	Max expected	Avg compressive strength (MPa)	Factor for 2 samples	(0.076* Avg)	Max expected of the two samples	Final Avg compressive strength (MPa)
0.087	1.64	18.43	19.27	20.07					18.80
0.087	1.71	19.29	19.82	21.00					19.62
0.087	1.19	13.29	14.33	14.48					13.73
0.087	1.77	19.26	21.36	21.03	20.86	0.076	1.59	21.95	20.86
0.087	1.40	15.99	16.17	17.39					16.11
0.087	1.12	12.07	13.85	13.19	12.38	0.076	0.94	13.01	12.38
0.087	0.93	10.41	10.98	11.34					10.67
0.087	1.20	13.53	14.33	14.73					13.82
0.087	1.21	13.69	14.23	14.90					13.89
0.087	1.40	15.99	16.17	17.39					16.11
0.087	1.12	12.75	13.07	13.87					12.88
0.087	0.60	10.34	10.37	10.94					6.90
0.087	1.04	11.34	12.41	12.38	12.20	0.076	0.93	12.93	12.20
0.087	1.10	12.02	13.06	13.12					12.68
0.087	1.10	12.21	13.23	13.31					12.68
0.087	1.02	11.18	12.24	12.19	11.38	0.076	0.86	12.04	11.38
0.087	0.89	10.03	10.37	10.92					10.25
0.087	0.82	9.08	9.97	9.90	9.13	0.076	0.69	9.77	9.13
0.087	0.90	9.98	10.99	10.88	10.02	0.076	0.76	10.74	10.02
0.087	0.94	10.27	10.99	11.21					10.75
0.087	0.93	10.06	11.44	11.00	11.06	0.076	0.84	11.52	11.06
0.087	0.92	10.13	11.43	11.05	10.13	0.076	0.77	10.90	10.13
0.087	0.90	10.30	10.52	11.21					10.39

Weight and Load of 28th day Mortar, curing at 20°c

% Replacement	Weight for sample 1 (g)	Weight for sample 2 (g)	Weight for sample 3 (g)	Load for sample 1 (KN)	Load for sample 2 (KN)	Load for sample 3 (KN)	Avg Load (KN)
0%	763	754.9	752.7	117.12	118.40	117.52	117.68
2.5%SLGP,7.5%ESP	732.9	731.4	736.3	117.37	114.86	114.86	115.69
5% SLGP,5%ESP	733.8	739.2	737.2	117.84	117.36	114.64	116.61
7.5% SLGP,2.5%ESP	740	745.8	750.1	121.83	118.19	118.19	119.41
10% SLGP	754.7	756.9	758.9	112.00	127.44	116.64	118.69
10%ESP	741.9	729.6	730.3	119.04	112.16	104.16	111.79
5% SLGP,10%ESP	724.9	730.5	726.6	93.92	97.42	97.60	96.31
7.5% SLGP,7.5%ESP	729.5	728.5	729.3	86.90	90.04	86.88	87.94
10% SLGP,5%ESP	734.5	734.6	734.8	96.63	95.02	82.88	91.51
15% SLGP	750.5	749.9	755.5	113.45	112.66	104.32	110.14
15%ESP	725.7	725.4	725.6	101.02	101.14	95.20	99.12
5% SLGP,15%ESP	722.9	727.5	724.6	91.04	93.92	97.60	94.19
10% SLGP,10%ESP	724.5	727.5	729.3	84.80	86.08	86.88	85.92
15% SLGP,5%ESP	733.8	729.9	732.6	96.24	84.40	82.88	87.84
20% SLGP	749	746.7	754.7	109.12	100.88	104.32	104.77
20%ESP	724.7	724.4	724.6	94.00	93.68	95.20	94.29
5% SLGP,25%ESP	722.4	724.5	722.9	78.40	76.48	80.08	78.32
10% SLGP,20%ESP	702.5	706.2	705.1	76.32	78.80	78.88	78.00
15% SLGP,15%ESP	711.7	708.4	709.3	78.56	78.48	81.04	79.36
20% SLGP,10%ESP	715.3	716.8	713.5	88.08	85.60	85.76	86.48
25% SLGP,5%ESP	736.5	725	726.4	104.96	93.28	102.00	100.08
30% SLGP	739.9	738.7	736.7	94.88	95.44	94.24	94.85
30%ESP	718.6	718	718.5	79.12	86.64	81.36	82.37

Compressive Strength of 28th day Mortar, curing at 20°c

% Replacement	compressive strength for sample 1 (MPa)	compressive strength for sample 2 (MPa)	compressive strength for sample 3 (MPa)	Avg compressive strength (MPa)
0%	23.90	24.16	23.98	24.01
2.5%SLGP,7.5%ESP	23.95	23.44	24.02	23.80
5% SLGP,5%ESP	24.06	23.94	23.39	23.80
7.5% SLGP,2.5%ESP	24.86	24.12	24.08	24.35
10% SLGP	22.86	26.02	23.80	24.23
10%ESP	24.29	22.90	21.26	22.81
5% SLGP,10%ESP	19.17	19.88	19.91	19.65
7.5% SLGP,7.5%ESP	17.74	18.38	18.02	18.05
10% SLGP,5%ESP	19.72	19.39	19.31	19.47
15% SLGP	23.15	22.99	22.17	22.77
15%ESP	20.62	20.64	20.52	20.59
5% SLGP,15%ESP	18.58	19.16	19.91	19.22
10% SLGP,10%ESP	17.31	17.57	17.73	17.54
15% SLGP,5%ESP	19.64	17.23	16.91	17.93
20% SLGP	22.26	20.59	21.29	21.38
20%ESP	19.18	19.12	19.43	19.25
5% SLGP,25%ESP	15.99	15.61	16.34	15.98
10% SLGP,20%ESP	15.58	16.08	16.10	15.92
15% SLGP,15%ESP	16.03	16.02	16.54	16.20
20% SLGP,10%ESP	17.97	17.46	17.50	17.65
25% SLGP,5%ESP	21.42	19.03	20.82	20.42
30% SLGP	19.36	19.47	19.24	19.36
30%ESP	16.15	17.69	16.60	16.81

Note: the one in red colors are faulty samples

Faulty samples check for Compressive Strength of 28th day Mortar, curing at 20°c

Factor for 3 samples	(0.087* avg)	min	max	Max expected	Avg compressive strength (MPa)	Factor for 2 samples	(0.076* Avg)	Max expected of the two samples	Final Avg compressive strength (MPa)
0.087	2.09	23.90	24.16	25.99					24.01
0.087	2.07	23.44	24.02	25.51					23.80
0.087	2.07	23.39	24.06	25.46					23.80
0.087	2.12	24.08	24.86	26.20					24.35
0.087	2.11	22.86	26.02	24.97	23.33	0.076	1.77	24.64	23.33
0.087	1.98	21.26	24.29	23.24	23.59	0.076	1.79	24.69	23.59
0.087	1.71	19.17	19.91	20.88					19.65
0.087	1.57	17.74	18.38	19.31					18.05
0.087	1.69	19.31	19.72	21.01					19.47
0.087	1.98	22.17	23.15	24.15					22.77
0.087	1.79	20.52	20.64	22.31					20.59
0.087	1.67	18.58	19.91	20.26					19.22
0.087	1.53	17.31	17.73	18.84					17.54
0.087	1.56	16.91	19.64	18.47	17.07	0.076	1.30	18.21	17.07
0.087	1.86	20.59	22.26	22.45					21.38
0.087	1.67	19.12	19.43	20.79					19.25
0.087	1.39	15.61	16.34	17.00					15.98
0.087	1.38	15.58	16.10	16.96					15.92
0.087	1.41	16.02	16.54	17.43					16.20
0.087	1.54	17.46	17.97	19.00					17.65
0.087	1.78	19.03	21.42	20.81	21.12	0.076	1.61	22.43	21.12
0.087	1.68	19.24	19.47	20.92					19.36
0.087	1.46	16.15	17.69	17.61	16.38	0.076	1.24	17.40	16.38

Weight and Load of 56th day Mortar, curing at 20°c

% Replacement	Weight for sample 1 (g)	Weight for sample 2 (g)	Weight for sample 3 (g)	Load for sample 1 (KN)	Load for sample 2 (KN)	Load for sample 3 (KN)	Avg Load (KN)
0%	757.7	764.2	759.3	153.28	161.60	166.48	160.45
2.5%SLGP,7.5%ESP	749.7	752.9	754	137.68	134.00	153.92	141.87
5% SLGP,5%ESP	747.2	744	755.7	137.68	134.00	153.92	141.87
7.5% SLGP,2.5%ESP	752.4	754	756.8	137.68	134.00	153.92	141.87
10% SLGP	749.8	752.8	756	144.08	151.12	148.16	147.79
10%ESP	747.4	735.6	739.9	120.24	103.44	113.28	112.32
5% SLGP,10%ESP	725.1	726.8	725.4	107.84	104.32	100.96	104.37
7.5% SLGP,7.5%ESP	736.4	730.5	733.1	110.96	102.00	108.40	107.12
10% SLGP,5%ESP	736.7	743	740.1	98.96	110.48	103.36	104.27
15% SLGP	756.4	757.1	756.6	131.28	139.12	132.16	134.19
15%ESP	730.2	734.2	732.3	109.92	123.52	109.36	114.27
5% SLGP,15%ESP	724.5	726.1	721.4	107.84	104.32	100.96	104.37
10% SLGP,10%ESP	734.4	729.9	730.7	110.96	102.00	108.40	107.12
15% SLGP,5%ESP	736	742.8	738.4	98.96	110.48	103.36	104.27
20% SLGP	754	757.7	752.6	131.28	139.12	132.16	134.19
20%ESP	724.8	734.8	717.5	109.92	123.52	109.36	114.27
5% SLGP,25%ESP	721.8	717.4	726.8	97.12	86.88	101.28	95.09
10% SLGP,20%ESP	719.9	727.3	732.9	97.60	97.60	102.24	99.15
15% SLGP,15%ESP	723.7	728.5	726.3	94.40	99.52	104.80	99.57
20% SLGP,10%ESP	720.6	718.9	733.1	91.68	83.76	99.44	91.63
25% SLGP,5%ESP	739.3	740.2	732.1	106.56	109.52	102.96	106.35
30% SLGP	744.7	748.9	752.6	101.20	112.72	111.12	108.35
30%ESP	735.7	738.8	737.3	94.48	93.60	92.24	93.44

Compressive Strength of 56th day Mortar, curing at 20°c

% Replacement	compressive strength for sample 1 (MPa)	compressive strength for sample 2 (MPa)	compressive strength for sample 3 (MPa)	Avg compressive strength (MPa)
0%	31.28	32.98	33.97	32.74
2.5%SLGP,7.5%ESP	28.44	28.24	29.84	28.84
5% SLGP,5%ESP	28.10	27.34	31.42	28.95
7.5% SLGP,2.5%ESP	29.95	30.48	31.14	30.53
10% SLGP	29.40	30.84	30.23	30.16
10%ESP	24.54	21.10	23.13	22.93
5% SLGP,10%ESP	21.76	22.24	21.79	21.93
7.5% SLGP,7.5%ESP	23.19	22.31	23.18	22.89
10% SLGP,5%ESP	21.78	23.79	22.85	22.81
15% SLGP	27.55	28.96	28.18	28.23
15%ESP	23.39	25.24	24.48	24.37
5% SLGP,15%ESP	22.01	21.29	20.61	21.30
10% SLGP,10%ESP	22.65	20.82	22.12	21.86
15% SLGP,5%ESP	20.19	22.55	21.10	21.28
20% SLGP	26.79	28.39	26.98	27.39
20%ESP	22.43	25.21	22.31	23.32
5% SLGP,25%ESP	19.82	17.73	20.66	19.41
10% SLGP,20%ESP	19.92	19.92	20.86	20.23
15% SLGP,15%ESP	19.26	20.32	21.38	20.32
20% SLGP,10%ESP	18.71	17.09	20.30	18.70
25% SLGP,5%ESP	21.75	22.35	21.01	21.70
30% SLGP	20.66	23.01	22.67	22.11
30%ESP	19.29	19.10	18.82	19.07

Note: the one in red colors are faulty samples

Faulty samples check for Compressive Strength of 56th day Mortar, curing at 20°c

Factor for 3 samples	(0.087* avg)	min	max	Max expected	Avg compressive strength (MPa)	Factor for 2 samples	(0.076* Avg)	Max expected of the two samples	Final Avg compressive strength (MPa)
0.087	2.85	31.28	33.97	34.13					32.74
0.087	2.51	28.24	29.84	30.75					28.84
0.087	2.52	27.34	31.42	29.86	27.72	0.076	2.11	29.45	27.72
0.087	2.66	29.95	31.14	32.61					30.53
0.087	2.62	29.40	30.84	32.02					30.16
0.087	1.99	21.10	24.54	23.10	23.84	0.076	1.81	24.94	23.84
0.087	1.91	21.76	22.24	23.67					21.93
0.087	1.99	22.31	23.19	24.30					22.89
0.087	1.98	21.78	23.79	23.76	23.32	0.076	1.77	24.62	23.32
0.087	2.46	27.55	28.96	30.01					28.23
0.087	2.12	23.39	25.24	25.51					24.37
0.087	1.85	20.61	22.01	22.46					21.30
0.087	1.90	20.82	22.65	22.72					21.86
0.087	1.85	20.19	22.55	22.04	20.65	0.076	1.57	21.76	20.65
0.087	2.38	26.79	28.39	29.17					27.39
0.087	2.03	22.31	25.21	24.34	22.37	0.076	1.70	24.01	22.37
0.087	1.69	17.73	20.66	19.42	20.24	0.076	1.54	21.36	20.24
0.087	1.76	19.92	20.86	21.68					20.23
0.087	1.77	19.26	21.38	21.03	19.79	0.076	1.50	20.77	19.79
0.087	1.63	17.09	20.30	18.71	19.50	0.076	1.48	20.19	19.50
0.087	1.89	21.01	22.35	22.90					21.70
0.087	1.92	20.66	23.01	22.59	22.84	0.076	1.74	24.41	22.84
0.087	1.66	18.82	19.29	20.47					19.07

Weight and Load of 7th day Mortar, curing at 60°c

% Replacement	Weight for sample 1 (g)	Weight for sample 2 (g)	Weight for sample 3 (g)	Load for sample 1 (KN)	Load for sample 2 (KN)	Load for sample 3 (KN)	Avg Load (KN)
0%	751.8	751.8	750.2	126.24	118.40	115.68	120.11
2.5%SLGP,7.5%ESP	723.9	726.1	725.1	118.90	121.40	118.94	119.74
5% SLGP,5%ESP	737	738.6	736.8	121.12	120.72	118.40	120.08
7.5% SLGP,2.5%ESP	739.2	741.6	742.2	121.01	123.32	127.40	123.91
10% SLGP	750.9	747.1	749.8	112.40	106.00	110.00	109.47
10%ESP	735.8	737.2	737.6	120.72	119.68	118.64	119.68
5% SLGP,10%ESP	713.3	719.2	714.0	101.14	108.07	101.49	103.57
7.5% SLGP,7.5%ESP	722.7	721.8	723.7	95.30	90.71	96.82	94.28
10% SLGP,5%ESP	735.3	732.1	729.5	117.56	116.26	113.02	115.61
15% SLGP	742.6	743.4	742.9	111.80	124.14	119.33	118.42
15%ESP	726.3	721.5	719.4	84.90	82.75	79.38	82.35
5% SLGP,15%ESP	716.9	712.4	722.6	98.88	86.16	94.32	93.12
10% SLGP,10%ESP	729.4	733.4	727.8	86.64	88.80	91.36	88.93
15% SLGP,5%ESP	725.3	735.8	720.8	111.76	115.04	103.84	110.21
20% SLGP	738.3	745.7	732.2	105.28	115.12	115.68	112.03
20%ESP	722.3	715.8	714.4	66.64	73.52	89.60	76.59
5% SLGP,25%ESP	704.4	712.7	697.8	82.00	59.92	84.72	75.55
10% SLGP,20%ESP	718.7	713.4	707.1	94.40	88.64	90.40	91.15
15% SLGP,15%ESP	708.9	710.5	705.2	94.80	92.88	89.52	92.40
20% SLGP,10%ESP	722.3	723.7	720.3	90.88	92.88	0.00	61.25
25% SLGP,5%ESP	729.2	734.3	727.9	88.08	96.08	97.60	93.92
30% SLGP	733.6	734.3	727.9	102.48	105.36	98.72	102.19
30%ESP	712.1	721.1	712.8	75.76	85.04	78.24	79.68

Compressive Strength of 7th day Mortar, curing at 60°c

% Replacement	compressive strength for sample 1 (MPa)	compressive strength for sample 2 (MPa)	compressive strength for sample 3 (MPa)	Avg compressive strength (MPa)
0%	25.77	24.16	23.60	24.51
2.5%SLGP,7.5%ESP	24.26	24.78	24.27	24.44
5% SLGP,5%ESP	24.71	24.63	24.16	24.50
7.5% SLGP,2.5%ESP	24.70	25.17	26.00	25.29
10% SLGP	22.94	21.63	22.45	22.34
10%ESP	24.63	24.42	24.22	24.42
5% SLGP,10%ESP	20.64	22.06	20.71	21.14
7.5% SLGP,7.5%ESP	19.45	18.51	19.76	19.24
10% SLGP,5%ESP	23.99	23.73	23.06	23.59
15% SLGP	22.82	25.34	24.35	24.17
15%ESP	17.33	16.89	16.20	16.81
5% SLGP,15%ESP	20.18	17.58	19.25	19.00
10% SLGP,10%ESP	17.68	18.12	18.64	18.15
15% SLGP,5%ESP	22.81	23.48	21.18	22.49
20% SLGP	21.48	23.50	23.62	22.86
20%ESP	13.60	15.00	18.29	15.63
5% SLGP,25%ESP	16.74	12.22	17.29	15.42
10% SLGP,20%ESP	19.27	18.10	18.46	18.61
15% SLGP,15%ESP	19.35	18.96	18.26	18.86
20% SLGP,10%ESP	18.54	18.96		12.50
25% SLGP,5%ESP	17.98	19.61	19.92	19.17
30% SLGP	20.91	21.50	20.15	20.85
30%ESP	15.46	17.36	15.97	16.26

Note: the one in red colors are faulty samples

Faulty samples check for Compressive Strength of 7th day Mortar, curing at 60°c

Factor for 3 samples	(0.087* avg)	min	max	Max expected	Avg compressive strength (MPa)	Factor for 2 samples	(0.076* Avg)	Max expected of the two samples	Final Avg compressive strength (MPa)
0.087	2.13	23.60	25.77	25.73	23.88	0.076	1.81	25.41	23.88
0.087	2.13	24.26	24.78	26.39					24.44
0.087	2.13	24.16	24.71	26.29					24.50
0.087	2.20	24.70	26.00	26.90					25.29
0.087	1.94	21.63	22.94	23.58					22.34
0.087	2.12	24.22	24.63	26.34					24.42
0.087	1.84	20.64	22.06	22.48					21.14
0.087	1.67	18.51	19.76	20.19					19.24
0.087	2.05	23.06	23.99	25.12					23.59
0.087	2.10	22.82	25.34	24.92	24.84	0.076	1.89	26.24	24.84
0.087	1.46	16.20	17.33	17.66					16.81
0.087	1.65	17.58	20.18	19.23	19.72	0.076	1.50	20.75	19.72
0.087	1.58	17.68	18.64	19.26					18.15
0.087	1.96	21.18	23.48	23.14	23.14	0.076	1.76	24.57	23.14
0.087	1.99	21.48	23.62	23.47	23.56	0.076	1.79	24.65	23.56
0.087	1.36	13.60	18.29	14.96	14.30	0.076	1.09	14.69	14.30
0.087	1.34	12.22	17.29	13.57	17.01	0.076	1.29	18.03	17.01
0.087	1.62	18.10	19.27	19.71					18.61
0.087	1.64	18.26	19.35	19.90					18.86
0.087	1.09	18.54	18.96	19.63					12.50
0.087	1.67	17.98	19.92	19.64	19.76	0.076	1.50	21.11	19.76
0.087	1.81	20.15	21.50	21.97					20.85
0.087	1.41	15.46	17.36	16.87	15.71	0.076	1.19	16.65	15.71

Weight and Load of 28th day Mortar, curing at 60°c

% Replacement	Weight for sample 1 (g)	Weight for sample 2 (g)	Weight for sample 3 (g)	Load for sample 1 (KN)	Load for sample 2 (KN)	Load for sample 3 (KN)	Avg Load (KN)
0%	739.2	726.1	719.3	148.24	138.48	146.48	144.40
2.5%SLGP,7.5%ESP	736.1	737.9	737.1	134.34	139.24	137.59	137.06
5% SLGP,5%ESP	749.3	745	741.8	140.00	142.00	135.52	139.17
7.5% SLGP,2.5%ESP	739.4	742.6	740.2	144.65	144.92	145.43	145.00
10% SLGP	760.8	757.8	757.3	166.00	160.16	163.44	163.20
10%ESP	740	734.3	738	129.12	128.56	130.16	129.28
5% SLGP,10%ESP	713.4	719.3	718.1	105.61	101.06	99.18	101.95
7.5% SLGP,7.5%ESP	722.8	721.9	724.3	101.41	103.69	104.50	103.20
10% SLGP,5%ESP	734.3	730.1	727.5	111.95	117.13	127.67	118.92
15% SLGP	744.6	743.4	739.9	153.54	157.15	152.65	154.45
15%ESP	727.3	723.5	720.4	113.49	111.95	116.82	114.09
5% SLGP,15%ESP	725.8	721	724.8	101.84	93.68	85.20	93.57
10% SLGP,10%ESP	723.9	724.3	734	96.08	102.40	109.76	102.75
15% SLGP,5%ESP	750	739.6	739.8	100.00	126.40	106.08	110.83
20% SLGP	743.1	741.5	741.2	152.56	140.72	154.16	149.15
20%ESP	732.1	722.7	722.8	118.24	103.92	105.60	109.25
5% SLGP,25%ESP	720.9	723.1	717.9	86.40	95.04	92.24	91.23
10% SLGP,20%ESP	716.8	721.7	717	87.84	93.12	85.12	88.69
15% SLGP,15%ESP	710.2	716.4	705	104.40	104.88	101.68	103.65
20% SLGP,10%ESP	721.4	713	707.9	110.56	105.04	100.00	105.20
25% SLGP,5%ESP	727.4	725.5	731.6	97.60	96.08	109.84	101.17
30% SLGP	743.4	736.4	736.7	116.24	112.48	110.40	113.04
30%ESP	719.1	718.6	720.1	80.00	79.28	84.32	81.20

Compressive Strength of 28th day Mortar, curing at 60°c

% Replacement	compressive strength for sample 1 (MPa)	compressive strength for sample 2 (MPa)	compressive strength for sample 3 (MPa)	Avg compressive strength (MPa)
0%	27.58	28.42	27.18	27.73
2.5%SLGP,7.5%ESP	27.42	28.42	28.08	27.97
5% SLGP,5%ESP	28.57	28.98	27.66	28.41
7.5% SLGP,2.5%ESP	29.52	29.58	29.68	29.59
10% SLGP	33.87	32.69	33.36	33.31
10%ESP	26.34	26.23	26.57	26.38
5% SLGP,10%ESP	21.55	20.62	20.24	20.81
7.5% SLGP,7.5%ESP	20.70	21.16	21.33	21.06
10% SLGP,5%ESP	22.85	23.90	26.06	24.27
15% SLGP	31.34	32.07	31.15	31.52
15%ESP	23.16	22.85	23.84	23.28
5% SLGP,15%ESP	20.78	19.12	17.39	19.10
10% SLGP,10%ESP	19.60	20.90	22.39	20.97
15% SLGP,5%ESP	20.42	25.80	21.66	22.62
20% SLGP	31.13	28.72	31.46	30.44
20%ESP	24.13	21.21	21.55	22.30
5% SLGP,25%ESP	17.63	19.39	18.83	18.62
10% SLGP,20%ESP	17.93	19.00	17.37	18.10
15% SLGP,15%ESP	21.31	21.40	20.74	21.15
20% SLGP,10%ESP	22.57	21.44	20.40	21.47
25% SLGP,5%ESP	19.92	19.60	22.42	20.65
30% SLGP	23.73	22.95	22.54	23.07
30%ESP	16.32	16.18	17.22	16.57

Note: the one in red colors are faulty samples

Faulty samples check for Compressive Strength of 28th day Mortar, curing at 60°c

Factor for 3 samples	(0.087* avg)	min	max	Max expected	Avg compressive strength (MPa)	Factor for 2 samples	(0.076* Avg)	Max expected of the two samples	Final Avg compressive strength (MPa)
0.087	2.41	27.18	28.42	29.60					27.73
0.087	2.43	27.42	28.42	29.85					27.97
0.087	2.47	27.66	28.98	30.14					28.41
0.087	2.57	29.52	29.68	32.09					29.59
0.087	2.90	32.69	33.87	35.59					33.31
0.087	2.30	26.23	26.57	28.53					26.38
0.087	1.81	20.24	21.55	22.05					20.81
0.087	1.83	20.70	21.33	22.53					21.06
0.087	2.11	22.85	26.06	24.96	23.376	0.076	1.78	24.62	23.38
0.087	2.74	31.15	32.07	33.89					31.52
0.087	2.03	22.85	23.84	24.87					23.28
0.087	1.66	17.39	20.78	19.05	19.95	0.076	1.52	20.64	19.95
0.087	1.82	19.60	22.39	21.42	21.65	0.076	1.65	22.55	21.65
0.087	1.97	20.42	25.80	22.38	21.04	0.076	1.60	22.01	21.04
0.087	2.65	28.72	31.46	31.37	31.30	0.076	2.38	33.51	31.30
0.087	1.94	21.21	24.13	23.15	21.38	0.076	1.62	22.83	21.38
0.087	1.62	17.63	19.39	19.25	19.11	0.076	1.45	20.28	19.11
0.087	1.57	17.37	19.00	18.94	17.65	0.076	1.34	18.71	17.65
0.087	1.84	20.74	21.40	22.58					21.15
0.087	1.87	20.40	22.57	22.27	20.92	0.076	1.59	21.99	20.92
0.087	1.80	19.60	22.42	21.40	19.76	0.076	1.50	21.10	19.76
0.087	2.01	22.54	23.73	24.54					23.07
0.087	1.44	16.18	17.22	17.63					16.57

Weight and Load of 56th day Mortar, curing at 60°c

% Replacement	Weight for sample 1 (g)	Weight for sample 2 (g)	Weight for sample 3 (g)	Load for sample 1 (KN)	Load for sample 2 (KN)	Load for sample 3 (KN)	Avg Load (KN)
0%	768.3	764.3	766.6	222.08	220.24	225.68	222.67
2.5%SLGP,7.5%ESP	748.1	747.2	749.6	138.08	137.20	145.84	140.37
5% SLGP,5%ESP	749	748.7	750.3	139.12	138.32	149.76	142.40
7.5% SLGP,2.5%ESP	749	748.7	750.3	142.72	152.88	147.20	147.60
10% SLGP	756.5	756	754	177.12	195.76	169.44	180.77
10%ESP	743.9	745.5	743.4	125.20	123.60	134.96	127.92
5% SLGP,10%ESP	739.2	738.9	739.5	146.72	141.68	133.68	140.69
7.5% SLGP,7.5%ESP	740.1	739.4	738.5	127.60	121.12	115.44	121.39
10% SLGP,5%ESP	749.3	745.6	742.3	156.80	151.76	152.64	153.73
15% SLGP	751.9	757.4	754.1	167.20	162.40	169.44	166.35
15%ESP	733.7	732.1	730.9	125.20	128.88	118.80	124.29
5% SLGP,15%ESP	732.7	726.9	733	144.88	138.48	128.24	137.20
10% SLGP,10%ESP	737.1	734.4	735.5	122.24	117.52	104.32	114.69
15% SLGP,5%ESP	749.4	741.6	742.3	153.04	148.24	151.44	150.91
20% SLGP	750.5	752.9	751.7	159.44	156.80	166.88	161.04
20%ESP	732.7	730.8	730.3	120.72	121.36	103.68	115.25
5% SLGP,25%ESP	725.4	720.3	719.9	122.24	106.64	111.84	113.57
10% SLGP,20%ESP	713.2	723.7	715.6	110.48	122.00	103.12	111.87
15% SLGP,15%ESP	718.8	715.7	719.3	120.24	109.92	118.00	116.05
20% SLGP,10%ESP	727.6	731.1	728.21	120.64	123.12	129.04	124.27
25% SLGP,5%ESP	733.4	743.8	736.6	124.56	132.88	135.76	131.07
30% SLGP	740.2	742	747.6	112.40	117.76	128.40	119.52
30%ESP	724.2	721.6	728.3	96.16	101.52	101.20	99.63

Compressive Strength of 56th day Mortar, curing at 60°c

% Replacement	compressive strength for sample 1 (MPa)	compressive strength for sample 2 (MPa)	compressive strength for sample 3 (MPa)	Avg compressive strength (MPa)
0%	45.31	44.94	46.05	45.43
2.5%SLGP,7.5%ESP	28.18	27.99	29.76	28.64
5% SLGP,5%ESP	28.39	28.23	30.55	29.06
7.5% SLGP,2.5%ESP	29.13	31.19	30.05	30.12
10% SLGP	36.14	39.95	34.58	36.89
10%ESP	25.55	25.22	27.54	26.11
5% SLGP,10%ESP	29.94	28.91	27.29	28.71
7.5% SLGP,7.5%ESP	26.05	24.71	23.55	24.77
10% SLGP,5%ESP	31.99	30.97	31.15	31.37
15% SLGP	34.13	33.14	34.58	33.95
15%ESP	25.55	26.30	24.25	25.37
5% SLGP,15%ESP	29.56	28.26	26.18	28.00
10% SLGP,10%ESP	24.95	23.98	21.30	23.41
15% SLGP,5%ESP	31.23	30.25	30.91	30.80
20% SLGP	32.54	32.34	34.05	32.97
20%ESP	24.63	24.76	21.15	23.51
5% SLGP,25%ESP	24.95	21.77	22.83	23.18
10% SLGP,20%ESP	22.54	24.90	21.05	22.83
15% SLGP,15%ESP	24.54	22.42	24.08	23.68
20% SLGP,10%ESP	24.62	25.12	26.33	25.36
25% SLGP,5%ESP	25.42	27.12	27.70	26.75
30% SLGP	22.94	24.04	26.21	24.40
30%ESP	19.62	20.72	20.66	20.33

Note: the one in red colors are faulty samples

Faulty samples check for Compressive Strength of 56th day Mortar, curing at 60°c

Factor for 3 samples	(0.087* avg)	min	max	Max expected	Avg compressive strength (MPa)	Factor for 2 samples	(0.076* Avg)	Max expected of the two samples	Final Avg compressive strength (MPa)
0.087	3.95	44.94	46.05	48.90					45.43
0.087	2.49	27.99	29.76	30.48					28.64
0.087	2.53	28.23	30.55	30.76					29.06
0.087	2.62	29.13	31.19	31.75					30.12
0.087	3.21	34.58	39.95	37.79	35.36	0.076	2.69	37.27	35.36
0.087	2.27	25.22	27.54	27.50	25.39	0.076	1.93	27.15	25.39
0.087	2.50	27.29	29.94	29.79	29.43	0.076	2.24	31.15	29.43
0.087	2.16	23.55	26.05	25.71	24.13	0.076	1.83	25.39	24.13
0.087	2.73	30.97	31.99	33.70					31.37
0.087	2.95	33.14	34.58	36.09					33.95
0.087	2.21	24.25	26.30	26.46					25.368
0.087	2.44	26.18	29.56	28.61	28.91	0.076	2.20	30.45	28.91
0.087	2.04	21.30	24.95	23.33	24.47	0.076	1.86	25.84	24.47
0.087	2.68	30.25	31.23	32.93					30.80
0.087	2.87	32.34	34.05	35.20					32.97
0.087	2.05	21.15	24.76	23.20	24.70	0.076	1.88	26.51	24.70
0.087	2.02	21.77	24.95	23.79	22.30	0.076	1.69	23.46	22.30
0.087	1.99	21.05	24.90	23.03	21.796	0.076	1.66	22.70	21.80
0.087	2.06	22.42	24.54	24.48	24.312	0.076	1.85	25.93	24.31
0.087	2.21	24.62	26.33	26.83					25.36
0.087	2.33	25.42	27.70	27.75					26.75
0.087	2.12	22.94	26.21	25.07	23.49	0.076	1.79	24.73	23.49
0.087	1.77	19.62	20.72	21.38					20.33