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INVESTIGATE THE SUITABILITY OF SCORIA AND GLASS WASTE AS A CEMENT REPLACEMENT IN BINARY AND TERNARY BLENDED CEMENT MORTAR

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INVESTIGATE THE SUITABILITY OF SCORIA AND GLASS WASTE AS A CEMENT REPLACEMENT IN BINARY AND TERNARY BLENDED CEMENT MORTAR

By

Kalab Amare Molla

Bahir Dar, Ethiopia

September 8, 2022

INVESTIGATE THE SUITABILITY OF SCORIA AND GLASS WASTE AS A CEMENT REPLACEMENT IN BINARY AND TERNARY BLENDED CEMENT MORTAR

By

Kalab Amare Molla

A Thesis Submitted to Bahir Dar Institute of Technology, BDU in Partial Fulfillment of the Requirement for the Degree Masters of Science in Construction Technology and Management

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Bahir Dar, Ethiopia

September 8, 2022

DECLARATION

This is to certify that the thesis entitled "Investigate the Suitability of Scoria and Glass waste as a cement replacement in binary and ternary blended cement mortar", submitted in partial fulfillment of the requirements for the degree of Master of Science in "**Specialization**" under Faculty of Civil and water Resources Engineering, Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

Kalab Amare

Name of the candidate	Signature	Date

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Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of Student: Kalab Amare Signature ______ Date: 30/12/2014

As members of the board of examiners, we examined this thesis entitled "Investigate the Suitability of Scoria and Glass Waste as a Cement Replacement in Binary and Ternary Blended Cement Mortar" by Kalab Amare. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of Science in "Construction Technology and Management".

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To my father and mother

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ABSTRACT

Climate change become as one of our societies' most pressing environmental issues. Production of Portland cements is high energy intensive and is not an environmentally favorable substance due to its huge CO_2 emission from the production process. To maintain sustainable development utilization of alternative materials should be employed. So, the main objective of this study is to evaluate the suitability of scoria powder (SP) and glass and scoria composition (GPSP) as supplementary cementitious materials in order to mitigate the environmental pollution and high cost of cement resulted from the manufacturing of cement. The influence of scoria and glass-scoria powder on consistency, setting time, soundness, workability, compressive strength, sulfate attack, water absorption, and ultrasonic pulse velocity tests was investigated on cement paste and mortar mixes. In addition to that, Fourier Transform InfraRed, Thermogravimetric Analysis, and Differential Thermal Analysis were done to evaluate the micro-structure of mortar. In this study, sample mortars were tested at the ages of 3, 7, 28, 56, and 90 days on specimens containing different contents of SP (0%, 10%, 15%, 20%, and 25%) and GPSP (22.5GP-7.5SP%, 15GP-15SP, and 7.5GP-22.5SP) substituting ordinary Portland cement. The study results demonstrate that the chemical and mechanical properties of SP and GPSP meet the relevant ASTM C 618 standard; it is found that the Strength Activity Index of GPSP is greater than that of SP. This result indicates incorporation of GP with SP initiates early strength development. The additive dosage increment increased the water demand and setting time, respectively, and the addition of SP and GPSP reduced cement expansion. With an increase in SP and GPSP, mortar became less workable. The result revealed that the incorporation of 10%SP and 15%SP powder improved the compressive strength at the later ages (28, 56, and 90 days), in comparison with that of the control mix. It is found that the lower early strength of SP can be accelerated by the incorporation of GP into ternary blended cement. Further, incorporation of scoria improves the sulfate attack resistance of mortar in later days of exposure (90-day) and results found a slight increment in water absorption and UPV compared to the control mix. According to experimental results, the addition of SP up to 20% and GPSP up to 30% is recommended.

Keywords, Glass powder (GP), Scoria powder (SP), Fresh Properties, Mechanical properties, Micro Structure, Durability.

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AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ASTM	American Society for Testing Material
FTIR	Fourier Transform Infrared
GP	Glass Powder
GPSP	Glass Powder - Scoria Powder
LOI	Loss of Ignition
MANOVA	Multivariate Analysis of Variance
OPC	Ordinary Portland cement
PPC	Portland Pozzolana cement
SAI	Strength Activity Index
SP	Scoria Powder
TGA	Thermo Gravimetric Analysis
UPV	Ultrasonic Pulse velocity
XRD	X-ray Diffraction

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Climate change is regarded as one of our societies' most pressing environmental issues. Carbon dioxide is one of the most major greenhouse gases. Portland cement, which is major component of concrete, is not an environmentally favorable substance. Cement manufacture is a high-energy process, and the cement industry is one of greatest CO_2 generators in the world, producing more than a billion tons of CO_2 per year (Lindsey, 2022; Preston & Lehne, 2018; Zhang et al., 2014). Portland cement is made by pyro- processing raw materials at temperatures ranging from 1400 to 1500 ^{0}C, and then grinding the clinker. This consumes approximately 4900 MJ of energy per ton of cement. Perhaps more concerning, extensive amount of carbon dioxide (CO_2) is released during the manufacture of Portland cement; on average, about 1 ton of CO_2 is liberated for each tonne of cement produced (Aïtcin & Mindess, 2011).

High consumption of natural sources, high production of industrial wastes and environmental pollution are some of the factors which are responsible for obtaining new solutions for sustainable development (Abdel-Shafy & Mansour, 2018). Sustainable development can be achieved by increasing the resource efficiency (Poudyal & Adhikari, 2021). By using less energy and materials, the resource efficiency can be increased thus; solution is utilization of industrial by-products or solid wastes such as fly ash, Coal bottom ash, waste foundry sand, slag, silica fume, and waste glass in producing concrete. Because they are inexpensive, have excellent durability, and are environmentally friendly, these concrete technologies lessen the negative consequences of the industry's economic and environmental issues (Aggarwal & Siddique, 2014; Bhardwaj & Kumar, 2017; Mohammed et al., 2021)**.**

Supplementary cementitious materials are typically byproducts or natural resources from other processes. They could be further processed for use in concrete or not. The physical, chemical, mechanical, and durability properties of mortar and concrete are significantly impacted by the substitution ratio and fineness of natural pozzolan used in the manufacturing of blended Portland cements. Additionally, these components are used in the production of cement after the kiln process, and they have significant economic and ecological advantages (Oss, 2007).

According to research, glass has a chemical makeup and phase that is similar to that of conventional additional cementitious materials (SCMs). Glass is high amorphous and has high silica content, more than 70% of glass structure is composed of amorphous silica which is a primary requirement for a pozzolanic materials and In order to manage the societally generated bulk glass waste, many researchers have looked into the use of glass as an additional cementitious ingredient for concrete production in the building sector (Aliabdo, Elmoaty, & b, 2016; Aseel & Zubaid, 2017; Sakale & Jain, 2016; Tamanna & Tuladhar, 2020). Studies showed that the use of finely grounded in concrete up to 15 % improves its mechanical properties and up to 60% cement substitution, the resistance to chloride ion and water penetration constantly increases with increasing glass powder content (Sakale & Jain, 2016).

According to (Kim, Chongku, & Zi, 2015) study utilization of Glass sludge with a composition of fly ash were studied. According to the result, slow early strength development of fly ash can be enhanced by incorporation of Glass. This result indicates that the high amorphous structure and high contents of Na_2O leads to more hydration product at early age.

Scoria, a result of explosive volcanic eruptions, has been utilized as a construction material around the world for ages. The use of scoria as a construction material in concrete manufacturing has been studied by a number of researcher. Scoria is predominantly made of SiO_2, Al_2O_3, and Fe_2O_3 and mainly categorized as a siliceous material, depending on the primary oxide composition (Aref al-Swaidani, 2018; Fares & Alhozaimy, 2015). According to (A. Al-swaidani & Aliyan, 2014) utilization of scoria lowers the early strength of mortar and concrete however, significantly improved the sulphate resistance and the Sulphuric acid resistance of mortar, especially at the early days of exposure, as well as water permeability, chloride penetrability and porosity of concrete reduced by utilization of scoria.

Scoria aggregate can be found across Ethiopia, particularly in the Great Rift Valley, which comprises over 30% of the country. In the north-eastern region of the nation, there are multiple scoria cones and a lava field. They were found predominantly in Adama, Bishoftu, Mojo, Butajira, and Giyon. World pumice and related materials production was 21 million tons in 2020, Ethiopia remains the dominant producer of pumice and scoria, with production estimated to be 2.4 million tons in 2020 next to Turkey (D. Newill & K. Aklilu, 1980; Robert D. Crangle, 2021).

1.2 Statement of the Problem

Due to the intense heat required to manufacture cement, manufacturing requires a lot of energy and produces a lot of emissions; cement production accounts for roughly 7% of annual industrial energy consumption worldwide. Due to the calcination of raw materials and the combustion of raw fuels, the cement industry produces a large amount of gas emissions; roughly 8% of all human-made emissions are a result of cement production. Our country Ethiopia is one of the fastest developing countries in Africa economies. The Ethiopian cement industry has become one of the nation's fastest-growing industries as a result of the construction of large-scale projects like the Grand Ethiopian Renaissance Dam, many industrial parks, sugar mills, and highway and rail lines. Environmental contamination is caused by rapid urbanization. In 2019, According to World Bank, CO_2 emission in Ethiopia reported at 0.16381 metric tonnes. The main sources of this environmental pollution are the burning of fossil fuels and the manufacture of cement. As the company grows, energy use and CO2 emissions are projected to increase. Utilizing locally available waste and appropriate natural materials in place of cement instead of clinker will help to solve the issue and preserve sustainable development (Bank, 2020; Cantini et al., 2021; Mulatu & Habte, 2018; Tesema & Worrell, 2015).

According to a World Bank study, 2.01 billion tonnes of municipal solid waste are produced globally each year, and 3.40 billion tonnes are predicted to be generated by the year 2050.The entire amount of waste generated in sub-Saharan Africa is anticipated to more than triple. Glass makes up around 100.5 million tonnes per year, or 5% of all municipal solid waste. Ethiopia is one of the sub-Saharan African nations with the greatest economic growth, and as a result, solid waste management is becoming an increasingly serious issue. Poor trash management results in glass waste being discarded along roadsides and in open spaces in numerous cities across the nation, harming human health and attracting vermin. Only 977 tonnes of Ethiopia's total estimated glass waste—which accounts for 2.4 percent of all waste is recycled; the remainder is dumped in landfills. Glass disposal in landfills has many negative effects on the environment because it is not biodegradable in nature (Islam & Kazi, 2017; report., 2014). Recycling glass benefits the environment and supplies inexpensive cementing material, which is a win-win situation.

1.3 Objectives

General objective

→ The general objective of this study is to investigate the potential use of scoria and glass powder as partial replacement of cement.

Specific Objectives

→ The specific objectives of this study are:

1. To investigate the chemical and physical property of scoria and glass powder.
2. To investigate the effect of partial cement replacement with scoria and glass powder on fresh and mechanical properties of mortar.
3. To investigate the effect of partial replacement of cements with Scoria and glass on microstructure and durability of mortar.
4. To determine the cost difference between blended cement and OPC cement.

1.4 Research Questions

Question that will be answered by this study are:

1. Does the chemical and physical property of Sample scoria meet the requirement set by ASTM-C618
2. Does the chemical and physical property of scoria and glass composite meet the requirement set by ASTM-C618?
3. Does scoria and glass powder mixture affect the compressive, sulphate resistance water absorption Property of Mortar?
4. To what extent scoria and glass powder mixture affect the property of Mortar?

1.5 Hypothesis of Study

The formation of the hypothesis is based on the multivariate analysis. The following alternative and null hypotheses are developed to interpret the data. The independent factors are curing age and mix type, while the dependent variables are compressive strength, sulphate attack, water absorption, and ultrasonic pulse velocity. Whether or not the means are significantly different, the age and mix-type effects on the dependent variables are done.

1. Ho_1 = the curing age doesn’t affect the compressive strength, ultrasonic pulse velocity Sulphate resistance, and water absorption of mortar.
2. Ho_2 = the partial replacement of cement with scoria and glass powder doesn’t affect the compressive strength, ultrasonic pulse velocity, Sulphate Resistance, and water absorption of mortar.
3. Ha_1 = the length of curing age affect the compressive strength, ultrasonic pulse velocity, Sulphate resistance, and water absorption.
4. Ha_2 = the partial replacement of cement with scoria and glass powder affects the compressive strength, ultrasonic pulse velocity Sulphate attack, and water absorption.

1.6 Significance of the Study

1. The research output is expected to benefit the construction industry for sustainable development by Promote wise utilization of scoria
2. Scoria is abundantly available material in a great rift valley of the country and mostly being used only for specific purpose in the construction. The study fills the gap of knowledge on scoria utilization on construction and cement industries in Ethiopia.
3. The research output provides the advantages of using Glass and scoria composition.
4. Additionally, it provides information for academicians and researcher to initiate further studies.

1.7 Scope and Limitation of the Study

This thesis only covers the natural type scoria deposit of Wegelsa, Zege Mesmer which is 35km far from Bahir Dar town. The study will address the suitability of scoria and composition of scoria and glass as partial replacing Cement replacing material, with studying the physical and chemical properties of scoria materials, mechanical, physical and chemical property of Mortar by conducting different test on 2-inch hydraulic cement mortar and by taking only samples quarry source for all the constituent materials from Bahir Dar. This research is geographically limited on Bahir Dar. Due to time and financial constraints, long-term durability tests, such as accelerated sulphate attack, corrosion resistance tests, and tests for chloride permeability, won't be carried out.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Cement

Cement has its origins in Roman times, when it was known as Opus Caementitium, a concrete-like masonry constructed of crushed stone particles bind together with burned lime and water. Cementum and Cement were later names for the mixture of brick powder and volcanic tuff with burned lime as the hydraulic binder. Hydraulic cement is a powdered material that combines with water to generate a strong, water-insoluble solid material. Hydraulic cements include, for example, Portland cement (PC) and high-alumina cement (hat). Because it is soluble in water, gypsum is not a member of this family of materials, nor is lime, which hardens through a reaction with carbon dioxide. The most common type of hydraulic cement is Portland cement by far, due to its price and qualities, and, as a result, due to the quantity consumed (Popovics, 1992).

2.1.1 Portland Cement

Hydraulic cements, such as Portland cement, are made mostly of hydraulic calcium silicates. Hydraulic cements react chemically with water to set and harden. Cement and water interact in this event, known as hydration, to form a paste that resembles a stone. The paste (cement and water) works as an adhesive, binding the particles together to make concrete (Popovics, 1992).

2.1.2 Manufacturing of Portland Cement

A mixture of limestone and clay is heated to create Portland cement. Or other materials with a similar bulk composition and adequate reactivity, to a temperature of around 1450 degrees Celsius. Clinker nodules are formed as a result of partial fusing. To manufacture cement, clinker is finely pulverized and combined with a small amount of gypsum. Gypsum regulates the rate of set and can be partially replaced with other calcium sulphate forms. Some specifications permit the insertion of additional materials during the grinding process. The clinker typically has four major phases: alite, belite, aluminate phase, and ferrite phase, and has a composition of 67 percent CaO, 22 percent SiO_2, 5 percent Al_2O_3, 3 percent Fe_2O_3, and 3 percent other components. Other phases, such as alkali sulphate and calcium oxide, are usually present in trace amounts (Taylor, 1990).

2.2 Composition of Portland Cement

Combinations of four oxides make up about 95 percent of Portland cement clinker. Lime, silica (, alumina, and iron oxide are the four minerals. Magnesia, sodium, and potassium oxides (alkalies); Titania; phosphorous, and manganese oxides are just a few of the minor ingredients or impurities (Popovics, 1992).

According to (Kosmatka, Kerkhoff, & William, 2003) Calcium reacts with the other components of the raw mix during the burning process in the creation of Portland cement clinker to generate four major compounds that make up 90% of the cement by mass. During the grinding process, gypsum (4–6%) or another calcium sulfate source, as well as grinding aids, are introduced. The components of clinker can also be described using the term "phase" rather than "compounds". Chemical shorthand (abbreviations) used by cement scientists to define compounds include:

$$A= Al_2O_3,\ C=CaO,\ F= Fe_2O_3,\ H=H_2O,\ M=MgO,\ S= SiO_2,\ \text{and}\ \overline{S} = SO_3$$

The chemical composition of Portland cement is often characterized in terms of the oxides of the various elements present, as stated in Table 2-1.

Table 2-1:Typical Oxide Composition of a General - Purpose Portland Cement (Mindess, Young, & Darwin, 2003)

Short hand Oxide	**common Notation**	**weight Name**	**percent**
CaO	C	Lime	64.67
SiO_2	S	Silica	21.03
Al_2O_3	A	Alumina	6.16
Fe_2O_3	F	Ferric oxide	2.58
MgO	M	Magnesia	2.62
K_2O	K	} Alkalis	0.61
Na_2O	N		0.34
SO_3	$\overline{S}$	Sulfur trioxide	2.03
CO_2	$\overline{C}$	Carbon dioxide	-
H_2O	H	water	-

2.2.1 Hydration of Portland Cement

According to (Nawy, 2008) Because of the individual cement grains vary in size and content, the hydration reactions between finely ground Portland cement and water are exceedingly complicated. As a result, the hydration products that result aren't all the same; their chemical composition and microstructural features vary not only over time but also depending on their location inside the concrete. The essential characteristics of Portland cement hydration can be summarized as follows:

a. As long as the individual cement grains remain separated from each other by water, the cement paste remains fluid.
b. The products of the hydration reactions occupy a greater volume than that occupied by the original cement grains.
c. As the hydration products begin to intergrow, setting occurs.
d. As the hydration reactions continue, additional bonds are formed between the cement grains leading to strengthening of the system.

Table 2-2: Portland Cement Phase Hydration Reactions and Oxide Notation (Kosmatka et al., 2003)

2(3CAO •SiO_2) Tricalcium silicate	+ 11 H_2O Water	=3CaO•2SiO_2•8H_2O Calcium silicate hydrate (C-S-H)	+ 3(CaO •H_2O) Calcium hydroxide
2 (2CaO •SiO_2) Dicalcium silicate	+ 9 H_2O Water	= 3CaO •2SiO_2 •8H_2O Calcium silicate hydrate (C-S-H)	+ CaO •H_2O Calcium hydroxide
3CaO •Al_2O_3 Tricalcium aluminate	+ 3(CaO•SO_3•2H_2O) Gypsum	+ 26 H_2O Water	=6CaO•Al_2O_3•3SO_3•32H_2O Ettringite
2 (3CaO •Al_2O_3) Tricalcium aluminate	+ 6CaO •Al_2O_3 •3SO_3 •32H_2O Ettringite	+ 4 H_2O Water	= 3(4CaO •Al_2O_3 •SO_3 •12H_2O) Calcium monosulfoaluminate
3CaO •Al_2O_3 Tricalcium aluminate	+ CaO •H_2O Calcium hydroxide	+12 H_2O Water	= 4CaO •Al_2O_3 •13H_2O Tetracalcium aluminate hydrate
4CaO •Al_2O_3 •Fe_2O_3 Tetracalcium aluminoferrite	+ 10 H_2O Water	+ 2 (CaO •H_2O) Calcium hydroxide	= 6CaO •Al_2O_3 •Fe_2O_3 •12H_2O Calcium aluminoferrite hydrate

2.2.2 Physical Properties of Cement

Cement specifications set restrictions on its physical qualities and, in some cases, chemical composition. Understanding the relevance of specific physical parameters can assist interpret cement test results? Instead of evaluating the qualities of the concrete, tests of the physical properties of the cements should be used. The qualities of cement are limited by the type of cement. ASTM C 183(AASHTO T 127) should be used to sample cement. Cement's chemistry and the following qualities are constantly evaluated during production (Kosmatka et al., 2003).

a. Particle Size and Fineness

The outcome of pulverizing clinker in the grinding mill is Portland cement, which is made up of individual angular particles of various sizes. Cement particles are typically less than 45 micrometers, with the average particle being around 15 micrometers in diameter. The fineness of cement refers to the overall particle size distribution, which influences the amount of heat released and the rate of hydration. Greater cement fineness accelerates strength development by increasing the rate at which cement hydrates. The effects of finer paste on paste strength are most noticeable within the first seven days (Kosmatka et al., 2003).

b. Setting Time

The goal of the setting time test is to determine (Kosmatka et al., 2003):

I. the period of time after water is added when the paste stops being fluid and plastic, also known as first set; and

II. The amount of time needed for the paste to attain a particular hardness level, also known as final set.

c. Soundness

Soundness refers to a paste's capacity to maintain its volume after hardening. Magnesia or hard burned free lime in excess amounts may result in delayed destructive expansion or a lack of soundness. Both the maximum expansion measured by the autoclave-expansion test and the amount of magnesia (percales) in Portland cement are frequently limited (Kosmatka et al., 2003).

d. Consistency

Consistency is the degree of flow or relative mobility of a freshly mixed cement paste or mortar. Pastes are combined to a typical consistency during cement testing, as demonstrated by a Vicat plunger penetration of 10 mm (Kosmatka et al., 2003).

Early stiffening is the early onset of stiffness in the working characteristics or plasticity of cement paste, mortar, or concrete. Both the false set and the flash set are mentioned here.

- False set happens after mixing when there is a significant loss of plasticity without a lot of heat being soon created.
- Paste, mortar, or concrete that abruptly loses its capacity to be worked suggests that it has flash set or quick set.

e. Heat of Hydration

Hydration heat is the term for the energy created when cement and water react. The chemical makeup of the cement mostly determines how much heat is produced, with C_3A and C_3S being the compounds most in charge of considerable heat evolution (Kosmatka et al., 2003).

f. Compressive Strength

The compressive strength of 50-mm (2-in.) mortar cubes that have been assessed in accordance with ASTM C 109 is specified in the ASTM cement standards (AASHTO T 106). The type of cement, or more precisely, the compound composition and fineness of the cement, affect compressive strength. While ASTM C 150 and C 595 (AASHTO M 85 and M 240) only establish a minimum strength criterion, ASTM C 1157 specifies both a minimum and a maximum strength (Kosmatka et al., 2003).

g. Loss on Ignition

A known-weight cement sample is heated to a constant weight between 900°C and 1000°C to evaluate the loss on ignition (LOI) of Portland cement. Next, the sample's weight loss is determined. A significant loss on ignition is typically a sign of pre-hydration and carbonation (Kosmatka et al., 2003).

h. Density and Relative Density (Specific Gravity)

The density of cement is defined as the mass of a unit volume of solids or particles, excluding air between particles. The units of measurement are mega grams per cubic meter or grams per cubic centimeter (the numeric value is the same for both units).The average particle density of Portland cement is 3.15 Mg/m3, however the range is 3.10 to 3.25 Mg/m^3 (Kosmatka et al., 2003).

2.3 Cement Production in Ethiopia

Dire Dawa, Ethiopia's first cement factory, was established in 1938. Addis Ababa Cement Plant, Mugher Cement Enterprise's first and second lines, as well as Messobo Cement Factory, were established afterwards. There are currently many cement plants. Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) are the two primary types of cement produced (PPC).In the past, PPC made about 82 percent of manufacturing in Ethiopia, whereas OPC made up roughly 18 percent (Mulatu & Habte, 2018).

2.3.1 Cement Demand

Economic growth in Ethiopia has been double digits, and it is expected to continue. And its economy wills one of the continent's fastest-growing ones. Cement production is one of the industries rising most quickly in Ethiopia. Demand for cement has expanded as a result of the construction of new mega-projects like the Grand Ethiopian Renaissance dam, many industrial parks, sugar refineries, highway and railroad routes, and private-sector projects (Mulatu & Habte, 2018).The cement sector will be held to a high standard in order to satisfy all of these demands and maintain the nation's economic growth. The average annual growth in cement consumption in Ethiopia during the past five years, from 2015 to 2020, has been 10.8 percent .There was a substantial discrepancy between cement demand and supply in 2019.In Ethiopia, the demand for cement amounted to over 12 million tons; however cement makers only supplied roughly 8.9 million tons, implying a 3.1 million tons shortfall (News, 2021).

2.3.2 Cost of Production

Ethiopian cement production is known for using expensive amounts of energy. Energy expenses make up between 50 and 60 percent of all operating expenses in Ethiopia. Vertical shaft kilns

(VSK) and rotary kilns are the two types of kilns used in Ethiopia. Most cement manufacturing facilities employ vertical shaft kilns. Vertical shaft kilns (VSK) are outdated technologies that produce low-quality output, excessive energy consumption, and high operating expenses. The high production costs of the cement industry in Ethiopia are mostly due to this. Additionally, the manufacture of cement in Ethiopia is highly dependent on foreign energy sources. The high manufacturing costs in the industry are significantly influenced by this circumstance. The use of alternative energy sources and the substitution of imported energy sources with locally accessible resources will have a favorable impact on the cement industry's operational expenses (Mulatu & Habte, 2018).

2.3.3 Energy Consumption and CO_2 Emission

In the process of making cement, a lot of CO_2, SO_2, and particulate matter (PM) are released into the environment. In 2010, it was predicted that CO2 emissions from fuel, power, and processes (such as the calcination of limestone) would be 513 kt, 1.1 kt, and 853 kt, respectively. This would result in an annual emission of 1.4 Mt CO_2 (Tesema & Worrell, 2015).

The Mughar Cement Factory's (MCF) annual fuel energy intensity ranged between 4065.2-4289.9 KJ/kg of clinker from 2010 to 2013, with an average of 4164.5 KJ/kg of clinker. The average energy intensity per kilogram of clinker in China's various cement mills is 2934.1 KJ.As a result, there is a 1214.5KJ/Kg difference in intensity between the typical practice and what is offered at MFC.

The energy intensity of the electricity used at MCF during 2010 to 2013 varied from 100.3 to 118.5 kWh/ton of cement, with an average of 110.33 kWh/ton of cement. In China, different cement plants use an average of 86.95 kWh of energy per ton of cement. The difference between standard procedure and what is used at MFC is therefore 23.38 kWh/per ton of cement (Mossie, 2016). New low-energy production techniques must be developed in addition to the nation's vast low-cost resources if it is to improve its economic situation and escape poverty.

2.4 Sustainability of Cement Production

The natural resources and energy sources in the world in which we live are scarce. Sadly, we are currently using up these natural resources at a rate that is unsustainable. Additionally, the ways we use to use and consume these resources, as well as the energy used to extract them, cause pollution and environmental harm. Global climate change is significantly influenced by the so-called greenhouse gas emissions from our resource usage, which are mostly carbon dioxide, methane, and nitrous oxide (Aïtcin & Mindess, 2011).

The phrase "development that satisfies the demands of the present without compromising the capability of future generations to meet their own necessities" is a typical definition of sustainable development (Brundtland, 1987).

The cement and concrete industries have a significant environmental impact: they utilize a great quantity of quarried raw materials, their processing takes a lot of energy, and the production of Portland cement generates a lot of Carbon dioxide. Portland cement is made by pyro- processing raw materials (usually limestone, clay, or shale) at temperatures ranging from 1400 to 1500 degrees Celsius, and then grinding the clinker. This consumes roughly 4900 MJ of energy per ton of cement. Perhaps more concerning, a significant amount of carbon dioxide (CO_2) is released during the manufacture of Portland cement; on average, about 1 ton of CO_2 is liberated per ton of cement produced (Aïtcin & Mindess, 2011).

2.5 Supplementary Cementitious Material

These substances are referred either as mineral admixtures or additional cementitious ingredients. Commonly, mineral elements are used to replace cement, boost the workability of fresh concrete, and lengthen the durability of hardened concrete. (Mindess et al., 2003).

The most efficient strategy to reduce energy use and greenhouse gas emissions is probably to replace some of the Portland cement with supplemental cementing materials (SCMs). Each kilogram of replacement saves the energy needed to create 1 kg of cement and reduces CO_2 emissions by around 1 kg. It is not surprising that increased focus is being made on utilizing more SCM because cement manufacture contributes for almost 95% of all CO_2 emissions from a cubic yard of concrete material (Obla, 2009).

2.5.1 Pozzolanic Materials

Pozzolana is described as a broad class of siliceous or siliceous and aluminous materials that have little to no cementitious value on their own but produce cementitious compounds when chemically interacted with calcium hydroxide in finely divided form and in the presence of moisture at room temperature. As a result, it is categorized as cementitious substance. There are artificial and natural pozzolans [38].

According to (ASTMC618-08, 2008) there are three classes of SCMs. Those are class N, F and C. The chemical and physical requirements for each class are tabulated on Table 2-3

Table 2-3: Chemical Requirements of SCM –ASTM C618

	Class		
	Class N	Class F	Class C
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min, %	70.0	70.0	50.0
Sulfur trioxide (SO_3), max, %	4.0	5.0	5.0
Moisture content, max, %	3.0	3.0	3.0
Loss on ignition, max, %	10.0	6.0	6.0

2.5.2 Artificial Pozzolan

Artificial pozzolanic materials include byproducts of industry or materials that have undergone processing or heat treatment. These processes cause them to alter their chemical and physical structure. The two types of artificial pozzolans are processed calcined material and industrial byproducts (Concrete, 2021).

❖ **Artificial Pozzolans: Industrial by Product**

Due to their chemical nature, industrial wastes are moderately to extremely reactive. Silica fume, fly ash, ground-granulated blast furnace slag, bottom ash, and steel slag are industrial by product of artificial pozzolans (Concrete, 2021).

A. Silica Fume

It is a by-product of the production of Ferro-silicon alloys and silicon metal. In this technique, silicon is produced by burning quarts of pure crystalline silicate at temperatures above 2000 degrees Celsius. In addition, the high temperature produces silica fume, which is created when silica dioxide vapor oxidizes and condenses. The chemical makeup and fineness of silica fume make it an extremely reactive amorphous pozzolan(Concrete, 2021)

B. Fly Ash

It results from the combustion of pulverized coal in steam and electricity plants. In a nutshell, it is a spherical, pozzolanic fine substance that is typically finer than Portland cement. The main oxide components of fly ash include silicon oxide, aluminum oxide, iron oxide, calcium oxide, and other minor oxides. Depending on its chemical make-up, fly ash is classified as either F or between classes C and F, the calcium content is the primary distinction. Class F typically has less than ten percent calcium oxide, but class C typically contains more than twenty percent calcium oxide(Concrete, 2021).

C. Ground – Granulated Blast Furnace Slag

It is a by-product of the iron extraction step, which is carried out in a blast furnace at a high temperature of roughly 2000°C.Iron ore becomes molten iron at the temperature of the blast furnace, and this molten iron descends to the bottom. As a result, the slag or impurities in the molten iron float to the top. After being taken out of the furnace, the slag is dried, cooled with air or water, and then ground into a fine powder. The outcome is an amorphous substance having cementitious qualities as the final product. The major components of ground granulated blast furnace slag are silicon dioxide, calcium oxide, and magnesium oxide (Concrete, 2021).

D. Bottom Ash

Bottom ash, which makes up about 10% of the trash, is the more coarsely ground component of coal ash.. It's typically the same size as sand, but much coarser than fly-ash. Bottom ash can be used either as a row material in the production of cement, fine aggregate or course aggregate, depending on its particle size distribution and pozzolanic activity. Bottom ash mainly consists of CaO, SiO_2, Fe_2O_3 and Al_2O_3 (Concrete, 2021).

E. Non-Ferrous Slag

It is a by-product of the processing of non-ferrous metals from natural ores, and after cooling, it takes the form of granular or rock-like material. Non-ferrous slags are primarily made up of calcium, silicon, aluminum, and ferrous oxide. However, depending on the type, the properties and chemical composition may differ (Concrete, 2021).

F. Fluid-Cracking Catalyst Residue

It's a by-product of petrol refineries' fluid catalytic cracking process. It could be made up of fine spherical particles that are less than fifty microns in size on average. Fluid cracking catalyst residue is a highly pozzolanic material, and mainly consists of silicon and aluminum oxides (Concrete, 2021).

❖ ***Artificial Pozzolans: Treated Calcined Materials***

Man-made pozzolans, or processed calcined minerals, undergo a high-temperature process before being ground. As a result, this process alters their chemical and physical structure and boosts their pozzolanic activity. This category includes a variety of materials, including discarded glass, calcined clays, burnt shale, metakaolin, burnt organic matter, and rice husk ash (Concrete, 2021).

2.6 Glass

Since roughly a century ago and even longer, a number of theoretical and empirical models have been put out to explain the definition of glass, citing control factors including density, temperature, structures that resemble solids or gases, particular molecular shapes, and interactions. Glass is an amorphous solid that shows a glass transition temperature by arresting kinetics below a super-cooled liquid phase when crystallization is bypassed" (Rajaramakrishna & Kaewkhao, 2018).

"Glass is an inorganic product of fusion that has cooled to a rigid condition without crystallization"(ASTMC162, 2005)

"Glass is an amorphous solid" (Doremus, 1994).

2.6.1 Important of Glass

Due to its transparency and versatility, glass is the most appealing material for creative exhibits. The two sectors of container glass and flat glass, which are used to make bottles for soft drinks, wine, beer, and spirits, as well as window panels, beautiful chandeliers made of glass, doors, and wide-neck jars for the food business, are the most crucial ones for the glass industry. Although these goods are typically viewed as commodities, a significant component of the industry is the creation of more expensive containers for the pharmaceutical and cosmetics sectors (Rajaramakrishna & Kaewkhao, 2018).

2.6.2 Composition of Glass

Glass can be made from a wide variety of materials; however the majority of industrial glass is made up of just ten oxides, which are produced using all of these ingredients. A batch of glass typically contains 60 to 80 percent silica, or SiO_2.In order to obtain silica, sand, which is essentially quartz, is required in the manufacturing process. Soda, Na_2O, is the second-most crucial oxide in the production of glass after silica. Sodium carbonate, sometimes referred to as soda ash, is the most widely used ingredient in soda. The silica in the most popular type of glass has been combined with soda and lime. According to tonnage, 90 percent of the glass that is currently melted is soda-lime glass. About 70% of soda-lime glass is made of silica, 15% of soda, and 10% is lime (CaO).Magnesia, MgO, or alumina, Al_2O_3, which are often employed to modify the chemical resistance or electrical properties, make up the remaining 5 percent. Typically, this sort of glass is used for containers, light bulbs, plates and sheets (including windows).Alkali silicate glass is a type of soda-containing glass (Phillips, 1941).

Table 2-4: Chemical Composition of Glass Powder

oxides	**Chemical composition by weight percentage**				
	Glass Powder				
	(Nyantakyi, 2020)	**(Kim et al., 2015)**	**(Shruthi & Chandrakala, 2015)**	**(Nyantakyi & Domfeh, 2020)**	**(Islam & Kazi, 2017)**
Silica Oxide (SiO_2)	71.42	68.2	72.42	72.12	68
Aluminum Oxide (Al_2O_3)	1.34	10.1	0.44	2.23	7
Iron Oxide (Fe_2O_3)	0.07	0.242	0.07	0.26	<1
Magnesium Oxide (MgO)	0.22	2.94	0.32	0.76	<1
Calcium Oxide (CaO)	11.40	9.90	11.50	10.49	11
Potassium Oxide (K_2O)	0.30	0.229	0.35	13.75	<1
Sodium Oxide (Na_2O)	13.54	7.62	13.64	0.20	12
Sulfur trioxide (SO_3)	0.11	0.367	0.21	-	-
Phosphate (P_2O_5)	-	-	-	0.05	-
TiO_2 (%)	0.025	-	0.035	0.14	-

Loss on Ignition (LOI)	-	1.1	-	-	-
SiO_2+Al_2O3+Fe_2O_3	**72.83**	**78.5**	**72.9**	**74.61**	**75**

❖ Chemical composition of glass powder is demonstrated in table 2-4. As it is shown major oxides concentrated in glass are of SiO_2, Na_2O, Al_2O_3, CaO and Fe_2O_3. Glass has higher, SiO_2, Na_2O, CaO but lower Al_2O_3 and Fe_2O_3 content. Glass chemical composition is in conformance with ASTM C618-02, which requires a sum of SiO_2 +Al_2O_3 +Fe_2O_3 higher than 70 percent for class N pozzolanic material.

2.6.3 Availability of Glass Waste

Glass production and uses have increased tremendously causing large amounts of generated waste glass materials. The IEA report estimated global production of glass in 2005 to be 130 million tons with container glass and flat glass accounting for approximately one fifth and one third of the total glass production respectively. In 2007, the total glass production in the world was about 89.4 million tons. Again, the EU countries were the largest glass producer, producing about 38.3 million tons, China and United States produced approximately 32 and 20 million tons respectively (IEA, 2007; Olofinnade & Ndambuki, 2017). Global production of glass in 2020 increased to 209 million tons produced annually. According to the EU report the total amount of glass production is expected to increase due to increase in industrialization and improvement in the living standard. However, there is no sufficient statistics on the quantity of waste glass generated in the world. In 2004, report by the UN estimated the volume of annual disposed solid waste in the world over to be about 200 million tons, of which 7% of the waste is made up of glass waste (EPA, 2011; Y. Jani & Hogland, 2014).

2.6.4 Impact of Glass Waste on Environment

Glass is a non-biodegradable material produced in many forms, colors and shapes, including container glass, bottle glass and flat glass. It is also an amorphous material containing relatively large amount of silica and calcium. As waste materials, its poses a major nuisance to waste management especially regarding landfill operations. Because of their nature, glass products take up a significant portion of landfill area, frequently leading to substantial environmental damage. Reusing these glass wastes is one of the best ways to reduce their negative environmental effects. (Tung-Chai, Chi-Sun, & Hau-Wing, 2013)

Table 2-5: Literature Review Summary of Glass Waste Related Study

Title	Journal Information	% Of Scoria replacement	Test conducted	Major Finding
Utilization of waste glass powder in the production of cement and concrete	(Aliabdo et al., 2016)	0%, 5%, 10%, 15%, 20% and 25%	Water requirement, setting time, Soundness Slump Compressive strength Tensile strength Water absorption Density TGA	Setting time and soundness of glass powder blended is similar to unblended Portland cement. Increases concrete slump & decreases the water requirement. Concrete compressive strength, tensile strength, absorption, voids ratio and density are improved by using 10.0% glass powder. 15% glass powder as cement addition increased concrete compressive strange by 16.0 percent and achieved better strength compared with control.
Waste glass powder as partial replacement of cement for sustainable concrete practice	(Islam & Kazi, 2017)	10–25% 5% interval	Flow Test Compressive strength X-ray fluorescence (XRF)	Slight increase in mortar flow was achieved with amount of cement replaced with glass powder. Lower mean compressive strengths compared to the control are obtained at 7, 14, 28 and 56 days age. The age of 90 days, glass concretes with 10, 15 and 20% glass addition delivered mean compressive strengths greater than the control 20% replacement of cement with waste glass was found undoubted

Partial Replacement of Cement with Glass Bottle Waste Powder in Concrete for Sustainable Waste Management: A Case Study of Kumasi Metropolitan Assembly, Ashanti Region, Ghana	(Nyantakyi, 2020)	30%, 50% and 70%	Slump test Dry Density Water Absorption compressive strength Split Tensile Test Ultrasonic Pulse Velocity Test XRD Tests Rebound Hammer Test	Slump flow were slightly lower compared to the control concrete mix and dry density of glass bottle concrete mix decreased Showed a decrease of water absorption as compared with control concrete mix. Compressive strength of concrete decreases. quality of concrete was outstanding as ultrasonic pulse velocity is 4.11km/s the study recommends a 30% glass powder to replace cement
application of Waste Glass Powder as a Partial Cement Substitute towards more Sustainable Concrete Production	(Olofinnade & Ndambuki, 2017)	0%, 15%, 18%, 21%, 24%, 27% and 30%	Strength activity index, workability, compressive strength split tensile scanning electron microscopy (SEM) X-ray fluorescence (XRF).	Concrete containing 21 percent cement replacement shows a higher strength index which is 99 percent. Workability of the concrete reduced with increase in percentage glass powder Significant improvement of the compressive strength of the concrete was achieved at 21% cement replacement More than 21% a decrease in strength with increasing percentage glass content was observed The tensile strength shows a reduction trend in strength at increasing glass powder. 20% cement replacement can be adopted as the optimum dosage level.

Sustainable Use of Recycled Glass Powder as Cement Replacement in Concrete	(Tamanna & Tuladhar, 2020)	10%, 20% and 30%	Slump Test, Density Compressive Strength Flexural and Tensile Strength Relative Water Requirement Rapid Chloride Permeability Test X-Ray Fluorescence (XRF)	Replacement level increased up to 30 GP, slump drastically increased due to less water affinity of GP A minor reduction in fresh density was observed with the addition of GP. Compressive strength decreases when GP content increase did not show any significant effects on the flexural strength and tensile Lower chloride permeability compared to that of control mix.
Waste Glass Powder as Cement Replacement in Concrete	(Hongjian & Kiang, 2014)	0, 15, 30, 45 and 60%	Heat of hydration Compressive strength Rapid chloride penetrability test Water penetration resistance SEM Electrical resistivity	Heat generated reduced continuously with higher OPC replacement level. The strength generally decreases with GP content more than 15%. At 28 and 91 days, no reduction in strength was observed for concrete with 15 and 30% GP, due to the pozzolanic reaction between GP and cement hydration product. the resistance to chloride ion and increases with the addition of glass powder and water penetration continuously increases with increasing glass powder content up to 60% cement replacement

Partial replacement of Portland cement with industrial glass waste in mortars	(Lopes & Piovesan, 2021)	10 %, 20 %, 30 and 40 %.	Alkali-silica reaction tests Pozzolanic activity Compressive strength XRD, TGA	Pozzolanic activity was studied chemically and physically and its use was deemed safe with regards to possible alkali-silica reactions The expansion is below from the restriction level Decrease in compressive strength The substitution of 20% showed to provide the best result
Study The Effect of Recycled Glass on The Mechanical Properties of Green Concrete	(Aseel & Zubaid, 2017)	11%, 13%, 15%	Slump Test Compressive Strength Flexural Tensile Strength Splitting Tensile Strength	Reduce the workability of the mixture The compressive strength and flexural tensile strength gets high value at 13% splitting tensile and flexural strength increase in all type of glasses more than the control concrete
Experimental Investigation on Strength of Glass Powder Replacement by Cement in Concrete with Different Dosages	(Sakale & Jain, 2016)	10% 20%, 30%& 40%	Workability Compressive strength Split tensile strength, Flexural strength	The slump of concrete decrease monotonically as the replacement Compressive, flexural and split strengths of concrete increase initially as the replacement percentage of cement with glass powder increases, and become maximum at about 20% and later decreases The replacement of cement up to about 20% by glass powder can be done without sacrificing the compressive strength

Investigation on the Mechanical Properties and Microstructure of Eco-friendly Mortar Containing WGP at Elevated Temperature	(Sedaghatdoost & Behfarnia, 2021)	0, 5, 10 and 15%	Compressive Strength Flexural Strength Mass Loss Petrography	Incorporation of Glass as partial replacement of cement Improve the strength of mortars at elevated temperatures Utilizing WGP in the cement mortars increases its flexural strength at all temperatures. The optimum percentage of replacement of cement with Glass powder at ambient and high temperatures was found to be 10%
Effect of Waste Glass Powder (WGP) on the Mechanical Properties of Concrete	(Olutoge, 2016)	0%, 10%, 20%, and 30%	Slump test Compressive flexural strength	The workability of concrete reduces as the percentage replacement of glass powder increases. Compressive and flexural strength reduce with glass powder content increase The optimum replacement level of glass powder for cement in concrete is 10%.
Partial replacement of cement in concrete using waste glass powder and m-sand as fine aggregate	(Shruthi & Chandrakala, 2015)	0%, 5%, 10%, 15%, 20% and 25%	Slump test Compressive Tensile strength Flexural strength	The slump of concrete appears to increment in glass powder in the concrete mix. The strength increases with addition of waste glass powder at 5%, 10% 15% and after that reduces at 20% and 25% It is found that addition of glass powder up to 15percent provide higher strength

2.6.5 Natural Pozzolan

Natural pozzolanic materials are formed by either the weathering and sedimentation of soil or the eruption of hot magma and rocks. In their native state, these minerals are additional cementitious materials. They mainly just need to be ground and sieved to the desired size. As a result, natural pozzolanic materials are divided into two categories: volcanic and sedimentary(Concrete, 2021).

I. Natural Pozzolans of Volcanic Origin

They are predominantly pyroclastic and made up of volcanic ash rocks. These minerals mostly consist of silica and alumina, with a minor quantity of alkalis and iron thrown in for good measure. Furthermore, weathering and geological change may alter the physical, chemical, morphological, and mineral content of these volcanic materials. Volcanic material are further classified into un-altered and altered pyroclastic materials

- Vitreous pumices, vitreous ashes, scoria, and tuffs are examples of unaltered pyroclastic materials
- Weathering and geological conditions are the primary causes of altered pyroclastic materials. This transformation transforms crystalline zeolites, such as zeolitised tuffs, into crystalline zeolites.

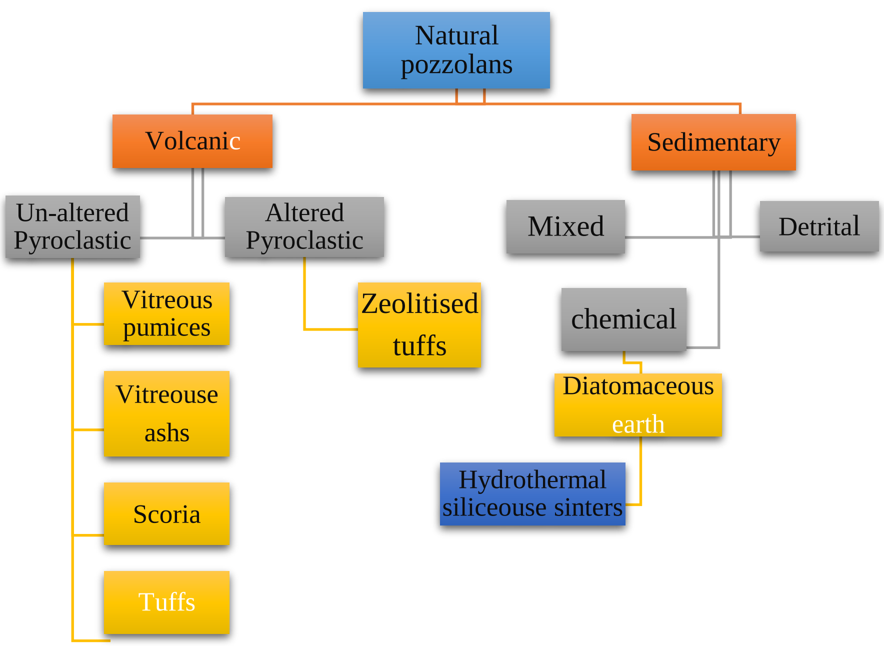


Figure 2-1:Classification of Natural Pozzolans (Concrete, 2021)

II. **Natural pozzolans of a Sedimentary Origin**

They are caused by weathering or erosion of rocks, as well as the accumulation of microorganisms and chemical substances, or both. There are two types of sedimentary natural materials: detrital and chemical, as well as a third class of mixed-origin sediments like Sacrofano.

2.7 Scoria

Scoria is a dark-colored igneous rock with vesicles, which are spherical bubble-like cavities. It comes in a variety of colors, ranging from black to dark gray to deep reddish brown. Scoria normally has a basalt-like composition, but it can also have an andesite-like composition. Small bits of scoria resemble the ash created in a coal furnace, according to many people (Hobart, 2005-2021).

2.7.1 Scoria Formation and Location

The Scoria consists of an explosive in the volcano, surplus gases, and volcanic ash when it erupts. Under extreme pressure, these gases dissolve in the magma. When the temperature drops below the surface, the magma from the volcanic explosion enters the air, releasing the pressure, and the magma solidifies. The gases in the melt are not liberated from the melt without solidification when the magma solidifies. These gases cause pores to be circular or lengthy. Otherwise, gases would not be squeezed. These pores were vesicles of rapidly emerging gas areas of melt solidification; otherwise, gases would not be crushed (Geologyscience.com, 2021).

Scoria is found in areas where the Earth's volcanic activity is active. It's a harsh rock with air bubbles that range from black to dark crimson in color. It is formed when gas escapes from a volcano and smashes the rock. Scoria has congregated around a volcano's vents. Scoria forms a cone-shaped mound called an ash cone. There are vast areas with multiple cone cones called volcanoes in different parts of the earth. Scoria-producing volcanoes usually have brief eruptions that last only a few minutes. It is frequently used as a lightweight aggregate in the landscape or in concrete (Geologyscience.com, 2021).

2.7.2 Chemical Composition of Scoria

Scoria is typically made up of 50 percent silica and 10 percent calcium oxide, with minor amounts of potash and soda. Plagioclase, pyroxene, and olivine are the primary components in this extrusive igneous rock. Apatite, biotite, hematite, hornblende, ilmenite, magnetite, and quartz are examples of minor minerals (Geologyscience.com, 2021).The chemical property of scoria summarized in table 2-6.

Table 2-6: Chemical Composition of Scoria

oxides	**Chemical composition by weight percentage**				
	Scoria Powder				
	(A. M. al-Swaidani & S. D. Aliyan, 2015)	**(Naaymi, 2015)**	(Dinku, 2005; Yifru & Mitikie, 2020)	**(Fufa & Ghebrab, 2019)**	**(Naaymi, 2015)**
Silica Oxide (SiO_2)	46.52	48.54	54.36	52.53	68.89
Aluminum Oxide (Al_2O_3)	13.00	16.51	16.27	15.49	13.17
Iron Oxide (Fe_2O_3)	11.40	12.24	11.02	11.0	3.43
Magnesium Oxide (MgO)	9.11	5.69	5.44	4.4	1.01
Calcium Oxide (CaO)	10.10	8.64	7.76	10.1	0.18
Potassium Oxide (K_2O)	0.77	1.01	1.6	<0.1	3.21
Sodium Oxide (Na_2O)	2.14	3.57	< 0.01	2.56	3.98
Sulfur trioxide (SO_3)	0.27	-	0.89	-	-
Phosphate (P_2O_5)	-	0.40	0.1	0.17	-
TiO2 (%)	-	1.85	0.62	0.88	-
Loss on Ignition (LOI)	2.58	1.82	1.78	0.85	1.1
SiO_2+Al_2O_3+Fe_2O_3	**70.92**	**77.29**	**86.65**	**79.02**	**85.49**

- The chemical composition of scoria is mainly composed of Silica Oxide (SiO_2), Aluminum Oxide (Al_2O_3), Iron Oxide (Fe_2O_3), and Calcium Oxide (CaO). The concentration of SiO_2+Al_2O_3 + Fe_2O_3 is higher than 70%, the requirement of ASTM 618.

2.7.3 Morphological, Chemical, and Mineralogical Composition of Scoria

The morphological and microstructural content of scoria samples from various regions was examined using FESEM analysis. Figure 2-2 depicts the FESEM analysis of SR samples. The FESEM analysis revealed that the morphological and microstructural components of the SR samples differed significantly. SR1 grains were discovered to be extremely porous, with small air bubbles of various sizes. SR2 exhibited a less porous structure with fewer air bubbles and a more homogeneous appearance, indicating a fused structure. As seen in Figure 2-2, SR3 had the lowest porosity and the maximum homogeneity (Fares & Alhozaimy, 2015).

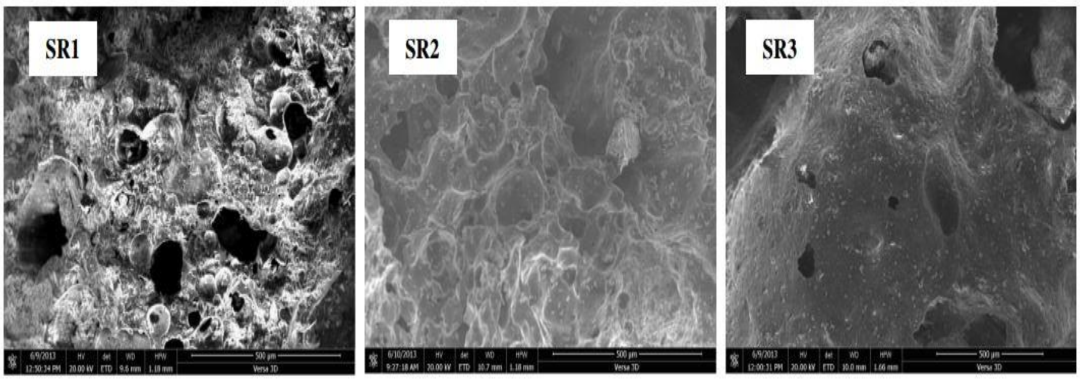
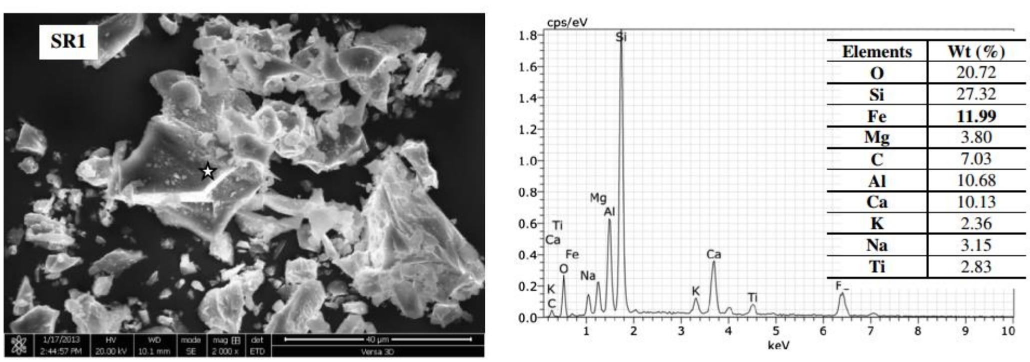


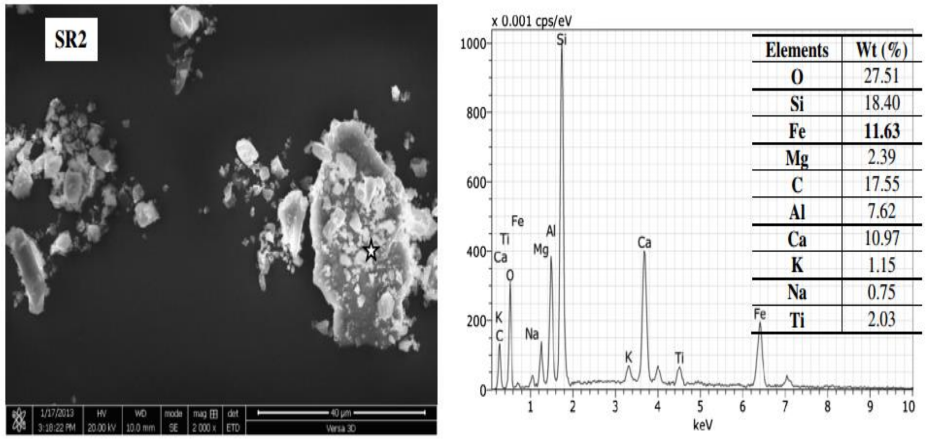
Figure 2-2: SEM Image of SRs

The EDS elemental spot analysis of the ground SRs is shown in Figure 2-3. The coarser SR particles were subjected to ED's elemental spot analysis, as indicated by an asterisk in each figure 2-3. Each FESEM photomicrograph has the intensity of each element and a weighted percentage next to it. As a tool for surface investigation, the EDS elemental spot analysis reveals the following:



Elements	Wt (%)
O	20.72
Si	27.32
Fe	**11.99**
Mg	3.80
C	7.03
Al	10.68
Ca	10.13
K	2.36
Na	3.15
Ti	2.83

FESEM-EDS Analysis of SR1



FESEM-EDS Analysis of SR2

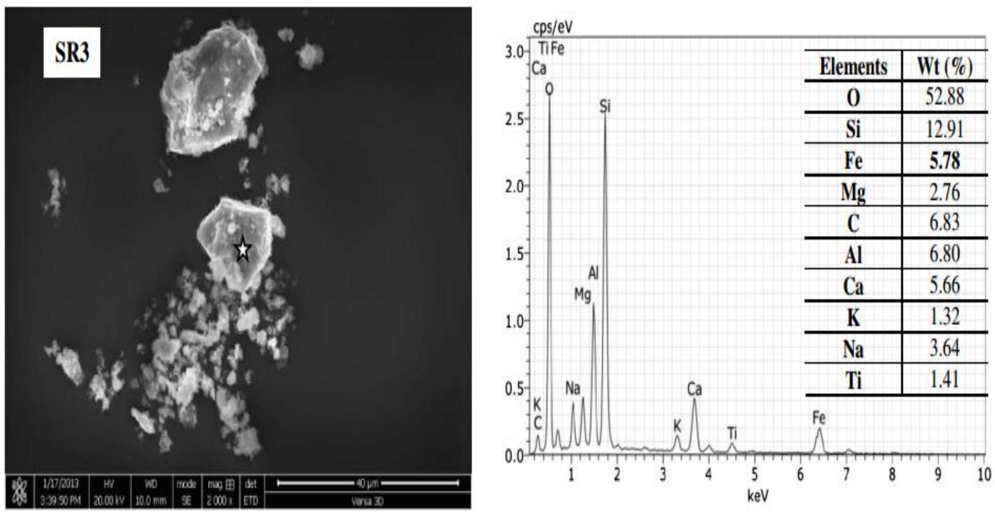
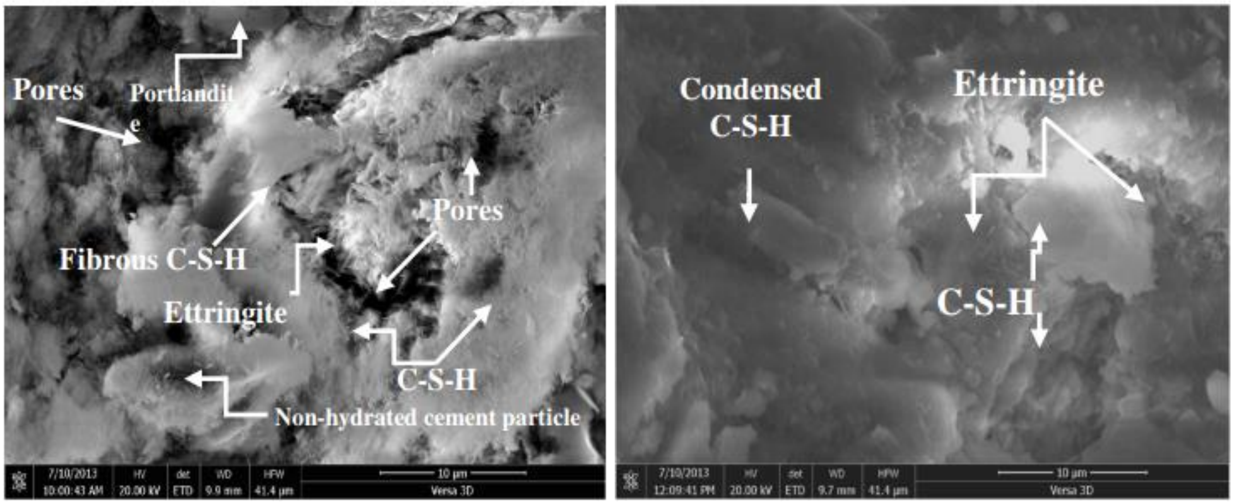


Figure 2-3: Microstructural FESEM-EDS Analyses of SR Particles

2.7.4 Microstructural Analysis of Scoria Blended Concrete

The FESEM microstructural analysis of freshly fractured surface at 28 days of CTRL, 20% SR3, concrete samples are shown in Figure 2-4. The microstructure of CTRL shows the presence of non-hydrated cement particles, micro-pores, as well as needlelike, sword-like and plate-like structures. The latter structures were identified as ettringite needles, C─S─H needles, and portlandite plates, respectively, which normally occupy the vacant areas, as shown in Figure 2-4(a). The microstructural analysis of the concrete mixture with 20% SR3 shows the minor presence of ettringite crystals with reduced micro-pores, as shown in Figure 2-4(b). This concrete mixture is characteristic with the presence of condensed C─S─H as the reaction product of SR3 grains with portlandite. The enhancement in the microstructure in the concrete mixtures with SR3 can be attributed to the formation of additional C─S─H, which generally fills in the pores, creates denser hydration products, and accordingly reduces permeability (Fares & Alhozaimy, 2015)



(a) (b)

Figure 2-4: SEM of Tested Mixtures: (a) Control; (b) 20SR3

2.7.5 Availability and Utilization of Scoria in Ethiopia

World pumice and related materials production was 21 million tons in 2020, Ethiopia remains the dominant producer of pumice and scoria, with production estimated to be 2.4 million tons in 2020 next to Turkey (Robert D. Crangle, 2021). The Main Ethiopian Rift (MER) began to open in the early-mid Miocene. Silicic volcanic eruptions dominated the southern and central MER, resulting in the formation of large-diameter calderas like those at Hawassa and extensive deposits of ash and pumice. As rifting progressed, basaltic and silicic volcanic materials erupted along the rift borders, depositing huge amounts of lava and pyroclastic debris on the MER's floor (Barberio MR, 1999). Scoria aggregate can be found across Ethiopia, particularly in the Great Rift Valley, which comprises over 30% of the country. In the north-eastern region of the nation, there are multiple scoria cones and a lava field. They were found predominantly in Adama, Bishoftu, Mojo, Butajira, and Giyon (D. Newill & K. Aklilu, 1980).

Table 2-7: Literature Review Summary of Scoria Related Study

Title	Journal Information	% Of Scoria replacement	Test conducted	Major Finding
Blended cement and lightweight concrete using scoria: Mix design, strength, durability and heat insulation characteristics	(Hossain, 2006)	0-40% 10% interval	alkali-silica reaction autoclave expansion strength activity index (SAI)	Mixes with 30 and 40% scoria content, satisfy the ASTM C 618 requirement of alkali–silica reaction The autoclave expansion of the cement paste mixes is decreased with the increase of scoria content. The SAI values range between 74 and 104% at 7 days and between 78 and 97% at 28 days recommends the use of 20% scoria
Chemical characterization of Patnos scoria (Ağri, Turkey) and its usability for production of blended cement	(Tolga & Tugba, 2012)	0%, 5% , 10% ,20%, 30%, 40%, 50%	X-ray diffraction (XRD), FTIR spectra Water demand, Soundness Setting Time (min.) Compressive Strength	Scoria has mainly amorphous structure some little crystalline mineral phases, anorthite and crystalline quartz Amorphous silica reacts with Ca $(OH)_2$ and forms cementitious materials Water demand, setting time increase Soundness and compressive strength decreases. Maximum replacement of 20% recommended.
Effect of Adding Scoria as Cement Replacement on Durability-Related Properties	(A. al-Swaidani & S. Aliyan, 2015)	0%, 10% , 15% 20 %, 25 % 30 % , 35%	Water demand, Soundness Setting Time (min.) Compressive Strength Accelerated Corrosion Test Rapid Chloride Penetrability Test	Water demand, setting time increases Setting time and soundness values meet the limits specified in ASTM C595 Compressive strength decreases longer corrosion initiation times, greater resistance to acid attack reduced the expansion of the mortar bars exposed to sodium

			Acid Attack Test Sulfate Attack Test	sulfate solution suggested that scoria can be used up to 30 % as a partial substitute for PC
Assessment of Pumice and Scoria Deposits in Dhamar Rada' Volcanic Field SW- Yemen, as a Pozzolanic Materials and Lightweight Aggregates	(Naaymi, 2015)	0%, 2%, 4%, 6% 8%, 10%, 12%	Water demand (%) Setting Time (min.) Compressive Strength	They have nearly the same water demand and Setting time increases with the scoria content increases compressive strength of scoria blended cement mortars decreases as the scoria content increases for all curing times suggested that scoria can be used up to 12% as a partial substitute for PC in production of blended cement
Production of more durable and sustainable concretes using volcanic scoria as cement replacement	(A. al-Swaidani, 2017)	0%, 10% , 15% 20 %, 25 % 30 % , 35%	Compressive strength flexural strength splitting tensile Water permeability Porosity Chloride penetrability	The compressive strengths of mortars and concretes containing scoria-based binders were much lower than those of plain cement mortar and concrete at early ages. Splitting tensile and flexural strength decrease in increasing scoria content Water permeability, chloride penetrability and porosity of scoria-based concrete mixes were much lower than those of plain concrete

Influence of scoria and pumice on key performance indicators of Portland cement concrete	(Mboya, 2019)	0%, 10%, 20%, 30%, 40%	Slump compressive strength shrinkage permeability	Slump decreased with increased in cement replacement. The compressive strength of 10% scoria blended cement shows better performance at 28 Day curing. Generally, reduction in compressive strength observed Result showed low shrinkage values for SN concrete b/c of microstructures with improved pore size and distribution caused pozzolanic reactions by the consumption of the CH and water in the pores by SN SN blended concrete at 10, 20, and 30% replacement levels, respectively, were very close to that of Portland cement concrete, However, at 40% cement replacement, the coefficient of permeability was very high, was due to the increased porosity.
Influence of volcanic scoria on mechanical strength, chemical resistance and drying shrinkage of mortars	(A. Al-swaidani & Aliyan, 2014)	10 %, 15 %, 20 % 25 %, 30 %, 35 %	Pozzolan activity index (ASTM C 618) Compressive strength Sulfate Attack Test Sulphuric acid resistance drying shrinkage	Pozzolanic activity index of scoria is 79 (at 7 days) 85 (at 28 days) Compressive strengths were comparable to the control mortar the increase of scoria significantly improved the sulphate resistance of mortars an increase in scoria addition improved the Sulphuric acid resistance of mortar, especially at the early days of exposure The results of drying shrinkage revealed that mortar bars exhibited a greater contraction when compared to the control mortar

Compressive Strength of Scoria Added Portland Cement Concretes	(Özvan & Tapan, 2012)	5%, 10%, 20%, 30%, 40%,50 %	Compressive strength XRD	results indicated that the compressive strength of the concrete mixtures with scoria added up to 30% exceeded the strength of the conventional mixture at 3, 7, 28 and 91 d Scoria added concrete mixtures (up to 30%) does not have the disadvantage of lower early strengths and therefore are suitable for structural concretes
Evaluation of Powdered Scoria Rocks from Various Volcanic Lava Fields as Cementitious Material	(Fares, Alhozaimy, Alawad, & Al-Negheimish, 2015)	0%, 20%, 30%	Fresh properties, compressive strength chloride-ion penetration resistance, scanning electron microscopy	a slight variation in the slump values of blended concrete mixtures with all replacement levels compared with the control mixture The compressive strength of concrete mixtures incorporating SRs is affected by both SR source and its replacement level SR mixtures yielded improved chloride-ion penetration

2.8 Gap Identification

Ethiopia remains the dominant producer of pumice and scoria, with production estimated to be 2.4 million tons in 2020, second only to Turkey. Scoria aggregate can be found across Ethiopia, particularly in the Great Rift Valley, which comprises over 30% of the country (D. Newill & K. Aklilu, 1980; Robert D. Crangle, 2021). However, Scoria is currently used mostly within the hollow-block housing industry (Hearn & Otto, 2019; Newill & K. Aklilu, 1980). These locally available materials have not been widely tested and approved for use in the Ethiopian construction industry due to a lack of confidence in using the material in concrete for structural purposes (Dinku, 2005; Yifru & Mitikie, 2020). Beside the sources of scoria affect the property of concrete incorporating scoria. For this reason, it is highly advised to investigate the scoria cones that have not yet been invested (Aref al-Swaidani, 2018; Fares & Alhozaimy, 2015) . Literature survey showed that no sufficient academic studies had been conducted on this scoria for its use as supplementary cementitious material in Ethiopia.

Research shows that glass has a chemical composition similar to standard supplementary cementitious materials (SCMs). Concrete incorporating glass powder possesses high pozzolanic reactivity when the glass powder exists in fine particles and has relatively high early strength due to the high content of Na_2O. Another study (Shevchenko & Kotsay, 2017) revealed that at the beginning of hydration production period, starting from the moment cement and water contact, the rate of heat realize is higher by 10-25% compared with that of the sample without glass. It means that alkali activity of glass powder acts as a catalyst, accelerator of hydration at the beginning of pre-induction period. Many authors claimed that scoria-containing concrete and mortar have low early strength due to the slow pozzolanic reaction at early age (A. Al-swaidani & Aliyan, 2014; A. M. al-Swaidani, 2017; DEPCI & EFE, 2012; Mboya, 2019; Naaymi, 2015). So this study also investigated the effect of glass powder incorporated with scoria powder on the rate of strength development. Previous researchers conducted a variety of studies on glass waste and scoria as cement replacement individually, but no research has been done by combining both Glass waste and scoria.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Introduction

The research consists of five main chapters; (1) introduction, (2) Review of the Literature, (3) Materials and Methods, (4) Experimental Work (5) Results and Discussion; (6) Conclusion and recommendation

The effect of partial replacement of Ordinary Portland Cement (OPC) with Scoria powder (SP) and Glass-Scoria powder (GPSP) on Mortar was investigated in this study. This chapter briefly discusses the methods (procedures), materials used, material attributes, design standards, test equipment, specimen mix proportions, and number of specimen. 20kg of scoria was collected from market and Glass powder collected from Bahir Dar university dump site. The scoria and glass were cleaned from any debris and dried in air. The scoria and glass sample were milled using a disk mill machine without any purification. The Chemical analysis of Scoria Powder and Glass Powder was done in the Ethiopian Geological Survey Laboratory.

The experimental groups are divided into two categories: control and experimental. The specimens in the control groups are produced and cast with Ordinary Portland cement. In this set of samples, there is no SP and GPSP substitution. The experimental groups are made up of specimens with varying amounts of SP and GPSP.

Main physical tests done to check the quality of fine aggregates such as gradation, density, moisture content, silt content, organic impurity, absorption, and specific gravity. To analyze the physical properties of Ordinary Portland cement and to investigate the effect of partial replacement of cement with varying amount of SP and GPSP proportions in cement paste, normal consistency, and setting time and soundness tests is carried out. Mortar cubes were casted according to ASTM C 109/M. ASTM specifies 2-inch mortar to investigate the property of mortar and ASTM C150 specified the minimum requirement of hydraulic cement paste and mortar. Mortar prepared with OPC and varying SP and GPSP percentage cement, tests for slump, compressive strength, sulphate attack, water absorption and ultra-pulse velocity (UPV) was carried out. Mortar was designed and Compressive strength test was done by taking standard casted molds of 5cmx5cmx5cm cube moist cured for 3, 7, 28, 56, 91.

3.2 Research Procedures

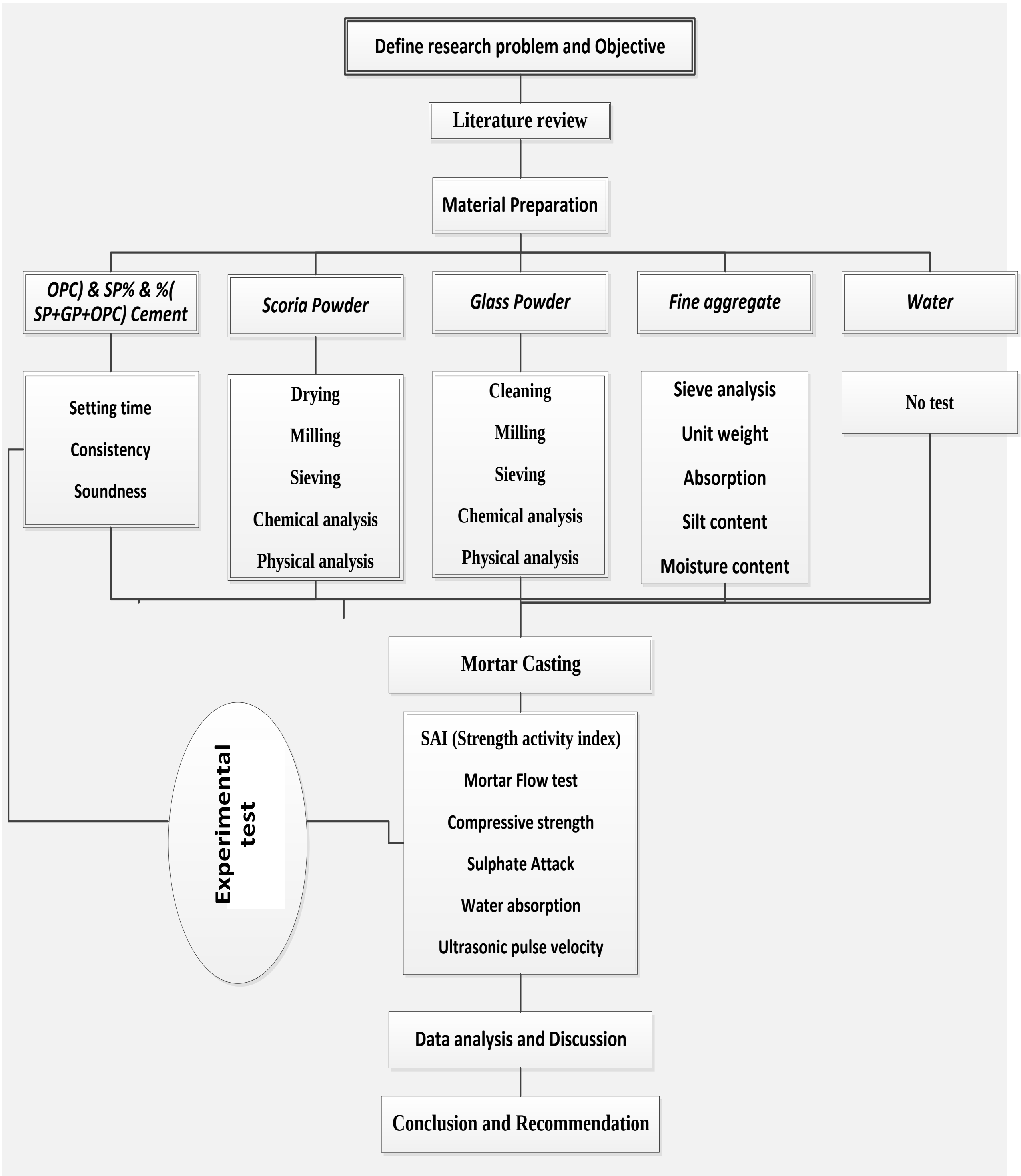


Figure 3-1: Research Methodology Flow Chart

3.3 Material Required

1. **Water**: Bahir Dar University potable water is used.
2. **Fine aggregate**: Natural River sand that meets ASTM C33 was used.
3. **Cement**: Derba ordinary Portland cement with grade 42.5N used.
4. **Scoria Powder:** Dried scoria gravel in air and pulverized to finely ground used.
5. **Glass Powder:** Clean flat Glass pulverized by disk mill used.

3.4 Test Method and Design Standards

3.4.1 Physical Property of Fine aggregate

The physical qualities of fine aggregates are examined in the laboratory using the following standards in Table 3-1 below.

Table 3-1: Tests on Fine Aggregate and Test Methods

No.	Properties	Standards
1.	Gradation	ASTM C136
2.	Bulk density (kg/m3)	ASTM C29
3.	Specific Gravity	ASTM C128
4.	Water Absorption (%)	ASTM C128
5.	Moisture	ASTM C566
6.	Silt content	IS 2386
7.	Organic content	ASTM C40

3.4.2 Physical and Chemical Property of Cement

The physical and chemical property of scoria and glass powder investigated using the following standard (Table 3-2).

Table 3-2: Tests on Cement and Test Methods

No.	**Properties**	**Standards**
1.	Complete silicate analysis	Geological Survey of Ethiopia test manual
2.	Specific gravity	
3.	Surface Area	Brunauer–Emmett–Teller (BET)
4.	Fineness of cement	ASTM C184

3.4.2 Physical Property of Cement

The physical property of control cement, binary and ternary blended cement investigated using the following standard (Table 3-3).

Table 3-3: Tests on Cement and Test Methods

No.	Properties	Standards
1.	Setting time	ASTM C191
2.	Consistency	ASTM C187
3.	Soundness	IS 4031-1988

3.4.3 Fresh and Hardened Mortar Properties

Properties of fresh and hardened mortar Properties are examined in the laboratory using the following standards (Table 3-4).

Table 3-4: Tests Method on Fresh and Hardened Cement Mortar Properties

No	Properties	Standards	Testing Date
a)	***Fresh Property of Mortar***		-
1.	Flow table test (workability)	ASTM C1437-07	-
b)	***Mechanical Properties of Mortar***		
1.	Strength activity Index (SAI)	ASTM C311	7-Day
2.	compressive strength of Mortar	ASTM C 109	3, 7, 28, 56, and 90
3.	Ultrasonic plus velocity (UPV) test	ASTM C597-16	
c)	***Durability Test***		
1.	Water absorption	ASTM C67	3, 7, 28, 56, and 90
2.	Sulfate attack	ASTM C109-109M/ ASTM C 1012	
d)	***Microstructure Test of Mortar***		
1.	Thermo gravimetric Analysis (TGA)	HENVEN ANALYSIS -HCT1	7&28-Day
2.	Differential thermal analysis (DTA)	HENVEN ANALYSIS- HCT1	7&28-Day
3.	Fourier Transform Infrared (FTIR)	Jasco FTIR-6600	7&28-Day

3.4.4 Mix Proportions and Experimental Design

A. Mix Proportions Of Binary Blended Mixes

Trial mix was done before deciding normal mixes. The proportion is determined based on (A. M. al-Swaidani & S. D. Aliyan, 2015) and (A. M. al-Swaidani, 2017) study, scoria powder decrease significantly the compressive strength at early age but strength at 90 and 180 days curing age is comparable to the control mix. The authors stated that scoria powder can replace cement up to 30%. After a trial mix was done up to 30% replacement the following normal mix was decided.

Table 3-5: Mix Proportion of Binary Blended Mixes

No.	Cement	Scoria powder (SP)	Mix designation
1.	100%0PC	0%	CT
2.	90%	10%	10SP
3	85%	15%	15SP
4.	80%	20%	20SP
5.	75%	25%	25SP

B. ***Mix Proportions of Ternary Blended Mixes***

Trial mix was done to decide the optimum scoria and glass powder composition to investigate further studies. 10GPSP, 20GPSP, 30GPSP, 40GPSP mix proportion was used for preliminary assessment of GPSP blended mix. All mixes except 40 GPSP mixes satisfy the minimum requirement specified by ASTM C150

Note; 30GPSP mix Selected and designed by variation of scoria and Glass powders to determine the effect of each material on cement mortar.

Table 3-6: Mix Proportion of Ternary Blended Mixes

No.	**Cement**	**Scoria powder (SP)**	**Glass Powder**	**Mix designation**
1	70%	7.5	22.5	22.5GP-7.5SP
2	70%	15	15	15GP-15SP
3	70%	22.5	7.5	7.5GP-22.5SP

3.4.5 Experimental Design

The experimental groups are divided into two categories: control and experimental. Specimens that are produced and cast with OPC make up the control group. In this collection of samples, there is no Scoria and Glass Powder substitute. The experimental groups are specimens with varying amounts of SP and GPSP. Compressive, Sulphate attack, water absorption and ultrasonic pulse velocity test specimens is manufactured for curing ages of 3, 7, 28, 56, 90 days. For each test substitution, three sets of mortar specimens will be produced. The total number of samples is 480 2-inch-mortar cubes.

Table 3-7: Total Number of Specimen Produced

MIX=CODE	**compressive, sulfate, absorption test, UPV**					**Total Cube**
	Cube AGE					
	3rd-Day	***7th-Day***	***28th-Day***	***56th-Day***	***90th-Day***	
CT	12	12	12	12	12	60
10SP	12	12	12	12	12	60
15SP	12	12	12	12	12	60
20SP	12	12	12	12	12	60
25SP	12	12	12	12	12	60
22.5GP-7.5SP	12	12	12	12	12	60
15GP-15SP	12	12	12	12	12	60
7.5GP-22.5SP	12	12	12	12	12	60
Total no. cubes for compressive, sulfate, absorption & UPV test						**480 cubes**

3.5 Data Analysis Methods

According to ASTM C109, the validity of the compressive strength test result was investigated to see if the experimental measure was valid when compared to the variable (compressive strength) score that was meant to be achieved. The compressive strength result for curing age of 3, 7, and 28 day was evaluated in accordance with ASTM C-150. The data will be analyzed using IBM SPSS Statistics version 20 software. Statistical analysis will be done by using Multivariate (MANOVA) and correlation

3.6 Experimental Work

3.6.1 Introduction

This chapter deals with the Experimental tests detail that conducted for the achievement of the specific objectives. After testing fine aggregate physical properties, chemical and physical property of finely grounded scoria and Glass powder was conducted in Ethiopian geological survey laboratory. Then after, ordinary Portland cement and blended cement tested. Different mixes prepared with vary amount of glass and scoria powder.

3.6.2 Glass and Scoria Preparation

Flat glass which is collected from Bahir Dar university disposal site and scoria aggregate collected from local market were processed with a disk milling machine and sieved with 150 micro-sieve and tested with 75 micro-sieve to obtain finer material conforming to IS 4031(Part-1996) recommendation.

Figure 3-2: Scoria and Glass Powder Preparation Procedures

A. RAW ***B. Milled*** ***C. Milled & Sieved***

Figure 3-3: Glass and Scoria Powder Production

3.6.3 Material Test

I. Fine Aggregate Test

As ASTM C33, fine aggregate is an aggregate, in which its' nominal maximum size is 4.75mm and minimum percent is passing through 0.15mm sieve. Washed fine aggregate free of injurious amounts of organic impurities and clay was used for the test. For this study, Belaya natural sand was used that meets ASTM C33 standard. Property of fine aggregate was tested according to ASTM standards. Brief explanation of experimental test described as follow.

A. Gradation

Fine aggregate sieve analysis done in accordance with ASTM C136 using wire-mesh sieves with square openings. 9.5, 4.75, 2.36, 1.18, 600, 300, 150 sieve size used. The range of particle sizes in sample aggregate and ASTM C33 Standard specification limits for fine aggregate is illustrated in Figure 3-4. According to ASTM C33 fine aggregate must not have more than 45% retained between any two consecutive standard sieves. The fineness modulus (FM) must be not less than 2.3 or more than 3.1. If the value is outside the required 2.3 to 3.1 range, the fine aggregate should be rejected unless suitable adjustments are made in proportions of fine aggregate.

Table 3-8: Sieve Analysis of Fine Aggregate

Sieve size (mm)	**Weight of sieve (gm.)**	**Weight of sieve & retained (gm.)**	**Weight of retained (gm.)**	**Percentage retained (%)**	**Cumulative percent Retained (%)**	**Cumulative percent pass (%)**	**ASTM C-33 limits**		
							Min	**Max**	**Remark**
9.5	686	686	0	0	0	100	100	100	OK
4.75	773	805	32	3.2	3.2	96.8	95	100	OK
2.36	737	812	75	7.5	10.7	89.3	80	100	OK
1.18	614.5	820.5	206	20.6	31.3	68.7	50	85	OK
600	603.5	943.5	340	34	65.3	34.7	25	60	OK
300	577.5	832.5	255	25.5	90.8	9.2	5	30	OK
150	572	652	80	8	98.8	1.2	0	10	OK
Pan	303	315	12	1.2	-	-	-	-	
Fineness modulus			**3.0**						

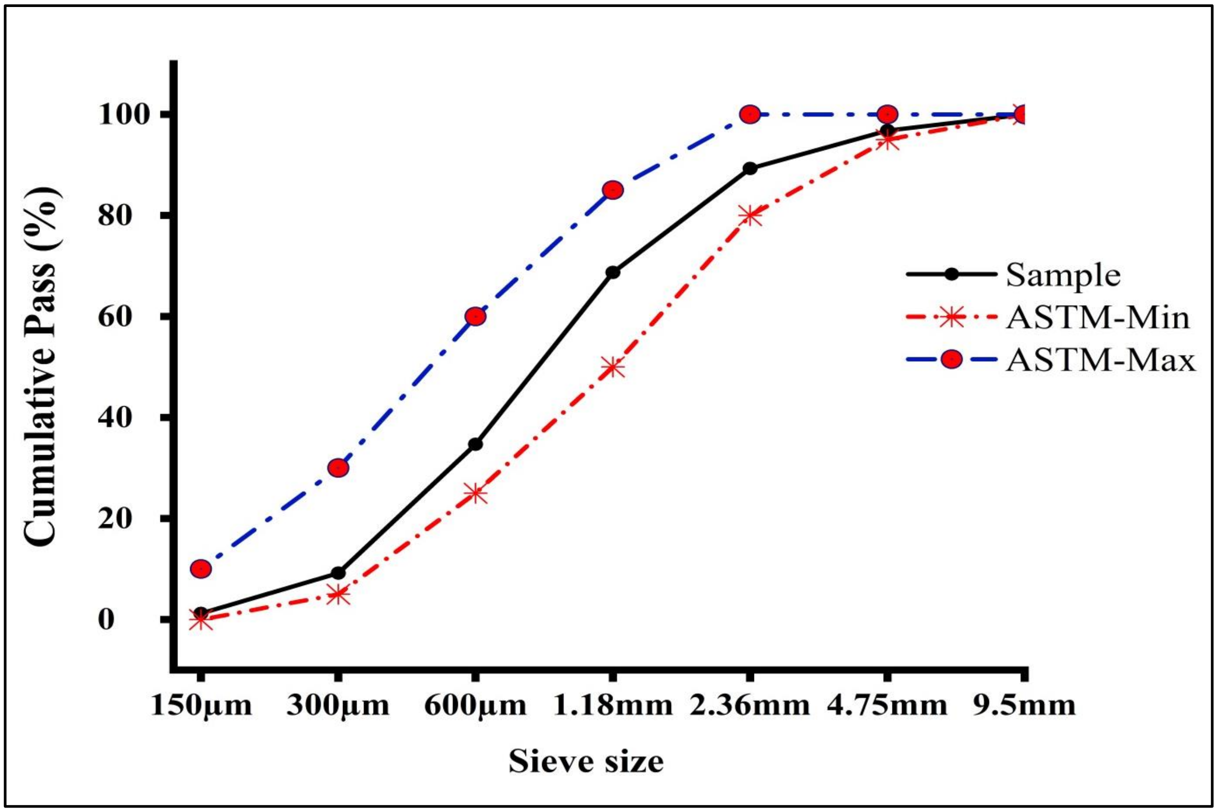


Figure 3-4: Particle Size Distribution

B. Specific Gravity and Absorption of Fine Aggregate

According ASTM C33 the relative density (specific gravity) of an aggregate is the ratio of its mass to the mass of an equal absolute volume of water. Most natural aggregates have relative densities between 2.40 and 2.90, which mean that the aggregates are 2.40 to 2.90 times as dense as water. Specific gravity and absorption of fine aggregate was done in accordance with ASTM C128. The specific gravity and water absorption value of used sample is 2.78 and 1.5% respectively.

C. Bulk Density

The bulk density or unit weight of an aggregate is the mass or weight of the aggregate required to fill a container of a specified unit volume. The volume is occupied by both aggregates and the voids between aggregate particles. The approximate bulk density of aggregate commonly used in normal-weight concrete ranges from about 1200kg/m^3 to 1750 kg/m^3 (75 lb./ft^3 to 110 lb./ft^3) (Kosmatka & Wilson, 2011).

D. Silt Content

Sand is obtained from glacial, river, lake, marine, residual and wind-blown. They often contain other material such as dust, loam and clay that are finer than sand. The presence of such material decreases the bond between the materials to be bound together and hence the strength of the mixture. The finer particles do not only decrease the strength but also the quality of mixture produced resulting in fast deterioration. Silt content of sample fine aggregate tested in accordance with IS 2386-2.

E. Organic Impurity

Natural aggregates may be sufficiently strong and resistant to wear and yet they may not be satisfactory for concrete-making if they contain organic impurities which interfere with the chemical reactions of hydration. The organic matter found in aggregate consists usually of products of decay of vegetable matter (mainly tannic acid and its derivatives) and appears in the form of humus or organic loam. Such materials are more likely to be present in sand than in coarse aggregate, which is easily washed. Sample aggregate tested in accordance with ASTM CASTM C 40-04.

Table 3-9: Evaluation of Physical Property of Sample Aggregate

Physical properties	**Test method**	**Test result**	**Specification**	**Range**	**Remark**
Fineness modulus	ASTM C136	3	ASTM C33	2.3 to 3.1	OK
Organic content	ASTM C40	colorless	ASTM C33	Colorless	OK
Silt content	IS 2386-2	2%	ASTM C33	Max 5%,	OK
Bulk density	ASTM C29	1636kg/m^3	S.H. Kosmatka	1200 - 1750 kg/m3	OK
Specific gravity	ASTM C128	2.78	S.H. Kosmatka	2.4 and 2.9	OK

3.6.4 Cement Tests

I. Conformance of SP and GPSP Powder to ASTM C 618

A natural pozzolans as a supplementary cementitious material in Portland cement must meet certain chemical and physical requirements. For instance, ASTM C 618 (ASTM, 2003) Class N additions must have a minimum SiO_2 + Al_2O_3 + Fe_2O_3 content of 70% and the maximum loss on ignition is limited to 10%.

The pozzolanic activity of a natural pozzolan is determined by finding its strength activity index, which is the ratio of the compressive strength of mortar cube test specimens prepared with a 20% pozzolan and 80% Portland cement mixture to that of control specimens prepared with 100% Portland cement. According to ASTM C 311, the tests on the mortar cubes may be conducted at 7 days or 28 days curing age or both. The strength activity index is calculated as in Equation (1):

- Strength activity index (SAI) = (A/B) *100………………………………. (1)

Where A is average compressive strength of test mixture cubes, and B is average compressive strength of control mixture Cube. ASTM C618 (ASTM, 2003) specifies that the test specimen must have a minimum of 75% of the strength of the control (SAI > 75)

The chemical property of SP and GPSP investigated and the chemical and physical requirement of pozzolans evaluated in accordance with ASTM C311 and ASTM C618. The strength activity index of SP and GPSP powder investigated at 7-day cube age.

II. Standard Consistency Test

For determination of standard consistency of different mixes, eight mixes were tested in accordance with ASTM C187-06 as shown in figure 3-5. Cement Mixes were mixed together using the laboratory Hobart mixer, in accordance with ASTM C305. To determine the amount of water required to form cement paste, different trials were taken by varying amount of water starting from a minimum percentage of water (26%) required to produce standard consistency. The paste shall be of normal consistency when the 10mm rod settles to a point 9mm to 11mm below the original surface in 30 seconds after being released.

Figure 3-5: Standard Consistency Test

III. Setting Time Test

The cement paste used for the determination of the time of setting is obtained by mixing 650 g of cement with the percentage of mixing water required for normal consistency in accordance with ASTM C187 as shown in figure 3-6. The cement paste specimen was allowed to remain in the moist room for 30 min after molding without being disturbed. Then the penetration of the 1-mm needle by allowing for 30sec on that time and every 15min thereafter was determined. Initial setting time was taken when a penetration of 25 mm or less was obtained. Final time of setting was taken when end point of 5mm needle does not mark the specimen surface with a complete circular impression. Initial and final setting time tests were taken as the cement physical tests as per ASTM C191-08

Figure 3-6: Setting Time Test

IV. Soundness Test

Soundness of cement may be determined by Le-Chatelier method in accordance with IS: 4031 (Part 3) – 1988. For determination of soundness lightly oiled mold was placed on a lightly oiled glass sheet and filled with cement paste formed by gauging cement with 0.78 times the water required to give a paste of standard consistency. Immediately it was submerging the whole assembly in the water and kept there for 24 hours and measured the distance separator to the nearest 0.5 mm. then the specimen was submerged again in water bath and the water brought to boiling point in 30 minute and kept it boiling for three hours. Removed the mold from the water, allowed it to cool and measured the distance between the indicator points as shown in figure 3-7.

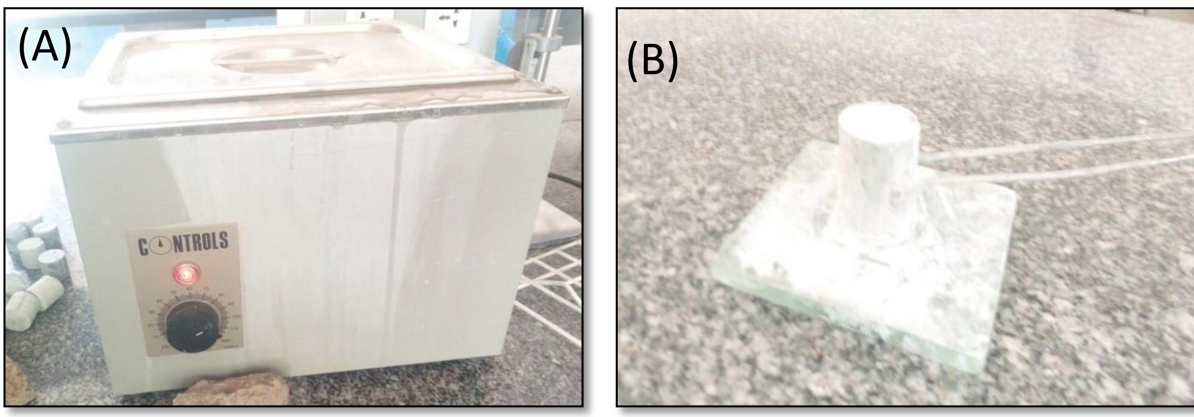


Figure 3-7: Water Bath (A) And (B) Le-Chatelier Mold With Sample

3.7 Cement Mortar Test

3.7.1 Flow Table Test

For determination of flow of different mixes, Mortar mixes were mixed together using the laboratory Hobart mixer according to ASTM C305. The mixing of the mortar first started with the control mortar to obtain a flow of 110 ± 5%. Sufficient amount of water was added to the mix to achieve this required flow. Different mixes with Scoria and Glass powder employed the same quantity of water. Immediately after mixing, the mortar was removed from the bowl, placed in a layer of about 25 mm in thickness in mold and was sufficiently tamped for 20 times. Then the mold filled with additional mortar and similar tamping was followed. When the mold was full the excess amount of mortar on the mold was removed and leveled. The test was carried out according to ASTM C1437 using flow table apparatus in accordance with ASTM C230. Four reading was taken after it was immediately dropped 25 times in 15 seconds as shown below in figure 3-8.

Figure 3-8: Flow Table Test

3.7.2 Mixing and Casting of Mortar Cube

Mix proportion was done per ASTM **C 109/C 109M**. The proportion of standard mortar was one part of cement to 2.75 parts of standard graded sand by weight. Water - cement ratio of 0.485 was used to all mixes to see the direct effect of cement replacement with scoria and Glass powder. The ingredients were mixed together mechanically using the laboratory Hobart mixer in accordance with ASTM C305. Two inch or 50mm test cube were used. The mortar mixes were filled in mold and compacted by a tamper 32 times in two layers. The cubes were cured one day in the mold and striped and cured in water until tested.

Figure 3-9: Hobart -Mixer

3.7.3 Curing

Curing plays an important role on strength development and durability of concrete and mortar. Curing took place immediately after the concrete was cast and expected to maintain desired moisture and temperature conditions, both at depth and near the surface, for an extended time. Concrete and mortar curing facilitates the continuation and extent of cement hydration. In this case, all of the mortar cubes were moist (water) cured in a laboratory curing tank until compressive strength testing as shown in figure 3-10.

Figure 3-10: Cured Mortar in Tanker

3.7.4 Compressive Strength and Sulphate Attack Test

As explained previously, mortar cube specimens were casted to determine the compressive strength of different mixes and the loss of compressive strength due to immersion in the sulfate solutions. The test was conducted using change in compressive strength by Test Methods of C 109/C 109M by modifying ASTM C1012. Specimens of different mixes were immersed in 5% Na_2SO_4, for 3, 7, 28, 56, and 90 days, respectively. The remaining specimens were submerged in water for curing age of 3, 7, 28, 56, and 90 days. The cube specimens were cured in the same way as the specimens immersed in the water. The compression strength of the cubes was determined after regular immersion periods (3, 7, 28, 56, 90 days) in sulfate solution and water

Figure 3-11: 28 Day Cured Specimen

3.7.5 Loading Rate

The strength of concrete is its resistance to rupture. It may be measured in number of ways, such as strength in compression, in tension, in shear, or in flexure. It is generally understood that the measured compressive strength of concrete increase with increasing loading rate as the stiffness increases with increased strain rate. Compressive strength decreases with decrease in rate of load because of creep effect. For this study a loading rate of 1800N/S used in accordance with ASTM C109.

A)

B)

Figure 3-12: Compression Strength Machine Used (A) and Screen Display (B)

3.7.6 Water Absorption Test

Water absorption tests were performed to determine the rate of water absorption of the Mortar samples. There were a few factors that may affect the water absorption rate, which include the use of additional materials, temperature and specimen exposure duration. For water absorption tests, the samples that have been cured for 3, 7, 28, 56 and 90 days were dried in the oven for 24 hours as shown in Fig 3-13 and let it cool before weighed. Subsequently, the samples are immersed in water for a period of 24 hours. After 24 hours, the samples were taken out from the water tank and dried using a dry towel before it was weighed. Percentage of water absorption was calculated using the formula below:

$$\text{Absorption\%} = \frac{(Wet-Dry)\ Mortar,gm}{Dry,\ \ Mortar,gm}$$

Figure 3-13: Specimen Oven Drying For Water Absorption

3.7.7 Ultra -Sonic Pulse Velocity Test

At the end of each curing day, three mortar cube samples were removed from curing tank and allowed to drain. They were, then, subjected to ultrasonic pulse velocity testing accordance with ASTM C 597 (2002)

Figure 3-14: Ultrasonic Pulse Velocity Apparatus Used

3.7.8 Micro structural test

Micro structure analysis was carried out on powder samples which were prepared by partially replacing with various percentage of scoria and glass powder. The percentage by weight is 0%, 15%, 25%, and 30%. Sample extracted from mortar is grinded into powder and sieved with 150 micro sieves. Then the sample dried in laboratory oven until constant weight measured to remove moisture content. TGA-DTA was done on DTA-TG apparatus, with 10 mg sample heated over the temperature range of 20 ^{o}C -900 ^{o}C at a constant rate of 20 ^{o}C under nitrogen atmosphere. FTIR analysis also was done on sample. Used apparatus shown in figure 3-15.

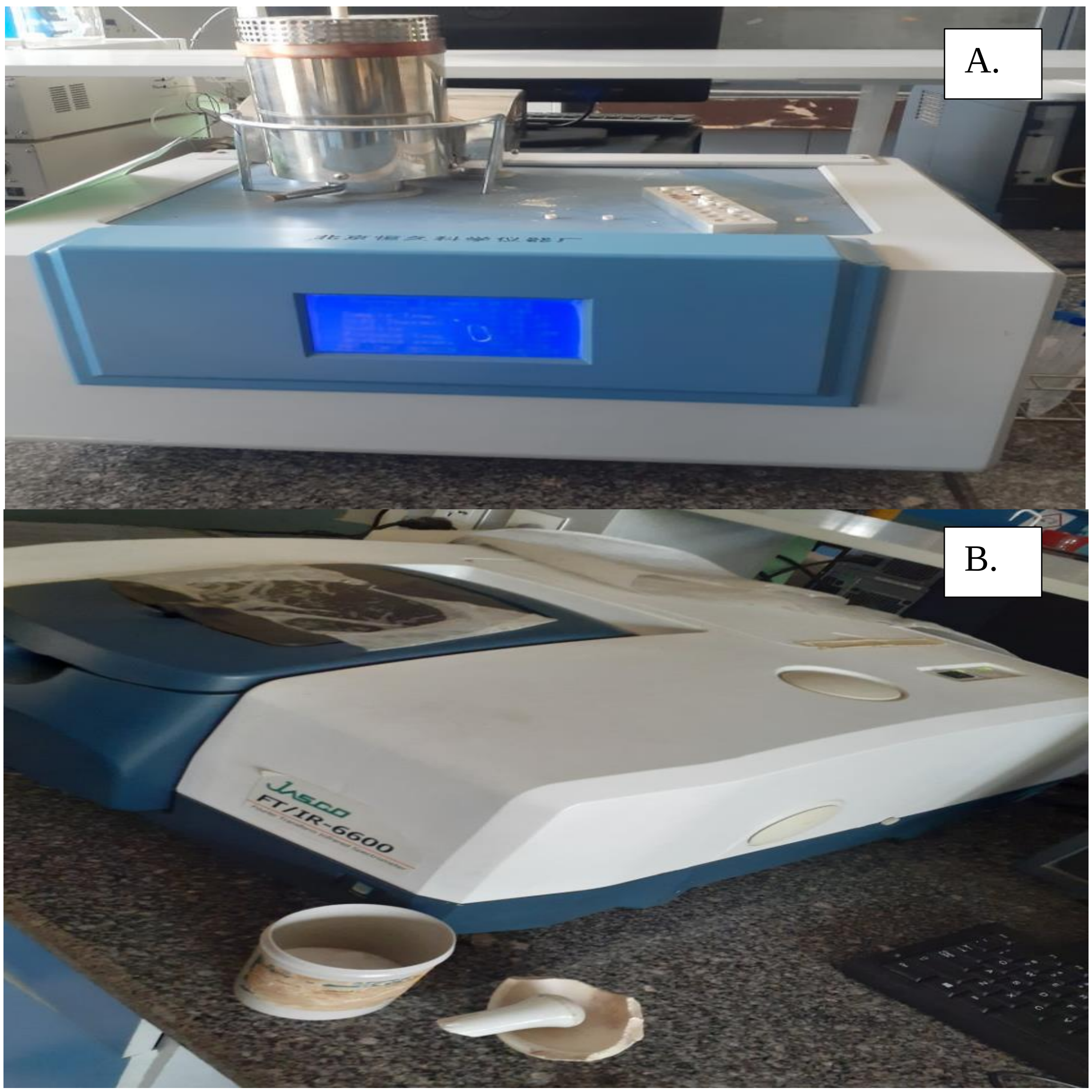


Figure 3-15 TGA-DTA (A) and FTIR (B) Apparatus

CHAPTER FOUR

4 Results and Discussions

4.1 Chemical and Physical Property of Glass and Scoria Powder

4.1.1 Chemical Property of Glass Powder

Silicon oxide is the largest ingredient in the Glass Powder, according to the Ethiopian Geological Survey's Mineralogical test as illustrated in table 5-1. Silicon oxide and aluminum oxide make up 77.72 and 3.11 percent of the total. The glass utilized in this study was mostly made up of SiO_2, Na_2O_3, CaO, and Al_2O_3.This indicates that the glass is Soda-Lime. Soda-lime glass accounts for 90% of all glass melted today, according to tonnage. Around 70% of soda-lime glass is Silica, 15% is soda, and 10% is lime (Phillips, 1941)

Table 4-1: Chemical Composition of Used Scoria, Glass, and OPC

No.	Oxide	Percentage by weight		
		Scoria Powder	**Glass Powder**	**Derba OPC Cement (KASSAYE, 2014)**
1.0	Silica Oxide (SiO_2)	48.4	75.9	22.7
2.0	Aluminum Oxide (Al_2O_3)	16.0	3.4	5.5
3.0	Iron Oxide (Fe_2O_3)	5.6	0.1	4.0
4.0	Magnesium Oxide MgO	5.2	3.2	1.8
5.0	Calcium OxideCO_2	17.1	6.3	60.0
6.0	Sodium Oxide (Na_2O)	3.2	10.2	0.2
7.0	Potassium Oxide (K_2O)	2.1	<0.01	0.5
8.0	Manganese Oxide (MnO)	0.0	0.0	
9.0	Sulfur trioxideSO_3			2.8
10.0	Phosphate (P_2O_5)	0.3	0.0	-
12.0	Water (H_2O)	<0.63	0.1	
13.0	Loss on Ignition (LOI)	0.9	0.4	0.8

4.1.2 Chemical Property of Scoria Powder

The primary oxides of scoria powder, according to chemical analysis, are SiO_2, Al_2O_3, Fe_2O_3, CaO, and MgO. Scoria is predominantly made of SiO_2 and is categorized as a siliceous material, depending on the primary oxide composition. This is important for binding because it forms compounds with the key components of cement, Tricalcium silicate and Dicalcium silicate, making it a substance with good binding qualities. Table 4.1 shows the chemical composition of glass, Scoria, and Scoria-Glass composition.

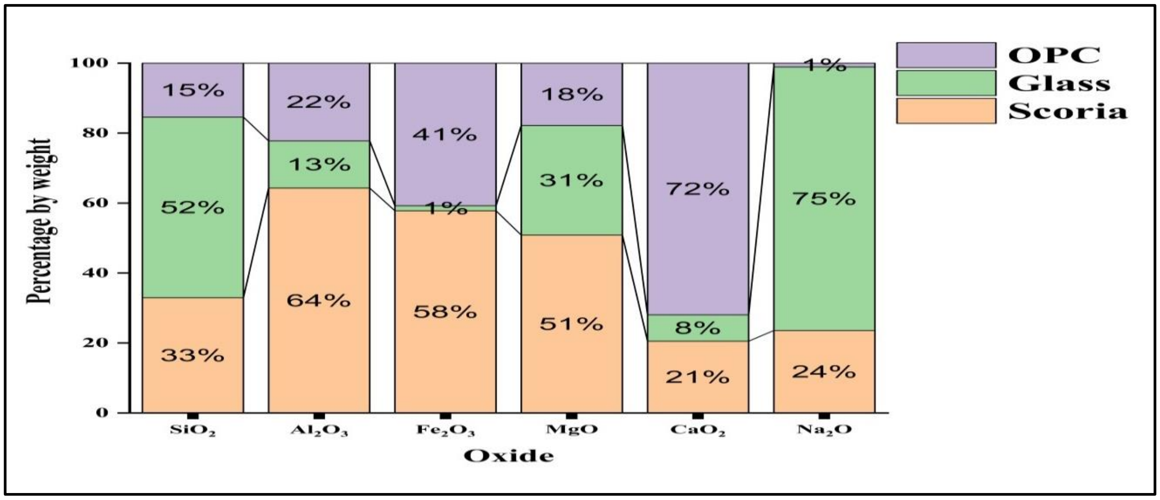


Figure 4-1: Major Chemical Composition of Scoria, Glass Composition

4.1.3 Physical Properties of Scoria Powder and Glass Powder

Flat glass and scoria were processed with a disk milling machine to obtain finer material than 150 micrometers, with the remainder of the sample being discarded and tested for fineness according to ASTM C 184. As illustrated below, the specific gravity of scoria and glass powder was examined. The standard value of fineness of cement should not be more than 10% as per IS recommendation. Used sample OPC and blended cement fulfill the requirement

Table 4-2: Physical Property of Used Glass and Scoria Powder

Physical Property	***Finely grounded Scoria powder***	***Finely grounded Glass powder***	***Derba Cement***
Passing150mm sieve	100%	100%	100%
Passing 75µm sieve	91.5	93.7	93%
Residue from 75 µm sieve	8.5%	6.3%	7%
BET (Surface Area)	283.692 m²/g	564.690 m²/g	415.532 m²/g
Specific gravity Are	2.85	2.51	3.15

4.1.4 Evaluation of Glass and Scoria Powder

The overall SiO_2, Al_2O_3, and Fe_2O_3 concentration in Glass and Scoria is 80.83 percent and 70.02 percent, respectively, which is higher than the ASTM C 618 Class N minimum requirement. There is no Sulphuric trioxide, and the moisture content and loss of ignition are both substantially lower than the ASTM standard's upper limit.

For the results of samples at 7 days, the strength activity index is determined, which is the ratio between the strength of the tested samples and the strength of the control samples. SP and GPSP have strength activities of 80.1 and 96.7, respectively, as indicated in table 4-3. As required by ASTM C 618, the SAI values are greater than 75%. Scoria blended mix test results are similar with the findings of a research conducted by (A. Al-swaidani & Aliyan, 2014). A pozzolans activity refers to both its ability to bind lime and the rate at which the binding reaction occurs; hence, it encompasses all of the processes that occur between the active components of the pozzolan, lime, and water. Pozzolans reactivity is governed by its chemical and mineralogical composition, the type and proportion of its active phases, the specific surface area of the particle, the lime-to-pozzolan ratio, water content, curing time, and temperature (Massazza, 2007)

GPSP powder strength activity surpasses SP powder; this could be due to the high amorphous structure of Glass powder and the alkalies in glass. Strength is primarily determined by the amorphousness and particle size of the pozzolan, according to (Walker & Pavı´a, 2011): a clear association between increasing amorphousness and increasing strength was demonstrated for all pozzolans.

Table 4-3: Test Report Comparing 'GP and SP' With the Requirements of ASTM C618

ASTM C 618 requirements		**Class N**	**Glass powder**	**Scoria powder**	**Composite of Glass and Scoria(GPSP)**
Chemical Requirement	$SiO_2+Al_2O_3+Fe_2O_3$ min	70	79.41	70.02	74.9
	Sulphuric trioxide (SO_3) max	4	-	-	-
	Moisture content max.	3	<0.01	0.63	0.4
	Loss on ignition (LOI) max.	10	0.59	0.9	0.7
Physical Requirement	Strength activity index at 7 days as percentage of control min.	75	-	80.1	96.7

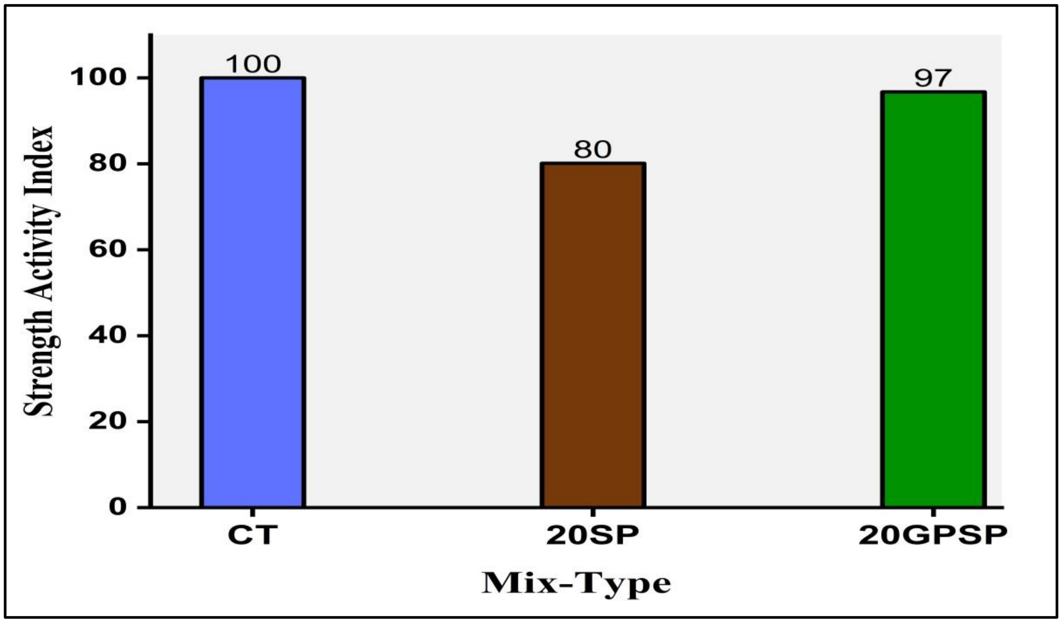


Figure 4-2: Strength Activity Index at 7-Day

- SP and GPSP blends meet both chemical and physical property requirements. As a result, Scoria in addition, Glass-Scoria has the potential to be utilized as an ingredient to Portland cement in the production of blended cement.

4.2 OPC, Binary and Ternary Blended Cement Test

4.2.1 Consistency Test

The amount of water required for normal consistency is expressed as a percentage of the dry cement's weight. The amount of water required increases with fineness, but is also affected by the cement composition. There are no specifications for the water content at normal consistency. The typical values for commercial Portland cements range from around 22 to 28 percent, slightly higher for Portland cements incorporating natural pozzolans, and lower for high alumina cements (Popovics, 1992).

The obtained experimental results (Table 4-4) demonstrate the effect of the SP and GPSP content on the water demand (w/cm ratio) in pastes to reach normal consistency. They almost have the same water demand ratio. As shown in Table 4-4, there was no significant change in water content even for the binder comprising 30% GPSP powder, which increased by only 0.7 percent compared to the Control Mix (CT). When a large amount of Glass Powder was added to ternary blended mix, the water demand of the ternary blended cement reduced. The possible reason for the increase of absorption in SP blended cement could be the porosity of scoria. The replacement of cement with 10% to 25% SP & GPSP provides the normal consistency with 26.2 % to 26.7% of water.

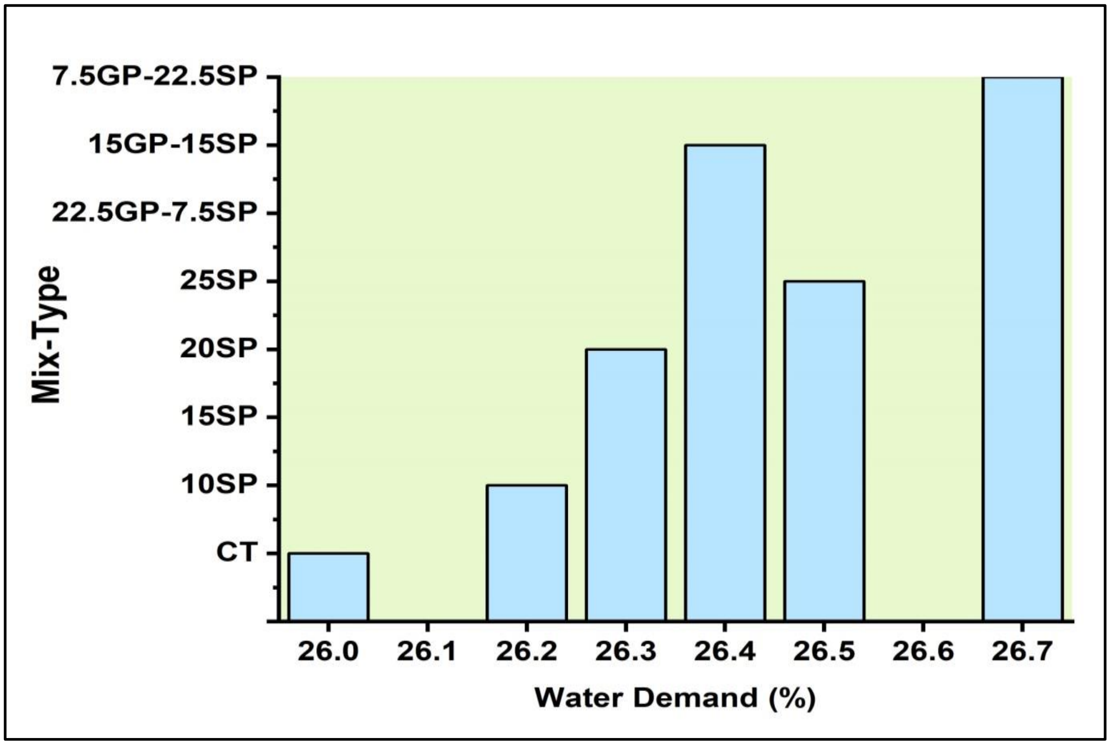


Figure 4-3: Water Demand of Cement

Table 4-4: Normal Consistency Cement

Mix-Type	Consistency (%)
CT	26
10SP	26.2
15SP	26.3
20SP	26.3
25SP	26.5
22.5GP-7.5SP	26.4
15GP-15SP	26.4
7.5GP-22.5SP	26.7

4.2.2 Setting Time Test

The initial and final setting times measurements performed on binary and ternary cement samples containing varied amount of SP and GPSP including control cement are presented in Table 4-5. The trend of variation in setting times shows an increase of initial and final setting time with the increase of SP powder and GPSP powder content (Figure 4-4) however; setting time was within limits as specified by the Ethiopian standard and ASTM C150. Initial setting time is increased from 75 min to 90 min. while final setting time is increased from 315 min to 345 min as the SP powder content is increased from 0 to 25% respectively. The Glass powder content increase the initial setting time to 105 min., and the final setting time is increased to 375 min. from the results it noted that setting time increases as the percentage replacement of cement with SP and GP increases. This indicates that the hydration process of cement was slowed down because of the increment percentage of SP and GPSP.

Table 4-5: Setting Time Test Result of OPC and Binary and Ternary Blended Cement

Mix-Type	**Initial setting time(min)**	**Final setting time(min)**	**Standard-setting time(min), ASTM C150**		
			Initial(min)	Final(max)	Remark
CT	75	315	45	375	Ok
10SP	82.5	330	45	375	OK
15SP	86	330	45	375	OK
20SP	87	345	45	375	OK
25SP	90	345	45	375	OK
22.5GP-7.5SP	105	375	45	375	OK
15GP-15SP	97.5	360	45	375	OK
7.5GP-22.5SP	95	345	45	375	OK

The reason for the increase in setting time is the presence of silicon oxide in SP and GP powder which exhibits the retarding of cement paste by contribute to the change in setting time, depending on the onset of the pozzolanic reaction (Aydin & R.Gul, 2007). The rise of SiO_2 results in reduction of C_3S percentage in cement paste which attributed to the delay of setting time. Since C_3S contributes to initial setting time of cement paste. The results showed that setting time retardation using more Glass powder in ternary blended cement powder is higher than any other mixes. This could be the presence of large amount of silicon oxide in Glass powder.

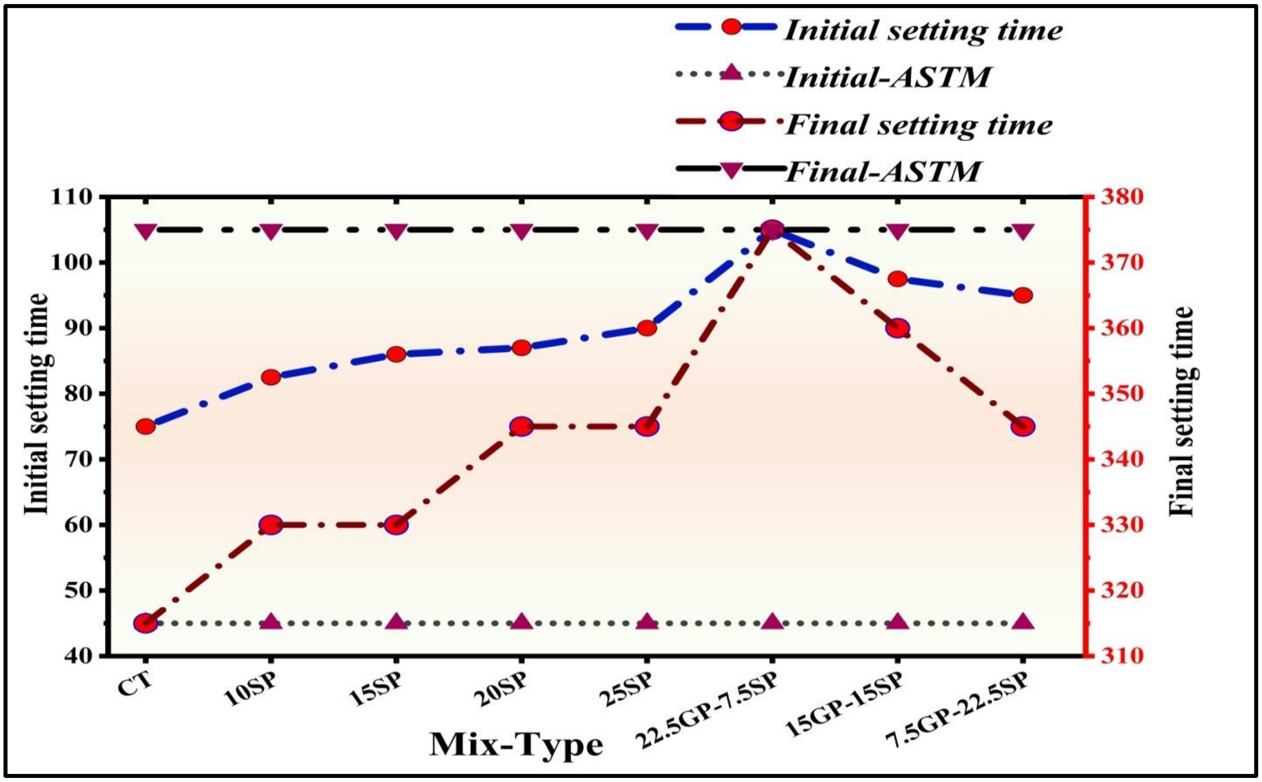


Figure 4-4: Initial and Final Setting Time of Cement

- The Ethiopian standard limits the cement final setting time not to exceed 10 hours, while the initial setting time not to be less than 45 minutes. ASTM C150 limits the initial setting time of hydraulic cement should be ≥45 min and ≤375min.

4.2.3 Soundness Test

It is essential that cement paste, once it has set, does not undergo a large change in volume. In particular, there must be no appreciable expansion which, under conditions of restraint, could result in a disruption of the hardened cement paste. Such expansion may take place due to the delayed or slow hydration, or other reaction, of some compounds present in the hardened cement, namely free lime, magnesia, and calcium sulfate(Neville, 2011).

According to(A. Al-swaidani & Aliyan, 2014) Since the free lime ratio will decrease as the natural pozzolan addition ratio increase, a decrease in the soundness can be expected. According to the experimental results, soundness decreases as the scoria content increase. As shown in figure 4-5, the volume expansions of samples having higher amounts of scoria and Glass powder show a visible drop compared to the control. This result indicates expansion of cement can be reduced by the incorporation of SP and GPSP.

Table 4-6: Soundness Test Result of Cement

Mix-Type	CT	15SP	25SP	15GP-15SP
Soundness	4.5	3	2.5	1.75

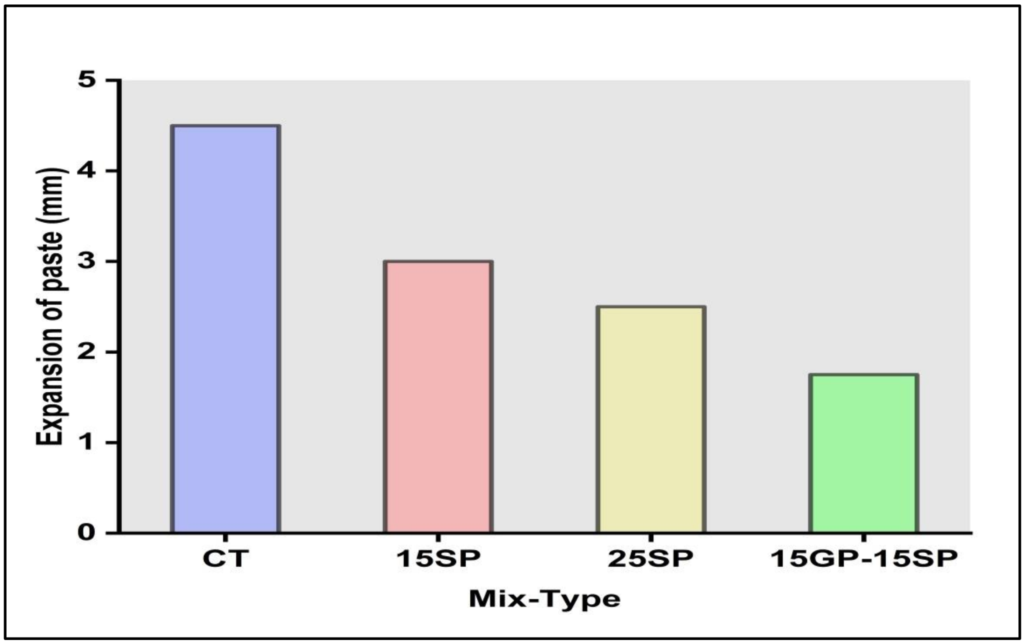


Figure 4-5: Soundness of Cement

4.3 Property of fresh and hardened Mortar

4.3.1 Flow of Mortar

The relationship between flow and the percent of cement replaced was studied. General decrease in flow observed as amount of scoria and glass increase. the result showed that at 10% replacement, scoria blended cement was slightly lower that of control and the flow keep reducing up to 25% replacement and when Glass powder used in high amount, it shows better workability than the other ternary blended mix. This may be because of low water absorption glass powder than scoria. According to (Mboya, 2019) the causes of flow reduction may be due to reduction in lubricity and stiffening of mortar arising from reduced heat of hydration of cement and increased water absorption.

Table 4-7: Workability (Flow Table) Test Result

Mix-Type	Workability (Flow Table)	
	Average slump (cm)	Mortar flow (%)
OPC	21.45	114.5
10SP	21.175	111.7
15SP	20.725	107.3
20SP	19.225	92.3
25SP	17.1	71
22.5GP-7.5SP	19.5	95
15GP-15SP	19.175	91.7
7.5GP-22.5SP	17.95	79.5

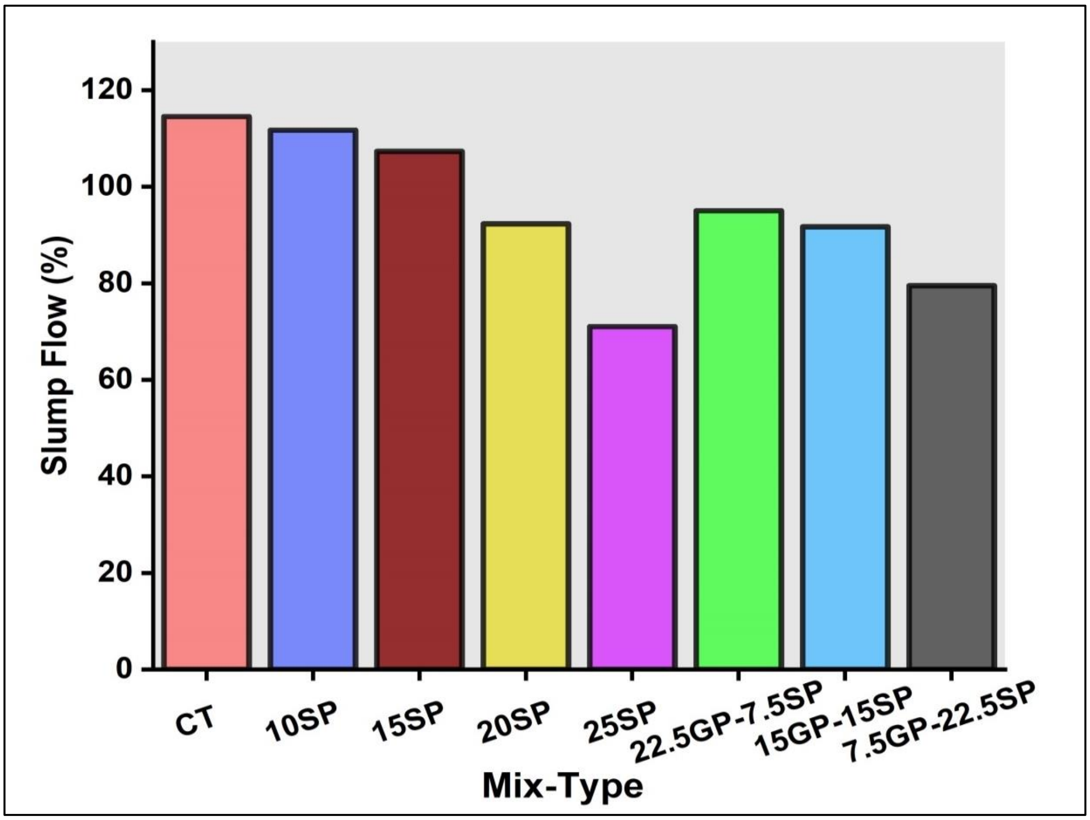


Figure 4-6: Slump Flow of Mortar

4.3.2 Water Absorption

The volume of pore space in concrete and mortar, as distinct from the ease with which a fluid can penetrate it, is measured by absorption; the two quantities are not necessarily related. Absorption is usually measured by drying a specimen to a constant mass, immersing it in water, and measuring the increase in mass as a percentage of dry mass. Various procedures can be used, and widely different results are obtained (Neville, 2011) . Water absorption is increased with an increase in the percentage content of SP and GPSP at all curing ages. Water absorption showed the highest results with 13% at 25%SP replacement, while the result is showed the lowest water absorption of 9.6% Control mix at age of 90days.

Table 4-8: Water Absorption of Mortars

Mix-type	**Mean water absorption capacity (%)**				
	3rd-Day	**7th-Day**	**28th-Day**	**56th-Day**	**90th-Day**
CT	11.2%	10.9%	9.9%	9.5%	9.6%
10SP	11.8%	11.4%	10.5%	9.8%	9.7%
15SP	11.9%	11.4%	10.9%	9.9%	9.7%
20SP	12.7%	11.6%	11.1%	10.9%	10.4%
25SP	13.0%	11.7%	11.3%	10.9%	10.6%
22.5GP-7.5SP	12.8%	12.1%	11.7%	11.6%	10.6%
15GP-15SP	12.6%	12.1%	11.6%	11.4%	10.9%
7.5GP-22.5SP	12.5%	11.9%	11.4%	11.3%	10.8%

It is observed that the water absorption for all SP and GPSP mortar are higher at early age and slightly higher at later age than that of CT at all curing age.

From the figure 5-6 shows that the high rate of water absorption at the early age of mortar specimen and Water absorption rate decrease gradually with curing age of mortar specimen. This might be due to denser and more compacted structure with the progress of the cement hydration which resulted pore refinement by the formation of cementitious phases, such as C-S-H and C-A-S-H. These might be formed through the continuation of cement hydration and the progress of the pozzolanic reaction between the amorphous Silica and CH released during cement hydration.

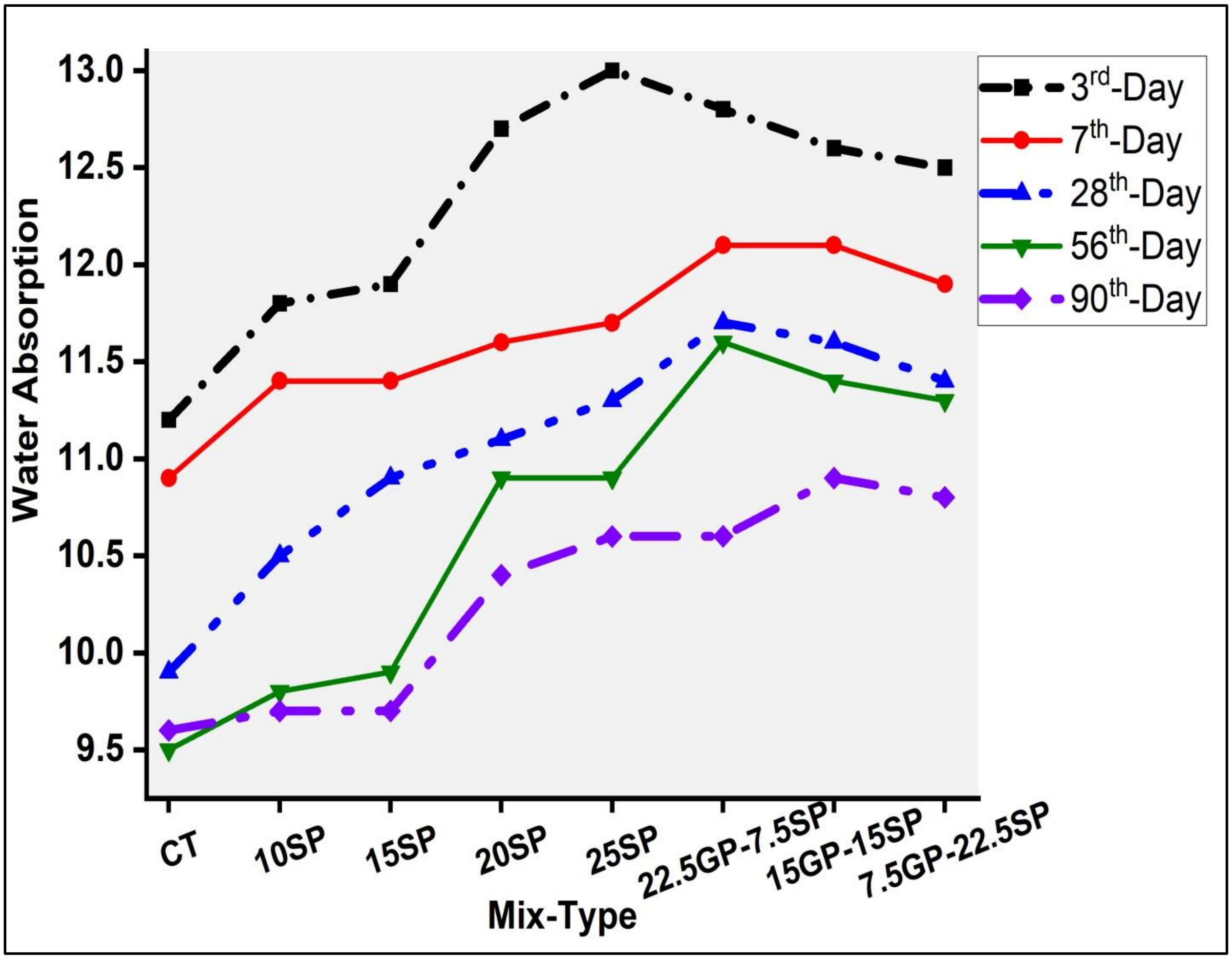


Figure 4-7: Water Absorption Of Mortar

4.3.3 Ultra-Sonic Pulse Velocity

Ultrasonic pulse velocity test result of mortar specimen is tabulated in Tables 4-9, from the result it would be noted that the ultrasonic pulse velocity decrease with SP and GPSP replacement and increase with increase in the age of mortar. Figure 4-8 shows, the effect of curing condition on average ultrasonic pulse velocity test. 3, 7, 28 Day curing condition have a great influence on UPV. The test results revealed that 3^{rd} and 7^{th} days of curing are relatively low compared to the result of the remaining curing days. After the curing age of 28^{th}-day the UPV variation decrease and remain constant at the age of 90-Day.

Control specimens has higher UPV value at the age of 3^{rd} ,7^{th} Day and 28^{th}-Day compared to binary and ternary blended cement. This is may be because of high compressive strength due to early strength of ordinary Portland cement, early development of hydration reaction leads to a denser material with a reduced capillary pore Network. In blended mix case SP and GPSP influences strongly the UPV value at Early Age which is lower UPV value. Furthermore, it is well known that the amount of Silica in pozzolanic material delay the compressive strength gain as a result of pozzolanic reaction between the Ca (OH) generated in the hydration process of the compound and the reactive SiO_2.

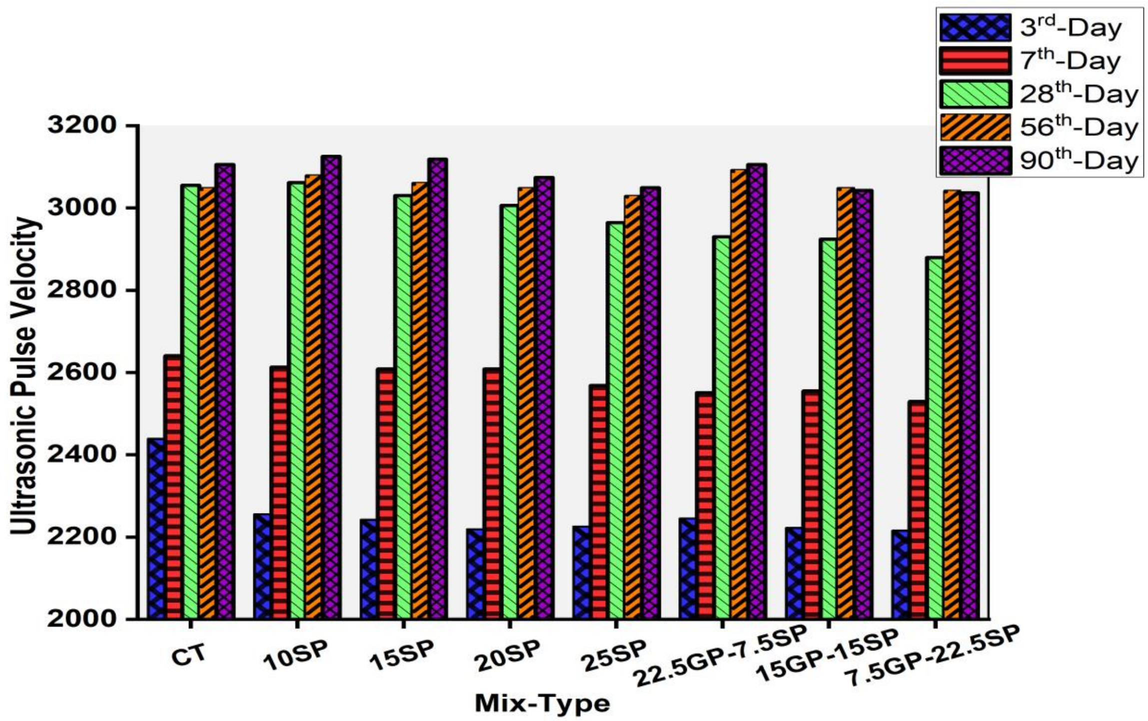


Figure 4-8: Ultrasonic-Pulse Velocity of Mortar

Table 4-9: Ultrasonic Pulse Velocity

Mix-type	3rd-Day	7th-Day	28th-Day	56th-Day	90th-Day
OPC	2439.0	2640.8	3055.0	3048.8	3105.6
10SP	2255.6	2613.2	3061.2	3080.1	3125.0
15SP	2242.2	2608.7	3030.3	3061.2	3118.5
20SP	2218.9	2608.7	3006.0	3048.8	3073.8
25SP	2225.5	2568.5	2964.4	3030.3	3048.8
22.5GP-7.5SP	2245.5	2551.0	2929.7	3092.8	3105.6
15GP-15SP	2222.2	2555.4	2924.0	3048.8	3042.6
7.5GP-22.5SP	2215.7	2529.5	2879.1	3042.6	3036.4

4.3.4 Compressive Strength

A. Binary Blended Cement

The results of compressive strength of 2-inch mortar made using scoria and scoria-Glass composite as cement replacement are shown in table 4-10. Compressive strength for the dried samples was determined after normal curing age of 3, 7, 28, 56, and 90-days, samples which immersed in potable water is presented in Figure 4-9**.** The results show that the compressive strengths were observed to decrease, as SP replacement increases. The strengths of mortar mixtures with 10SP, 15SP, 20SP, and 25SP Mixes are lower at 3, 7, and 14 days, than those of the control. The reduction in compressive strength can be explained with the lower cement content which had a bad impact on early-age strength due to the delay in pozzolanic reaction Rather than the control. However, at 28 days and 56 days, the strength of 10%SP and 15SP is higher than the control mixes respectively and kept increasing. This result was also observed by (Tumaini & Abeid, 2021) when 10% Scoria were used as partial substitution of cement in concrete production.

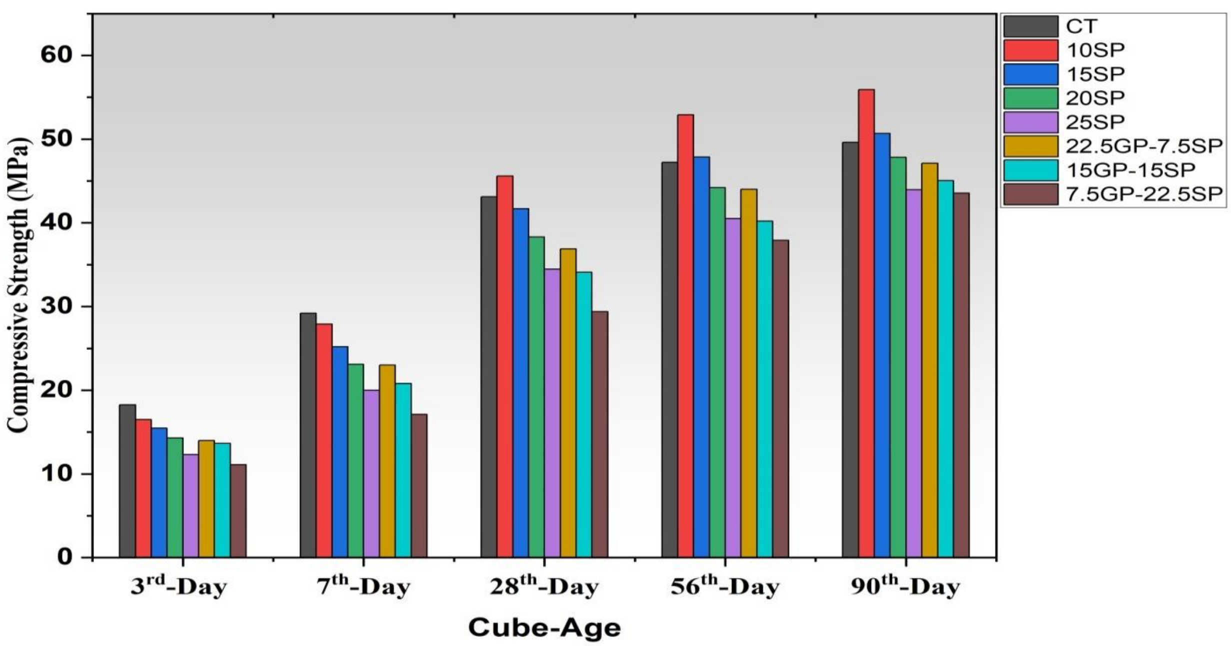


Figure 4-9: Compressive Strength of Mortars

Table 4-10: Mean Mortar Compressive Strength Test Results

Mix-Id	**Mean compressive strength of different cube age**									
	3rd-Day		**7th-Day**		**28th-Day**		**56th-Day**		**90th-Day**	
	MPa	***MPa (%)***	***MPa***	***MPa (%)***	***MPa***	***MPa (%)***	***MPa***	***MPa (%)***	***MPa***	***MPa (%)***
CT	18.3	100.0	29.2	100.0	*43.1*	100.0	47.2	100.0	49.6	100.0
10SP	16.5	90.3	27.9	95.5	45.6	105.8	52.9	112.1	55.9	112.7
15SP	15.5	84.7	25.2	86.3	41.7	96.8	47.9	101.4	50.7	102.2
20SP	14.3	78.3	23.1	79.1	38.3	88.9	44.2	93.6	47.8	96.4
25SP	12.3	67.5	20.0	68.5	34.5	80.0	40.5	85.8	43.9	88.6
22.5GP-7.5SP	14.0	76.6	23.0	78.8	36.9	85.6	44.0	93.2	47.1	95.0
15GP-15SP	13.6	74.7	20.8	71.2	34.1	79.1	40.2	85.2	45.1	90.8
7.5GP-22.5SP	11.1	60.8	17.1	58.6	29.4	68.2	37.9	80.3	43.5	87.8

As expected, the compressive strength of the mortar increases with curing time with a high rate of strength gains at early ages which gradually decrease at longer ages. Control mortar specimens have higher compressive strengths at early age when compared with blended cement mortar. The 3^{rd} -day and 7^{th}-day compressive strength proves that Scoria containing mixes has lower early strength than OPC (control). The compressive strength at 3^{rd} and 7^{th}- days decreases from 18.3 to 12.3 and 29.2 to 20 MPa when control mix and blended mix with 25% of scoria were used, respectively.

At the age 28^{th}-day the compressive strength of mortar specimen containing scoria shows an interesting strength gain. As shown in figure 5-8. 10% scoria containing mortar specimen increased by 5.6%, 11.4%, 12.7% than the control specimen at the age of 28, 56, 90 Day respectively. 15% SP shows slight increase than that of the control mix at the age of 56 and 90 days. Over all the strength SP containing specimen shows better strength development at later age, which the compressive strength of SP become comparable to control mix at the age of 90. The reduction of strength at early age could be the reduction of cement content in the mix with the increase of volcanic scoria content; i.e. the dilution effect and (ii) the slowness of the pozzolanic reaction and the strength increment could be due to the continuation of Pozzolanic reaction and the formation of a secondary C-S-H, a greater degree of hydration was achieved resulting in strength (A. M. al-Swaidani, 2017).

B. Ternary Blended Cement

The compressive strength values of all hardened Ternary blended cement mortar with curing age shown in figure 4-9. From the figure, it is clear that there is an improvement in compressive strength values continuously with increasing hydration time (curing age). High reduction of compressive strength observed at early age such as 3^{rd} -&7^{th}-Day. At 28, 56, and 90 day the compressive strength of ternary blended cement show noticeable increment. This could be explained by the interaction between the reactive silica which is in the glassy portion of the addition and the $Ca\ (OH)_2$ released by the hydration of the cement and leads to the formation of a secondary C–S–H. Based on the obtained experimental results The strengths of mortar mixtures with 22.5GP-7.5SP, 15GP-15SP, 7.5GP-22.5SP are lower at 3, 7, 28, 56 and 90 day, than those of the control. The reduction in compressive strength can be explained with the lower cement content, rather than the control. However, at 90 days, the strength of ternary mortar is comparable to control.

The compressive strength at 3rd and 7th- days decreases from 18.3 to 11.1 and 29.2 to 17.1 MPa when control mix and Ternary blended mix with 30% of scoria and glass were used, respectively. The compressive strength reduction decreases at later age but the specimen with ternary blended mix reduced by 43.1 to 29.4 and 47.2 to 37.9 MPa at the curing age of 28 & 56 respectively. At the age of 90 the compressive strength becomes comparable to control specimen which reduced by only 12.2% from control mix.

From the experimental investigation result it is observed that the specimen with **22.5GP-7.5SP** replacement shows better performance than that of 15GP-15SP, 7.5GP-22.5SP and 25SP Mixes. The reason behind of higher compressive strength when GP used at higher amount could be due to the high amorphous silica structure of Glass powder which leads to high reactivity with free calcium hydroxide (CH). According study (Kim & Yi, 2015) X-ray diffraction (XRD) patterns of the glass powder shows amorphous structure and no crystals were found, it is evident that GP is a typical amorphous material. Another reason that Ternary mortar containing high amount of Glass Powder has relatively higher early strength is due to the high content of Na_2O in GP Powder. alkalis in cement affect the morphology both of the C-S-H and CH, and lead rapid hardening and high strength development at early age (Jawed & Skalny, 1977). These results show that the slow strength development of Mortar with Scoria can be enhanced, by using the Glass Powder. It was demonstrated that the hybrid incorporation with 22.5 GP and 7.5%SP as cement replacement materials has a positive effect on the early strength, as well as the late age strength, compared with the mortars with 25SP, 7.5GP-22.5SP and 15GP-15SP,

4.3.5 Evaluation of Compressive Strength of Binary and Ternary Blended Mortar

According ASTM C150 (standard specification for Portland cement) Compressive strength of Type-I shall meet minimum compressive strength of mortar is 12MPa, 19MPa and 28MPa at normal curing age of 3, 7, and 28 days respectively. All binary and ternary blended cement full fill the minimum compressive strength except 7.5GP-22.5GP at the age of 3 and 7 day. This is because of slow pozzolanic reaction of scoria content. Binary blended mix that contains up to 20%SP shows much higher strength than required by ASTM C150.

The standard deviation between the mortar cube specimens is one way to check the validity of the compressive strength test results. In this regard, according to ASTM C109 average of three specimen values shall be taken as the representative of the batch provided the Individual variation should not be more than 8.7 percent of the average. From the test result, the mean standard deviation for all proportion of SP and SPGP mix with their respective curing ages is less than 8.6% except 3rd day 15%SP mix, 25SP and 7.5GP-22.5SP and 7th day 7.5GP-22.5SP mix as shown in Table 4-11.

Table 4-11: compressive strength mean standard deviation from average value

Mix-ID	Variance%				
	3rd-Day	**7th-Day**	**28th-Day**	**56th-Day**	**90th-Day**
CT	3.7	2.1	1.7	0.9	1.4
10SP	3.2	3.2	2.2	1.6	3.1
15SP	8.8	3.1	2.5	0.9	3.9
20SP	7.2	3.8	2.5	4.1	1.9
25SP	9.7	4.7	1.6	3.4	1.8
22.5GP-7.5SP	2.9	3.1	2.7	3.7	1.6
15GP-15SP	6.2	2.9	1.8	2.8	3.8
7.5GP-22.5SP	14.6	9.5	3.4	5.0	2.9

4.3.6 Sulphate Attack Test

For evaluation of cubes durability, 3, 7, 28, 56, 90 days age cubes were kept in 5% Na_2SO_4 solutions. The cubes cast with varying amount of SP and GPSP. The compressive strength of specimen shows an increase in early age. The reason in increment at early age is because of sodium sulphate (an ion which activates of the strength development at an early age). When, Si, Al, Low Ca chains disintegrated by high alkalies environment, the speed of pozzolanic reaction accelerated. Availability of alkalies led to increased C-S-H gel and ettringite formation which improve early strength. Figure 4-10, illustrated Compressive strength of cubes reduced as age increased. Result showed Reduction in compressive strength begins at 28-Day and increase reduction of strength at 56 and 90 days. Control specimen and 10SP specimen has higher compressive strength reduction at the 90 -day sulphate curing age. Generally, sulphate attack resistance shown with the increase of SP and use of GPSP. This could be the consumption of Portlandite by amorphous Silica (Si) in SP and GP powder. Cements potentially containing little or no calcium hydroxide on hydration perform much better on sulphate attack resistance[6].

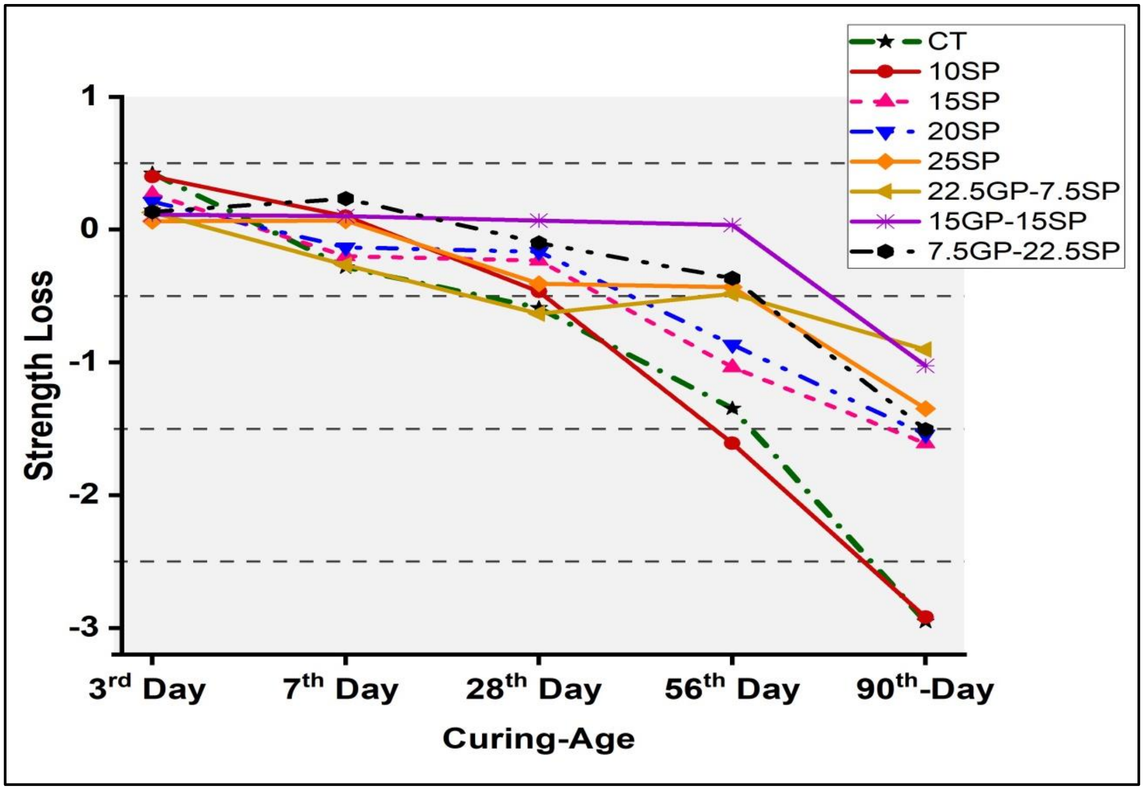


Figure 4-10: Strength Loss of Mortar

Table 4-12: Strength Loss (%)

Mix-Type (%)	Compressive Strength (MPa) and curing condition														
	3rd Day			7th Day			28th Day			56th Day			90-Day		
	water	*sulfate*	*Loss (%)*	*water*	*sulfate*	*Loss (%*	*water*	*sulfate*	*Loss (%)*	*water*	*sulfate*	*Loss (%)*	*water*	*sulfate*	*Loss (%)*
CT	18.3	18.7	2.3%	29.2	28.9	-1.0%	43.1	42.5	-1.4%	47.2	45.9	-2.9%	49.6	46.7	-6.0%
10SP	16.5	16.9	2.4%	27.9	28.0	0.4%	45.6	45.1	-1.0%	52.9	51.3	-3.0%	55.9	53.0	-5.2%
15SP	15.5	15.7	1.7%	25.2	25.0	-0.8%	41.7	41.5	-0.6%	47.9	46.8	-2.2%	50.7	49.1	-3.2%
20SP	14.3	14.5	1.5%	23.1	23.0	-0.6%	38.3	38.1	-0.4%	44.2	43.3	-2.0%	47.8	46.3	-3.2%
25SP	12.3	12.4	0.5%	20.0	20.1	0.3%	34.5	34.1	-1.2%	40.5	40.1	-1.1%	43.9	42.6	-3.1%
22.5GP-7.5SP	14.0	14.1	0.9%	23.0	22.7	-1.2%	36.9	36.3	-1.7%	44.0	43.5	-1.1%	47.1	46.2	-1.9%
15GP-15SP	13.6	13.7	0.8%	20.8	20.9	0.5%	34.1	34.2	0.2%	40.2	40.2	0.1%	45.1	44.0	-2.3%
7.5GP-22.5SP	11.1	11.2	1.2%	17.1	17.3	1.4%	29.4	29.3	-0.3%	37.9	37.5	-1.0%	43.5	42.0	-3.5%

4.4 Micro-Structure Analysis

4.4.1 Introduction to Thermal Analysis

Since many years ago, thermal analysis methods have been available to examine hydraulic reactions and cement interactions with both chemical and mineral admixtures. The chemical and physical characteristics of cementitious materials and the raw materials used to make cement can be examined via thermal analysis. Thermal analysis entails gradually heating a tiny sample to a high temperature (at least 1000°C).Changes in the sample's weight, temperature, energy, or condition (gas, solid, or liquid) that take place as a function of time or temperature are documented when materials react or disintegrate. The usual applications of thermal analysis are (Vinila, Satheesh, & Reenu Jacob, 2019).

4.4.2 Thermogravimetric Analysis (TGA)

The amount of that component in the sample is indicated by the size of the weight shift. An investigation of changes in the physical and chemical characteristics of materials is done using the thermal analysis technique known as thermo gravimetric analysis (TGA).It calculates weight changes that happen when a sample is heated evenly. This process gives information on a sample's thermal stability (Vinila et al., 2019).

Thermogravimetric analysis (TGA) is a method that weighs or measures the mass of a sample as it is gradually heated or cooled. A sample's weight change is influenced by its composition, temperature, rate of heating, and kind of furnace gas (air, oxygen, nitrogen, argon, or other gas).The existence of a given chemical substance can be determined by a change in mass within a specified temperature range (Memon, Javed, Haris, Khushnood, & Kim, 2021).

TGA calculates weight changes in proportion to temperature changes. Information about the recorded weight loss curve includes:

- ❖ Changes in sample composition
- ❖ Thermal stability
- ❖ kinetic parameters for chemical reactions in the sample

4.4.3 Differential Thermal Analysis (DTA)

Through the analytical process of differential thermal analysis (DTA), the temperature difference between a sample and a control is tracked when the samples are heated. The control material is typically an inert substance that doesn't react over the temperature range being investigated, such as powdered alumina. When a sample reacts at a specific temperature, the reaction will either produce heat (exothermic) or absorb heat, causing the sample's temperature to rise or fall in comparison to the (inert) control (endothermic).Each material's temperature is measured via a thermocouple, which enables the difference in temperature to be recorded. DTA is the best method for keeping track of how cement phases change as they hydrate. TGA and DTA can be carried out simultaneously (Vinila et al., 2019).

4.4.4 TGA-DTA Analysis

Figure 4-11 and figure 4-12 illustrated a typical graphical display of the TGA-DTA curves for control mix and blended cement mix of curing age of 7 and 28 days respectively. The first endothermic peaks were determined by the DTA curves to be 171, 164, 162, 132 for curing age of 7^{th}-Day and 128, 128, 118, 161 for curing age of 28^{th}-Day for CT, 15SP, 25SP, and 15GP-15SP, which were caused by the separation of the C-S-H interlayer water as a result of C-S-H dehydration. The Dehydration of C-S-H is the main cause of weight loss that can be seen in the temperature range of 110 to 300 C (Memon et al., 2021).

According to TGA/DTA curves, the weight loss of calcium hydroxide was discovered at the temperature range of 450–550 C. This could have mostly been caused by the dehydroxylation of portlandite (Memon et al., 2021). In the case of this investigation, the endothermic peaks 493, 494, 487, 493 for curing age of 7 days and 497, 491, 494, 491 for curing age of 28 days of CT, 15SP, 15GP-15SP in figure 5-10 and 5-11, respectively are attributed to the decomposition of CH. Then, the breakdown and decarburization of $CaCO_3$ are depicted in a series of significant exothermic peaks on the DTA figure between 710 and 800°C (Memon et al., 2021). All samples lost weight when the curing time was extended. At curing age of 7^{th}-Day, the weight loss of binary mixes containing SP was lower than that of the control sample. This may be related to the slow hydration rate of mixes at an early age and the high thermal stability of scoria, however it is discovered that 25 SP mixes lose more weight at day 28 than the control mix does because more C-S-H gel is formed as a result of the pozzolanic reaction. Due to the glass powder's high amorphous structure and high Na_2O content, which triggers the early strength of mixes by forming more hydration products, 15SP-15GP exhibits greater weight loss at the 7^{th}-day curing age compared to control and SP mixes. This result proofs GP powder initiates the hydration rate of ternary blended mix at early ages.

The total weight losses From TGA curves of all examined samples for 7^{th} and 28^{th} obtained from Equation 1 summarized in Table 4-13, which is calculated from TG data.

Table 4-13: Weight Loss of Sample

Mix-Type	**7^{th}-Day**				**28^{th}-Day**			
	mi(g)	**mf(g)**	**∆m(g)**	**%**	**mi(g)**	**mf(g)**	**∆m(g)**	**%**
CT	10.00	9.66	0.34	3.4%	10.00	9.31	0.69	6.9%
15SP	10.00	9.81	0.19	1.9%	10.00	9.68	0.32	3.2%
25SP	10.00	9.86	0.14	1.4	10.00	9.05	0.95	9.5%
15-15GPSP	10.00	9.63	0.37	3.7	10.00	9.18	0.82	8.2%

Where

1. **mi(g)**= Initial sample (gm)
2. **mf (g)**= Final in gm.
3. ∆**m(g**) = weigh loss in gm.

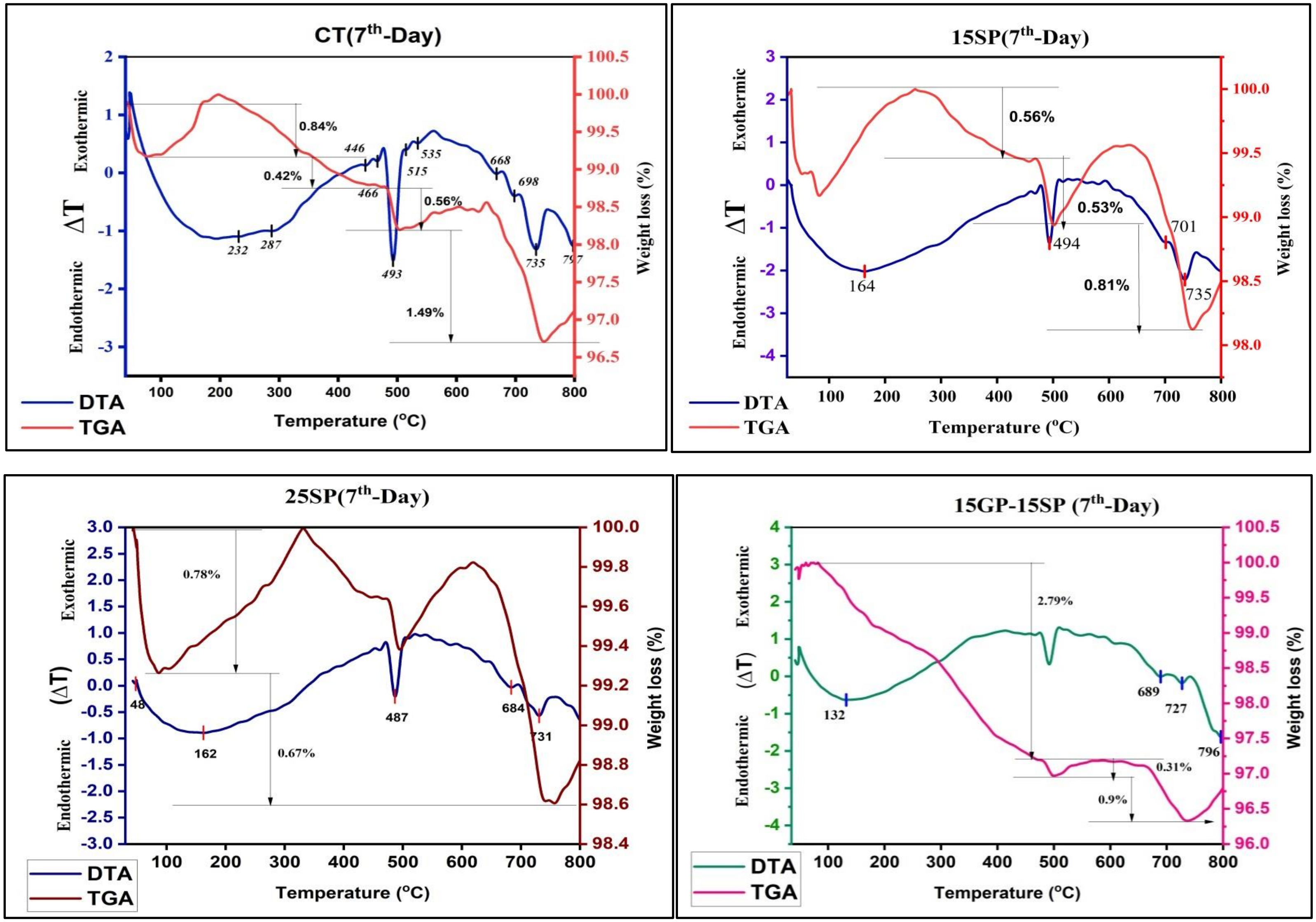


Figure 4-11: TGA-DTA 7^th^-Day graph

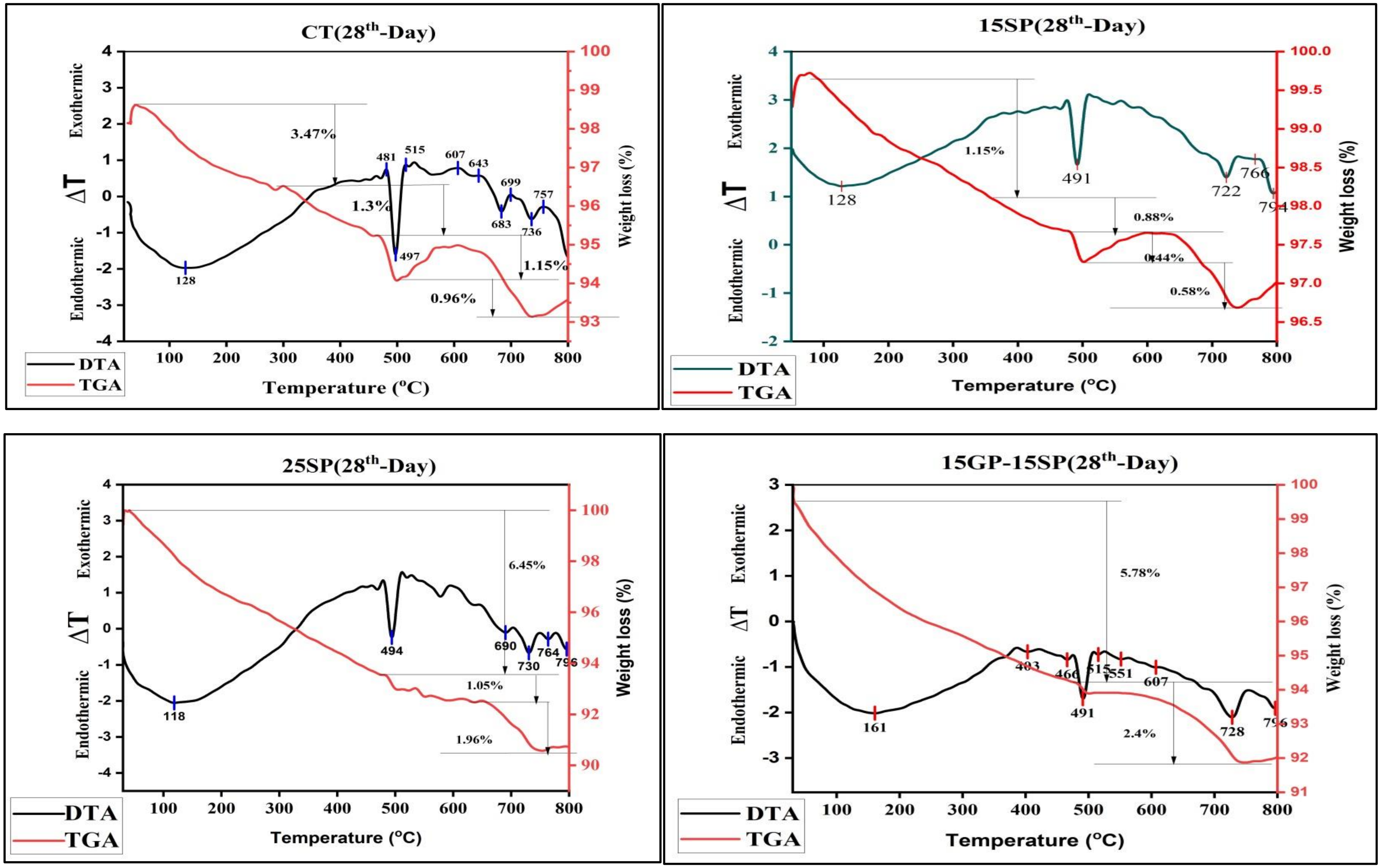


Figure 4-12 TGA-DTA 28th-Day graph

4.4.5 Fourier Transform InfraRed (FT-IR) Analysis

FT-IR stands for Fourier Transform InfraRed, the preferred method of infrared spectroscopy. In infrared spectroscopy, IR radiation is passed through a sample. Some of the infrared radiation is absorbed by the sample and some of it is passed through (transmitted). Fourier Transform Infrared (FTIR) has been developed as a tool for the simultaneous determination of organic components, including chemical bond, as well as organic content (e.g., protein, carbohydrate, and lipid). Fourier transform infrared (FTIR) is one of the important analytical techniques for researchers. This type of analysis can be used for characterizing samples in the forms of liquids, solutions, pastes, powders, films, fibers, and gases. This analysis is also possible for analyzing material on the surfaces of substrate (Fan, Dai, & Huang, 2012; Nandiyanto & Oktiani, 2019).

In the FTIR analysis procedure, samples are exposed to contact with infrared (IR) radiation. The IR radiations then have impacts on the atomic vibrations of a molecule in the sample, resulting the specific absorption and/or transmission of energy. In cement hydration, water, carbonate, sulphate, and silicate are the major bands identified through FTIR (Thiruppathi & Barathanb, 2014).

Figure 4-13 and 4-14 shows the IR Spectra of the refference (Control) cement Mix and blended cement mixes varied amout of Scoria Powder and scoria-glass composition Mix at 7thand 28th-Day curing age. Seven bands were discovered in FTIR test Result. The Bands summerised bellow.

1. Band 1 at wave length between 3440-3500 cm^{-1} corrosponds to the streching vibration of O-H groups of water linked to different hydration compound. Of the cement pastes.
2. Band 2 at Wave length around 2925 cm-1 is associated with the streching –CH2
3. Band 3 at wave length around 1632 cm^{-1} corrosponds to H–O–H bending.
4. Band 4 at wave Length around 1410 cm^{-1} due To Carbonation intensity increases ashydration progress
5. Band 5 at wave length between 1100-1150 cm^{-1} due S-O stretching (sulphate band)
6. Band 6 at wave length between 900-1100 cm^{-1} due Si-O streching vibration of silicate.
7. Band 7 at wave length 440-850 cm^{-1} Due streching vibration of Si-O-S

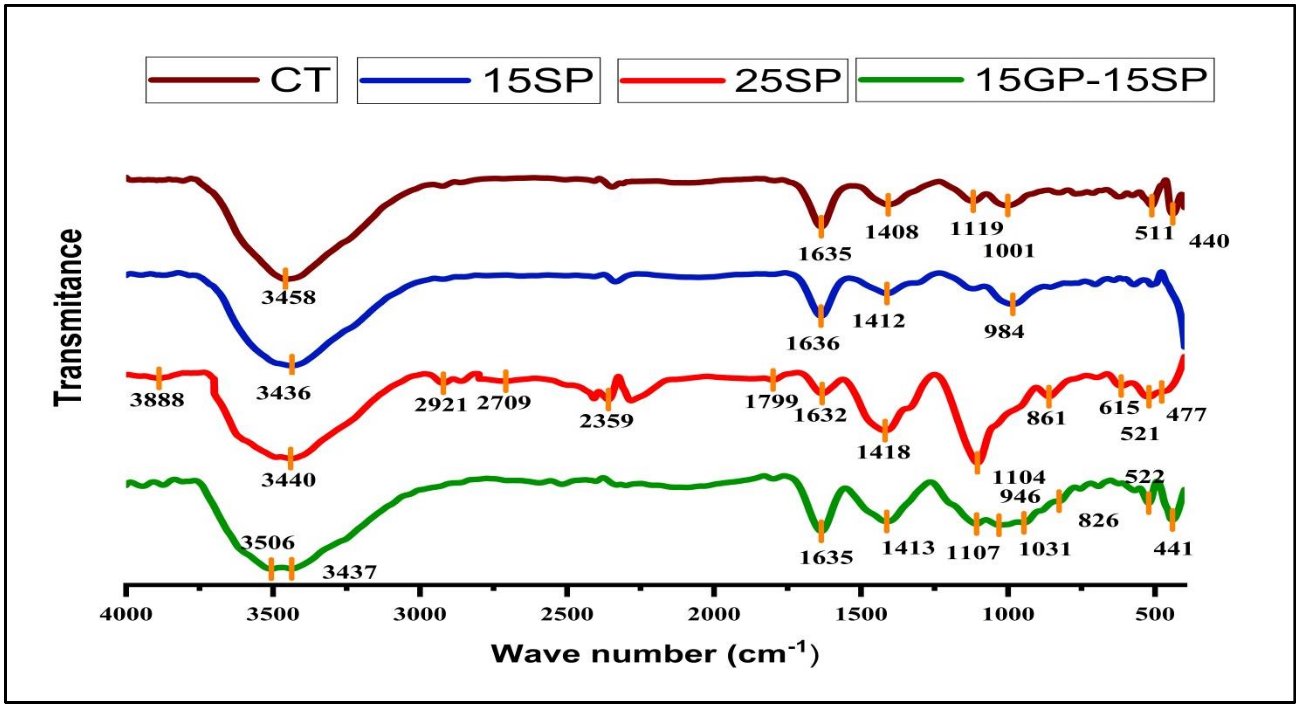


Figure 4-13: FTIR of 7th-Day Cured Mortar

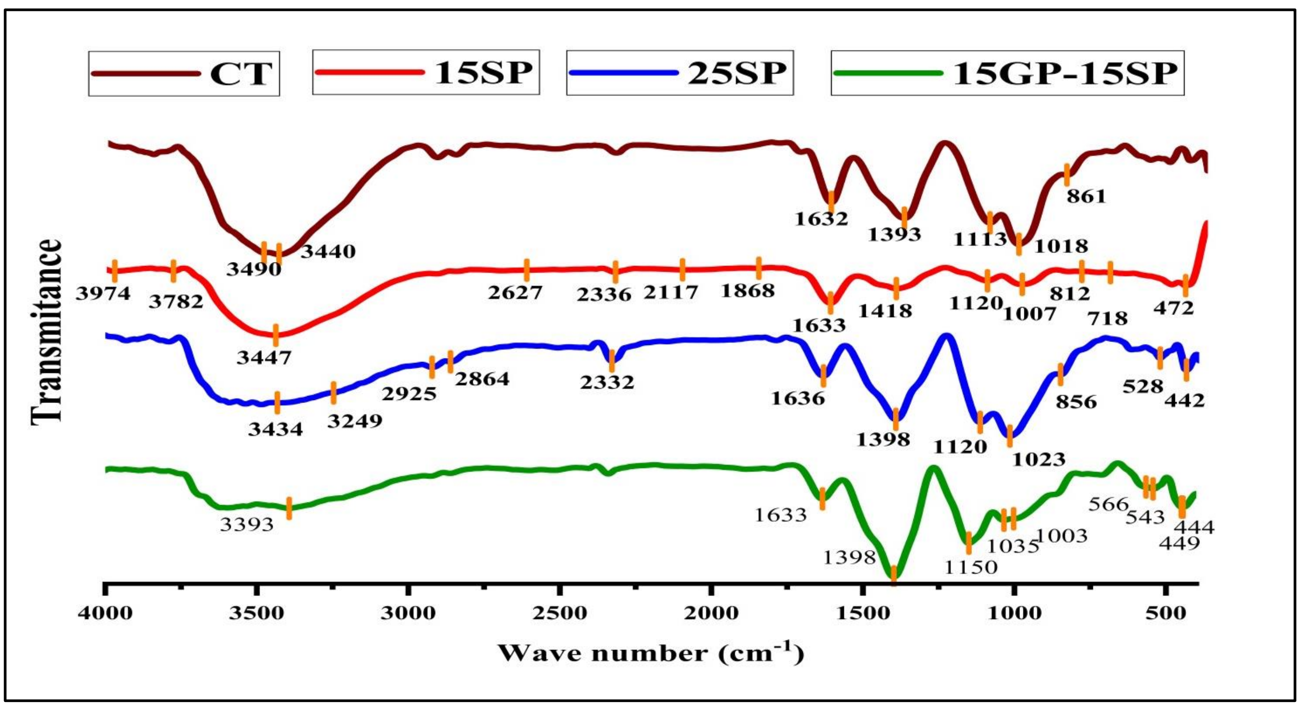


Figure 4-14: FTIR of 28th-Day Cured Mortar

FT-IR spectroscopy highlights the presence of water, a medium intensity band is shown around 1632 and 3400 cm^{-1}wavenumber, which are present in Control, 15 SP, 25SP, 15GP-15SP mixes. H-O-H bending and H-O-Vibrations are responsible for generation of these bands. Both these bands are associated with adsorbed water on surface of Mortar mixes and due the end products of hydration of C_3S and C_2S. Intensity of these bands decreased in 28-Day curing time when compared with 7-Day curing age. This is because of Decrease in available free water due to the formation of complex C-S-H gel (Kashyap & Agrawal, 2021). Even the decrease in these bands is more for samples containing Scoria and glass-scoria composition as compared to control mix.

A Peak shown in fig at wave number 2900 cm^{-1} is attributed to the stretching vibration - CH_2. Another Sharp band was observed around 1410 cm^{-1} wave number is due to the C-O stretching vibration of carbonate molecules. Carbonate molecules are formed due to the reaction between calcium hydroxide and carbon dioxide present in the air (Yılmaz & Olgun, 2008). These bands shifted toward slower wavenumber side of 1418-1393 with increasing scoria and glass-scoria content, where very minor shift in these bands is observed for control mix. Other than this according to the sulphate region (S-O stretching) in cement powder is characterized by three Absorption bands namely a sharp peak at 1153.6 and two shoulder at around 1114 and 1097 cm-1 and O-S-O bending at around 603.7 and 59.7cm-1 (Priyanka, Bhat, & Debnath, 2011). The FTIR band at 1120, 113, 1150 can correlated with the presence of ettringite.

FT-IR spectroscopy also used to study the shift of the bands assigned to Calcium Silicate Hydrate (C-S-H) according to the conditions of cure and ageing. The main characteristic peaks of C-S-H are located in the range between 1100 and 900 cm-1. During ageing and de-calcification process, these IR bands shift according to the process of polymerization of the silica (Horgnies, Chen, & Bouillon, 2013). In this study Si-O asymmetric stretching bonds are identified near to 1000$cm^{-1}$are attributed to the generation of hydraulic compounds such as C-S-H. 1001 cm-1, 986, 1031 cm-1, wave number at Curing age of 7^{th}-Day and 1018 cm^{-1}, 1007cm^{-1}, 1023cm^{-1}, and 1035cm^{-1} wave number at 28^{th}-Day Curing age is associated with Si-O streching vibration of silicate. Unreacted particles can be detected by looking the vibration of the Si–O–Si bond at wave numbers 427, 472, 442, and 543 cm-1 (Yehualaw, Hwang, Vo, & Koyenga, 2021).

4.5 Cost Analysis

The cost comparison considers material cost, transportation cost and power and fuel cost. Other costs such as labor cost, equipment cost, profit, maintenance, and overhead costs assumed to be the same to OPC. Material cost for glass is taken as the same of scoria. The effect of replacement of scoria and glass powder on cement cost per quintal is, assessed based on the material prices collected from most common sources and suppliers and other costs estimated from life cost assessment of cement detail energy and cost estimation presented in Appendix F Part. The cement replacement with 10% Scoria powder saves 38 ETB per quintal of cement or 5.42% of total cost per quintal. Similarly, the partial replacement of cement with 15SP, 20SP, 25SP, 30GPSP can save 57 ETB/Quintal (8.14), 76 ETB/Quintal (10.9%) and 94 ETB/Quintal (13.42), 113ETB/ Quintal (16.14%) of total cement cost per quintal as shown in graph 4-15.

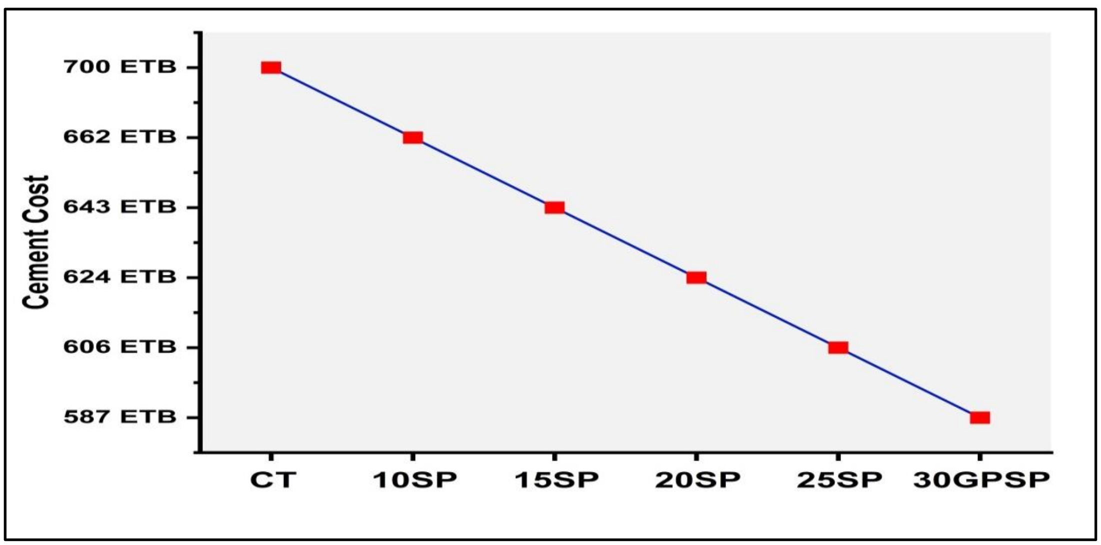


Figure 4-15: Cost of cement per Quintal

4.6 Energy Saving

The cement production is accompanied by the higher consumption of energy both thermal and electrical. Portland cement is produced by pyro-processing the raw materials (mostly limestone and clay or shale) at temperatures from 1400◦C to1500◦C, and then grinding the resulting clinker. This requires an energy input of about 4900 MJ/tonne of cement. But by utilization of Scoria and Glass this large amount of energy can be reduced by half based on the estimation. The production of glass and scoria consume 2150 MJ/tonne, since this material doesn’t require kiln process, heating energy is not issue. Substituting Glass and scoria up to 30 percent can save 826

MJ/tonne of cement and reduce 30kg of CO_2/quintal of cement. Therefore, utilization of scoria and recycling of glass waste is vital to provide environmentally friendly and low cost construction material.

4.7 SPSS Data Analysis

4.7.1 Introduction

This chapter studies on the statistical analysis applied to the laboratory test results to analyze and interpret. IBM SPSS Statistics 20 application is used to analysis. The experiment has multiple dependent variables, and each dependent variable is affected by two independent variables. In the analysis of variance we compare the variability between the groups (how far the means area part) to the variability within the groups (how much natural variation there is in the measurements). This is why it is called analysis of variance, often abbreviated to ANOVA (Shiker, 2012).

4.7.2 Multivariate Analysis of Variance (MANOVA)

Is an extension of the analysis of variance (ANOVA) used to determine whether there are any differences between independent groups on more than one continuous dependent variable. Multivariate ANOVA, used based on the dependent variable (compressive strength, sulfate attack resistance, water absorption, and ultrasonic pulse velocity) and two independent variables (Mix percentage of SP and GPSP and Curing age of mortar).

4.7.3 Hypotheses Formulation

Hypothesis Testing can be used to test the validity of trueness of a conclusion or argument against a data set. The hypothesis is an assumption made at the beginning of the research and can hold or be false based on the analysis result. There are two types of hypotheses in statistics, null hypothesis and Alternative hypothesis. The Null and alternative hypotheses are used in statistic hypothesis testing.

A. ***The Null Hypothesis (H_O):*** is a statement of no difference between sample means or proportions. In other word, the difference equals 0.

B. ***The Alternative Hypothesis (H_a)*** predicts there is an effect or relationship. Therefore, the followings null hypotheses and alternative hypothesis are developed.

For this study, eight null hypotheses and eight alternative hypotheses is are developed

1. Ho_1 = the curing age doesn't affect the compressive strength, Sulphate resistance, water absorption, and ultrasonic pulse velocity of mortar
2. Ho_2 = the partial replacement of cement with scoria and glass powder doesn't affect the compressive strength, Sulphate resistance, water absorption, and ultrasonic pulse velocity test.
3. Ha_1 = the length of curing age (days) affect the compressive strength, Sulphate resistance, water absorption, and ultrasonic pulse velocity test.
4. Ha_2 = the partial replacement of cement with scoria and glass powder affects the compressive strength, Sulphate attack, water absorption, and ultrasonic pulse velocity.

4.7.4 Multivariate Test Result

The relationship between variables (dependent and independent) was analyzed using multivariate test. With a 95% Confidence Interval and a Significant Level of α =0.05. The first part of the output is shown in Table 4-14. Each row shows the statistics of a separate multivariate test method: Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. If the significance is smaller than 0.05, it is possible to conclude that the means are significantly different. In this case the output displays the value of different multivariate measures. The means of variables are all significantly different as (shown Sig being .000). The interaction effect of age with Mix-Type replacement less than 0.05; that tells the variables are significant for 95% confidence interval

4.7.5 Tests of Between-Subject Effects

The Tests of Between-Subjects Effects gives the sum of squares, degrees of freedom, Mean Square value, the F values and the significance levels for each dependent variable. As shown in table 4-15, with P-values less than 0.05 for Curing age variables, indicating that the four (compressive strength, Sulphate attack, UPV. And water absorption) dependent variables were significantly ($p<.05$), affected by curing age. And except sulphate attack all dependent variables (Compressive strength, water absorption, UPV) were significantly affected by Mix-Type.

So that the Following null hypothesis are rejected and accepted.

Table 4-14: Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	1.000	238189.278[b]	4.000	77.000	.000	1.000
	Wilks' Lambda	.000	238189.278[b]	4.000	77.000	.000	1.000
	Hotelling's Trace	12373.469	238189.278[b]	4.000	77.000	.000	1.000
	Roy's Largest Root	12373.469	238189.278[b]	4.000	77.000	.000	1.000
Curing-Age	Pillai's Trace	2.084	21.748	16.000	320.000	.000	.521
	Wilks' Lambda	.000	184.818	16.000	235.877	.000	.863
	Hotelling's Trace	349.004	1646.861	16.000	302.000	.000	.989
	Roy's Largest Root	343.407	6868.133[c]	4.000	80.000	.000	.997
Mix-Type	Pillai's Trace	1.842	9.757	28.000	320.000	.000	.461
	Wilks' Lambda	.011	24.760	28.000	279.050	.000	.675
	Hotelling's Trace	25.267	68.132	28.000	302.000	.000	.863
	Roy's Largest Root	23.068	263.639[c]	7.000	80.000	.000	.958
Curing-age * Mix-Type	Pillai's Trace	1.920	2.638	112.000	320.000	.000	.480
	Wilks' Lambda	.052	3.045	112.000	308.401	.000	.523
	Hotelling's Trace	5.146	3.469	112.000	302.000	.000	.563
	Roy's Largest Root	2.718	7.765[c]	28.000	80.000	.000	.731

a. Design: Intercept + Curing-Age + Mix-Type + Curing-Age * Mix-Type

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

Table 4-15: Tests of Between-Subject Effect

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	**Compressive Strength**	**21534.992[a]**	**39**	**552.179**	**387.494**	**.000**	**.995**
	Sulphate Attack	**167.333[b]**	**39**	**4.291**	**.910**	**.621**	**.307**
	Water Absorption	**.010[c]**	**39**	**.000**	**39.494**	**.000**	**.951**
	UPV	**640.193[d]**	**39**	**16.415**	**280.203**	**.000**	**.993**
Intercept	**Compressive Strength**	**135408.008**	**1**	**135408.008**	**95023.164**	**.000**	**.999**
	Sulphate Attack	**83.333**	**1**	**83.333**	**17.668**	**.000**	**.181**
	Water Absorption	**1.503**	**1**	**1.503**	**229201.258**	**.000**	**1.000**
	UPV	**39708.770**	**1**	**39708.770**	**677816.844**	**.000**	**1.000**
Curing-Age	**Compressive Strength**	**19579.950**	**4**	**4894.988**	**3435.079**	**.000**	**.994**
	Sulphate Attack	**57.167**	**4**	**14.292**	**3.030**	**.022**	**.132**
	Water Absorption	**.006**	**4**	**.002**	**238.310**	**.000**	**.923**
	UPV	**625.172**	**4**	**156.293**	**2667.875**	**.000**	**.993**
Mix-Type	**Compressive Strength**	**1731.392**	**7**	**247.342**	**173.573**	**.000**	**.938**
	Sulphate Attack	**23.733**	**7**	**3.390**	**.719**	**.656**	**.059**
	Water Absorption	**.003**	**7**	**.000**	**75.431**	**.000**	**.868**
	UPV	**7.592**	**7**	**1.085**	**18.513**	**.000**	**.618**
Curing-Age * Mix-Type	**Compressive Strength**	**223.650**	**28**	**7.988**	**5.605**	**.000**	**.662**
	Sulphate Attack	**86.433**	**28**	**3.087**	**.654**	**.896**	**.186**
	Water Absorption	**.000**	**28**	**1.382E-005**	**2.107**	**.005**	**.424**
	UPV	**7.429**	**28**	**.265**	**4.529**	**.000**	**.613**
Error	**Compressive Strength**	**114.000**	**80**	**1.425**			
	Sulphate Attack	**377.333**	**80**	**4.717**			
	Water Absorption	**.001**	**80**	**6.557E-006**			
	UPV	**4.687**	**80**	**.059**			
Total	**Compressive Strength**	**157057.000**	**120**				
	Sulphate Attack	**628.000**	**120**				
	Water Absorption	**1.514**	**120**				
	UPV	**40353.650**	**120**				
Corrected Total	**Compressive Strength**	**21648.992**	**119**				
	Sulphate Attack	**544.667**	**119**				
	Water Absorption	**.011**	**119**				
	UPV	**644.880**	**119**				

a. R Squared = .995 (Adjusted R Squared = .992)
b. R Squared = .307 (Adjusted R Squared = -.031)
c. R Squared = .951 (Adjusted R Squared = .927)
d. R Squared = .993 (Adjusted R Squared = .989)

4.7.6 Post Hoc Tests

Post-hoc tests are used at the second stage of the analysis of variance (ANOVA) or multiple analyses of variance (MANOVA) if the null Hypotheses are rejected. Tukey HSD test is used; as it is one of the popular post-hoc test methods. The post-hoc test result of SP replacement and GP-SP replacement And Curing age is illustrated below.

A. Compressive Strength

From Table 4-16, 3rd- Day, 7th-Day, 28th-Day, 56th-Day, 90th-Day compressive strength means of different mixes are significantly different, since the P value is .000

Table 4-16: Multiple Comparisons (Tukey HSD) Compressive Strength

Dependent Variable	(I) Curing-Age	(J) Curing-Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Compressive Strength	3rd-Day	7th-Day	-8.71*	.345	.000	-9.67	-7.75
		28th-Day	-23.63*	.345	.000	-24.59	-22.66
		56th-Day	-29.83*	.345	.000	-30.80	-28.87
		90th-Day	-33.50*	.345	.000	-34.46	-32.54
	7th-Day	3rd-Day	8.71*	.345	.000	7.75	9.67
		28th-Day	-14.92*	.345	.000	-15.88	-13.95
		56th-Day	-21.12*	.345	.000	-22.09	-20.16
		90th-Day	-24.79*	.345	.000	-25.75	-23.83
	28th-Day	3rd-Day	23.63*	.345	.000	22.66	24.59
		7th-Day	14.92*	.345	.000	13.95	15.88
		56th-Day	-6.21*	.345	.000	-7.17	-5.25
		90th-Day	-9.87*	.345	.000	-10.84	-8.91
	56th-Day	3rd-Day	29.83*	.345	.000	28.87	30.80
		7th-Day	21.12*	.345	.000	20.16	22.09
		28th-Day	6.21*	.345	.000	5.25	7.17
		90th-Day	-3.67*	.345	.000	-4.63	-2.70
	90th-Day	3rd-Day	33.50*	.345	.000	32.54	34.46
		7th-Day	24.79*	.345	.000	23.83	25.75
		28th-Day	9.87*	.345	.000	8.91	10.84
		56th-Day	3.67*	.345	.000	2.70	4.63

B. Sulphate Attack

From Table 4-17, 3rd- Day strength loss means compared to 7th-Day, 28th-Day, 56th-Day are not significantly different since the P value is greater than 0.05. 3rd-Day curing age is significantly different from 90th-Day curing age.

Table 4-17: Multiple Comparisons (Tukey HSD) Sulphate Attack

Dependent Variable	**(I) Curing-Age**	**(J) Curing-Age**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
						Lower Bound	**Upper Bound**
Sulphate Attack	3rd-Day	7th-Day	-1.42	.627	.169	-3.17	.33
		28th-Day	-.58	.627	.884	-2.33	1.17
		56th-Day	-1.21	.627	.312	-2.96	.54
		90th-Day	-2.00*	.627	.017	-3.75	-.25
	7th-Day	3rd-Day	1.42	.627	.169	-.33	3.17
		28th-Day	.83	.627	.674	-.92	2.58
		56th-Day	.21	.627	.997	-1.54	1.96
		90th-Day	-.58	.627	.884	-2.33	1.17
	28th-Day	3rd-Day	.58	.627	.884	-1.17	2.33
		7th-Day	-.83	.627	.674	-2.58	.92
		56th-Day	-.63	.627	.856	-2.37	1.12
		90th-Day	-1.42	.627	.169	-3.17	.33
	56th-Day	3rd-Day	1.21	.627	.312	-.54	2.96
		7th-Day	-.21	.627	.997	-1.96	1.54
		28th-Day	.63	.627	.856	-1.12	2.37
		90th-Day	-.79	.627	.715	-2.54	.96
	90th-Day	3rd-Day	2.00*	.627	.017	.25	3.75
		7th-Day	.58	.627	.884	-1.17	2.33
		28th-Day	1.42	.627	.169	-.33	3.17
		56th-Day	.79	.627	.715	-.96	2.54

C. Water Absorption Capacity

All mixes, the 3rd, 7th, 28th, 56th and 90th day mean water absorption has statistical difference with curing age, because the P value is less than 0.05 as shown in Table 4-18 column 6

Table 4-18: Multiple Comparisons (Tukey HSD) Water Absorption Capacity

Dependent Variable	**(I) Curing-Age**	**(J) Curing-Age**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
						Lower Bound	**Upper Bound**
Water Absorption Capacity	3rd-Day	7th-Day	.00664*	.000739	.000	.00458	.00870
		28th-Day	.01271*	.000739	.000	.01065	.01477
		56th-Day	.01646*	.000739	.000	.01439	.01852
		90th-Day	.02038*	.000739	.000	.01832	.02244
	7th-Day	3rd-Day	-.00664*	.000739	.000	-.00870	-.00458
		28th-Day	.00607*	.000739	.000	.00401	.00813
		56th-Day	.00982*	.000739	.000	.00775	.01188
		90th-Day	.01374*	.000739	.000	.01168	.01580
	28th-Day	3rd-Day	-.01271*	.000739	.000	-.01477	-.01065
		7th-Day	-.00607*	.000739	.000	-.00813	-.00401
		56th-Day	.00375*	.000739	.000	.00168	.00581
		90th-Day	.00767*	.000739	.000	.00561	.00973
	56th-Day	3rd-Day	-.01646*	.000739	.000	-.01852	-.01439
		7th-Day	-.00982*	.000739	.000	-.01188	-.00775
		28th-Day	-.00375*	.000739	.000	-.00581	-.00168
		90th-Day	.00392*	.000739	.000	.00186	.00599
	90th-Day	3rd-Day	-.02038*	.000739	.000	-.02244	-.01832
		7th-Day	-.01374*	.000739	.000	-.01580	-.01168
		28th-Day	-.00767*	.000739	.000	-.00973	-.00561
		56th-Day	-.00392*	.000739	.000	-.00599	-.00186

D. Ultrasonic Pulse Velocity

Based on the Tukey HSD test of Table 4-19, we can conclude that, there is a statistical significant difference between UPV values in different curing age. However, 56th-Day curing age compared to 90th-Day curing age has P value of 0.820 and this number is greater than 0.05. Thus, there is no statistically significant difference between 56th-Day and 90th-Day curing age.

Table 4-19: Multiple Comparisons (Tukey HSD) UPV

Dependent Variable	I) Curing-Age	(J) Curing-Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
UPV	3rd-Day	7th-Day	2.813*	.0699	.000	2.617	3.008
		28th-Day	5.362*	.0699	.000	5.167	5.558
		56th-Day	5.804*	.0699	.000	5.609	5.999
		90th-Day	5.879*	.0699	.000	5.684	6.074
	7th-Day	3rd-Day	-2.813*	.0699	.000	-3.008	-2.617
		28th-Day	2.550*	.0699	.000	2.355	2.745
		56th-Day	2.992*	.0699	.000	2.797	3.187
		90th-Day	3.067*	.0699	.000	2.872	3.262
	28th-Day	3rd-Day	-5.362*	.0699	.000	-5.558	-5.167
		7th-Day	-2.550*	.0699	.000	-2.745	-2.355
		56th-Day	.442*	.0699	.000	.247	.637
		90th-Day	.517*	.0699	.000	.322	.712
	56th-Day	3rd-Day	-5.804*	.0699	.000	-5.999	-5.609
		7th-Day	-2.992*	.0699	.000	-3.187	-2.797
		28th-Day	-.442*	.0699	.000	-.637	-.247
		90th-Day	.075	.0699	.820	-.120	.270
	90th-Day	3rd-Day	-5.879*	.0699	.000	-6.074	-5.684
		7th-Day	-3.067*	.0699	.000	-3.262	-2.872
		28th-Day	-.517*	.0699	.000	-.712	-.322
		56th-Day	-.075	.0699	.820	-.270	.120

Based on observed means.
The error term is Mean Square (Error) = .059.
*. The mean difference is significant at the .05 level.

4.7.7 Correlation

Correlation is a measure of the strength of a relationship between two variables. Correlations do not indicate causality and are not used to make predictions; rather they help identify how strongly and in what direction two variables co-vary in an environment.

Types:

a. Pearson (parametric, assumes linear relationship)
b. Spearman (non-parametric, can be non-linear)
c. Kendall's Tau (non-parametric, can be non-linear)

1. Measuring Correlation

We make use of the linear product-moment correlation coefficient, also known as Pearson's correlation coefficient, to express the strength of the relationship. This coefficient is generally used when variables are of quantitative nature, that is, ratio or interval scale variables. Pearson's correlation coefficient is denoted by r and is defined by

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{\{\sum x^2 - (\sum x)^2\}\{n\sum y^2 - (\sum y)^2\}}}$$

The value of r always lays between –1 and 1 inclusive, that is, **$-1 \leq r \leq 1$.**If Y increases when X increases; we say that there is positive or direct correlation between them. However, if Y decreases when X increases (or vice versa), then we say that they are negatively or inversely correlated. The reader must have noticed that direct and inverse are terms that are used in the context of variation or proportionality

2. Interpretation of the Correlation Coefficient

The extreme values of *r*, that is, when *r* = ±1, indicate that there is *perfect* (positive or negative) correlation between *X* and *Y*. However, if *r* is 0, we say that there is *no* or *zero* correlation.

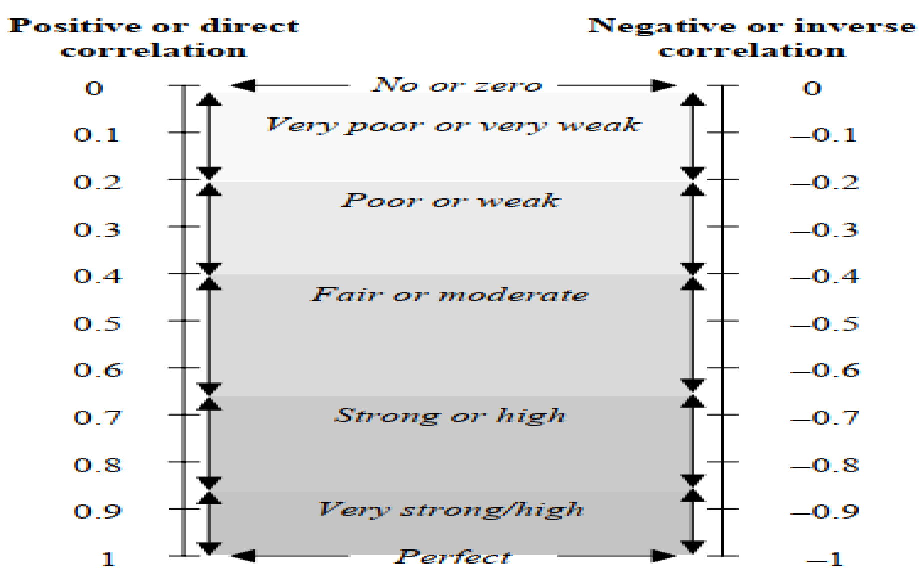


Figure 4-16: Interpretation Of Correlation Coefficient

Table 4-20: Correlations

		Mix-Type	Curing-Age	Compressive Strength	Sulphate Attack	Water Absorption	UPV
Mix-Type	Pearson Correlation	1	.000	-.256**	.020	.528**	.101
	Sig. (2-tailed)		1.000	.005	.832	.000	.271
	N	120	120	120	120	120	120
Curing-Age	Pearson Correlation	.000	1	.928**	.234*	-.760**	-.900**
	Sig. (2-tailed)	1.000		.000	.010	.000	.000
	N	120	120	120	120	120	120
Compressive Strength	Pearson Correlation	-.256**	.928**	1	.219*	-.864**	-.935**
	Sig. (2-tailed)	.005	.000		.016	.000	.000
	N	120	120	120	120	120	120
Sulphate Attack	Pearson Correlation	.020	.234*	.219*	1	-.209*	-.181*
	Sig. (2-tailed)	.832	.010	.016		.022	.048
	N	120	120	120	120	120	120
Water Absorption	Pearson Correlation	.528**	-.760**	-.864**	-.209*	1	.783**
	Sig. (2-tailed)	.000	.000	.000	.022		.000
	N	120	120	120	120	120	120
UPV	Pearson Correlation	.101	-.900**	-.935**	-.181*	.783**	1
	Sig. (2-tailed)	.271	.000	.000	.048	.000	
	N	120	120	120	120	120	120

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3. Correlation Test Result Analysis

The relationship between dependent variables (Compressive strength, Sulphate attack, Water absorption capacity, and ultrasonic pulse velocity) and the independent variables (curing age and Percentage replacement of Blended cement were analyzed by correlation test. The above table 4-20 shows Mix-Type has no (zero) correlation with curing age and sulphate attack. However there is Moderate positive correlation with water absorption capacity and week negative correlation with compressive strength and very week positive correlation with Ultrasonic pulse velocity. The correlation test result also shows very strong positive correlation with compressive strength and very strong negative correlation with water absorption and ultrasonic-pulse velocity.

The test result revealed also compressive strength has very strong negative correlation with water absorption capacity and ultrasonic pulse velocity. And water absorption capacity has very strong positive correlation with ultrasonic pulse velocity and week negative correlation with sulphate attack.

4.7.8 Regression

A Technique used for the modeling and analysis of numerical data which exploits the relationship between two or more variables so that we can gain information about one of them through knowing values of the other. Regression can be used for prediction, estimation, and hypothesis testing, and modeling causal relationships. In this case, the compressive strength was taken as dependent variable and water absorption was taken as the independent variable. Linear regression was done using IBM SPSS. Tables 4-21 and 4-22 jointly, as they provide information how well the independent variables relate to the dependent variable. The R^2 provided in Table 4-21 seems satisfactory and is above the value of 0.30.

Table 4-21: Model Summaryb

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.864[a]	.746	.743	6.831312

a. Predictors: (Constant), Water Absorption

b. Dependent Variable: Compressive Strength

Table 4-22: ANOVAa

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16142.307	1	16142.307	345.905	.000[b]
	Residual	5506.684	118	46.667		
	Total	21648.992	119			

a. Dependent Variable: Compressive Strength

b. Predictors: (Constant), Water Absorption

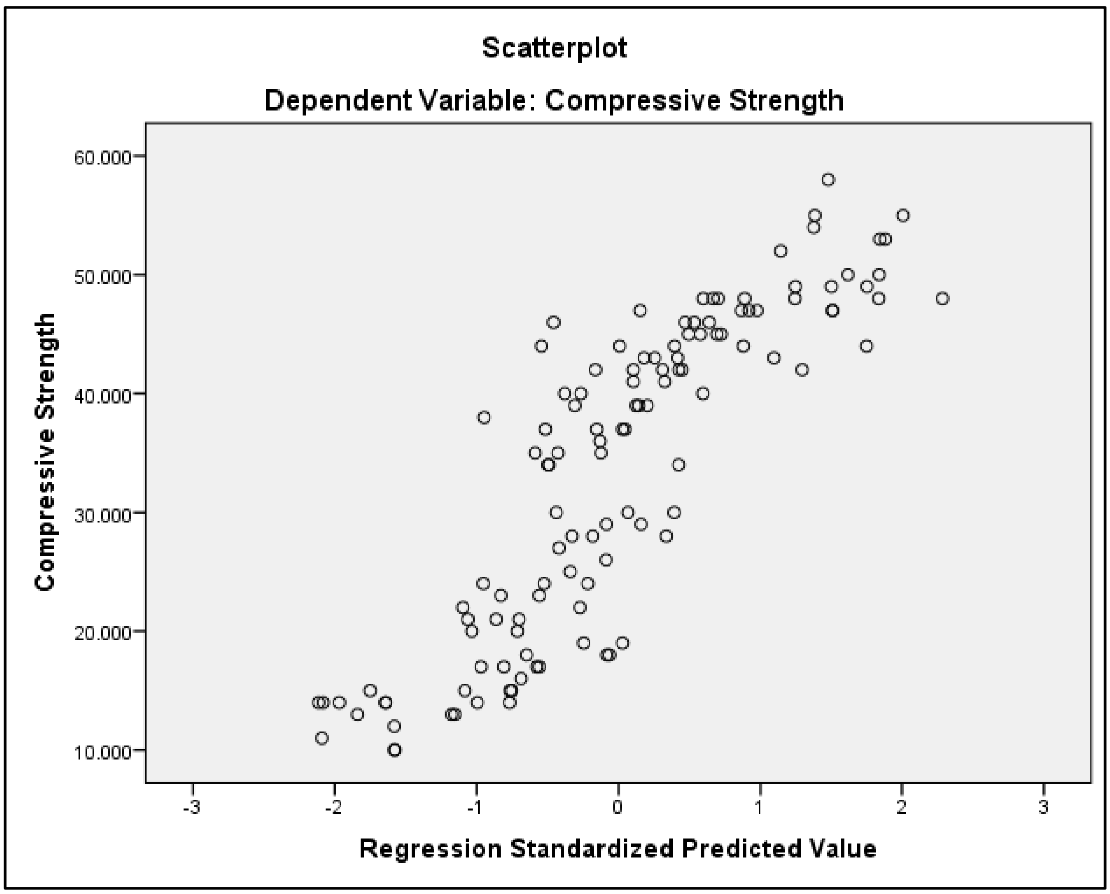


Figure 4-17: Scatter Plot

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study was conducted to investigate the Suitability of scoria and Glass Powder from for supplementary cementitious material. Based on the experimental results of this study, the following conclusions could be drawn.

1. The studied scoria and Glass powder is a suitable material for utilization as a natural pozzolans. They are mainly composed of $SiO_2+Al_2O_3+Fe_2O_3$ conforming to the chemical requirements of ASTM C618. Scoria and Glass Powder possess sufficient pozzolanic characteristics to be used as an additive as cement replacement and the strength activity index shows Glass-Scoria composition has higher performance than scoria.
2. The workability of the mortar mix decreases as the percentage of Scoria increases. 22.5GP-7.5SP mix shows better performance compared to 15GP-15SP and 7.5GP-22.5SP due to lower water absorption capacity. The compressive strength of Mortar containing scoria powder generally decreases than control cement Mortar at all curing age except 10SP and 15%SP at 28-Day, 56^{th}-Day, 90^{th}-Day. 22.5GP-7.5SP shows better performance than the other ternary blended mix. The use of glass Powder with scoria initiates the early strength as well as later strength.
3. Water Absorption and UPV decreases with addition of Scoria and the use of Glass-Scoria composition. Based on the results, Adding scoria and Glass as cement replacement reduced the loss of strength of the mortar exposed to sodium sulfate solution. This is shown at longer curing age at 90^{th}-Day. TGA-DTA test result revealed the weight loss SP sample decreases at lower age (7day) when compared to control mix but increase at 28 day. FTIR result show Decrease in available free absorbed water in SP and GPSP sample due to the formation of C-S-H.
4. The use of scoria and glass as blended cement is economical and environmentally friendly. Based on the results obtained, it is suggested that scoria can be used up to 20 % and Glass-Scoria composition with 22.5GP-7.5SP ratio as a partial substitute for Portland cement in production of blended cements considering cost and environment pollution.

5.2 Recommendation

- Scoria as finely grounded in cement replacement has higher absorption capacity than control mix. So, in using the material for production of mortar and concrete, reduction on the workability needs consideration.
- The study consider constant water/cement ratio of 0.485 in order to see the direct effect of scoria and Glass Powder. So, farther studies are required on the area with different water cement ratio to obtain the best property of these materials.
- Ternary blended mix with varied percentage amount should be investigated to obtain better performance blended cement.
- It is both economical and environmentally friendly to incorporate Scoria and Glass waste for production of cement, but detailed economic and environmental impact analysis shall be conducted as the study here is insufficient.

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APPENDIX A
Fine Aggregate Quality Tests

Aggregate is used in construction to give asphalt and concrete mass and strength. Aggregates are found naturally in the earth as sand, gravel, or clay. All aggregate is different. Testing of aggregate is done in order to determine the quality of material. Doing a simple visual test is inadequate. this chapter explain the procedure followed to test natural Belaya sand.

1. Sieve Analysis /Gradation/ for Fine aggregate (ASTM C136)

This analysis is carried out to classify aggregates as well graded, poorly graded, uniformly graded, gap graded, etc. each of the above aggregate categories has close association with a range of quality of concrete produced using the aggregate. The size of the test sample, after drying, shall be 300 g minimum.

Procedure

1) 500gm of dried fine aggregate taken
1) Arranging sieves based on their size order, Weight the empty sieve and record the data.
2) Put 500gm of sample on the top of the sieve
3) Continue sieving for a sufficient period
4) The retained materials on each sieve were weighed together with the sieve and recorded.
5) Calculate the weight retained on each sieve

Table A.1: Observation and Calculation of Particle Size

Sieve size (mm)	Weight of sieve (gm.)	Weight of sieve & retained (gm.)	Weight of retained (gm.)	Percentage retained (%)	Cumulative percent Retained (%)	Cumulative percent pass (%)	ASTM C-33 limits		
							Min	Max	Remark
9.5	686	686	0	0	0	100	100	100	OK
4.75	773	805	32	3.2	3.2	96.8	95	100	OK
2.36	737	812	75	7.5	10.7	89.3	80	100	OK
1.18	614.5	820.5	206	20.6	31.3	68.7	50	85	OK
600	603.5	943.5	340	34	65.3	34.7	25	60	OK
300	577.5	832.5	255	25.5	90.8	9.2	5	30	OK
150	572	652	80	8	98.8	1.2	0	10	OK
Pan	303	315	12	1.2	-	-	-	-	

Sum of cumulative percent retained = 300.1

Fineness modulus $= \frac{\text{Sum of cumulative percent retained}}{100} = \frac{300.1}{100} = 3.0$

Discussion

The fine aggregate gradation satisfies the ASTM minimum and maximum limits set by ASTM C33 and the fineness modulus of 3.0 is acceptable for normal strength concrete design which requires fineness modulus to be in the range of 2.3 to 3.2 according to ASTM C33

2. *Specific Gravity and Absorption of Fine Aggregate (ASTM C128)*

To determine the bulk and apparent specific gravity of fine aggregates and water absorption

The specific gravity is the ratio of the density of a substance to the density of a reference substance (water); equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume.

Absorption is the process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body; also, the increase in mass of a porous solid body resulting from the penetration of a liquid into its permeable pores. The moisture content of fine aggregate is the total amount of water present in internal pores and on the surface of aggregate. This moisture content affects workability and the compressive strength of concrete.

Procedure

1. Partially filled the pycnometer with water. Introduce into the pycnometer 500 gm saturated surface-dry fine aggregate prepared.
2. Manually rolled, the pycnometer to eliminate visible air bubbles.
3. Brought the water level in the pycnometer to its calibrated capacity. and the total mass of the pycnometer, specimen, and water determined.
4. Fine aggregate removed from the pycnometer, dried in the oven to constant mass at a temperature of 110±5, cooled in air for 1 ± 1⁄2 h, and the mass determined.
5. The mass of the pycnometer filled to its calibrated capacity with water determined.

Table A.2: Specific Gravity and Water Absorption

No	Sample	Result(gm.)
1.	Weight of SSD sample (S)	500
2.	Weight of sand + water + pycnometer (C)	1929.4
3.	Weight of water + pycnometer (B)	1608.4
4.	Oven dry sample (A)	492.6

I. **Specific Gravity**

According To ASTM C128 Relative density specific gravity (OD), Relative Density (Specific Gravity) Saturated Surface-dry), Apparent relative density (apparent specific gravity) is calculated as follow.

1. *Relative density specific gravity (OD) =* $\frac{A}{B+S-C} = \frac{492.6}{1608.4+500-1929}$=***2.74***

2. *Relative density specific gravity (SSD) =* $\frac{S}{B+S-C} = \frac{500}{1608.4+500-1929} = \mathbf{2.78}$

3. *Apparent relative density (apparent specific gravity) =* $\frac{A}{B+A-C} = \frac{492.6}{1608.4+492.6-1929} = \mathbf{2.86}$

I. Water Absorption

According To ASTM C128

1. $Absorption, \% = 100(\frac{S-A}{A}) = \frac{500-492.6}{492.6}$ =***1.5%***

Where;

A=oven Dry Sample

B=Weight of water + pycnometer

C=Weight of sand + water + pycnometer

S= Weight of SSD sample

❖ **Discussion**

According to Most natural aggregates have relative densities between 2.4 and 2.9 with corresponding particle (mass) densities of 2400 and 2900 kg/m3 (150 and 181 lb./ft3). And fine aggregate will generally have absorption levels (moisture contents at SSD) in the range of 0.2% to 2%.

3. Moisture Content of Aggregate by Drying (C 566 – 97)

To determination, the percentage of evaporable moisture in a sample of aggregate by drying both surface moisture and moisture in the pores of the aggregate.

1. Determine the mass of the sample to the nearest 0.1 %
2. Dry the sample thoroughly in the sample container by means of the selected source of heat

Table A.3: Moisture Content Test Result

No.	Sample	Result
1.	Weight of original SSD (w)	500
2.	oven dry sample for moisture (D)	493.5

$$Moisture\ Content\ (P) = 100\left(\frac{W-D}{D}\right) = \frac{500-493.5}{493.5} = \mathbf{1.3\%}$$

Where:

p = total evaporable moisture content of sample, percent,

W = mass of original sample, gm.

D = mass of dried sample, gm.

4. Bulk Density ASTMC (29/C 29M – 07)

To determination bulk density (“unit weight”) of aggregate in a compacted or loose condition, and calculated voids between particles in fine aggregate based on the same determination.

Procedure

1. The measure was filled one-third full and leveled the surface with the fingers. And Rod the layer of aggregate with 25 strokes of the tamping rod evenly distributed over the surface.
2. The measure was filled again two-thirds full and again leveled and rod as above.
3. Finally fill the measure to overflowing and rod again in the manner previously mentioned.
4. n rodding the first layer, do not allow the rod to strike the bottom of the measure forcibly. In rodding the second and third layers, use vigorous effort, but not more force than to cause the tamping rod to penetrate to the previous layer of aggregate

5. Determine the mass of the measure plus its contents, and the mass of the measure alone, and record the values.

Table A.4: Bulk Density Test Result

No.	**Sample**	**Result**
1.	Weight of container	2960 g
2.	Weight of aggregate + container	7868 g
3.	Volume of container = 0.003 m³	0.003 m³

Bulk Density $(M) = (\frac{G-T}{V}) = \frac{7868-2960gm/1kg(1000)}{0.003}$ =***1636kg/m³***

Where:

M = bulk density of the aggregate, kg/m^3.

G = mass of the aggregate plus the measure, kg.

T = mass of the measure, kg

V = volume of the measure, m^3

Discussion

According to the approximate bulk density of aggregate commonly used in normal-weight concrete ranges from about 1200 to 1750 kg/m3 (75 to 110 lb./ft3). Based on the test result the sand used for this experiment lays between the ranges.

5. Silt Content (IS 2386-2)

This test method covers the determination of the amount of material finer than a 75-µm (No. 200) sieve in aggregate

Procedure

1. Sand was filled up to 50 ml mark and water added up to 100 ml. And 1% of salt.
2. The sample was shaken vigorously for one minute and the last few shakes being in a sidewise direction to level off the sand.
3. cylinder was allowed to stand for three hours during which time any silt present will settle in a layer on the top of the sand and its thickness can be read off on the cylinder itself

Table A.5: Silt Content Test Result

No.	**Sample**	**Result**
1.	Amount of silt deposited above the sand (A)	2ml
2.	Amount of clean sand (B)	98ml

Silt content = $(\frac{A}{B}) = \frac{2ml}{98ml}$ ***=2.04%***

6. Organic Content (ASTM C40)

To determination of the presence of injurious organic impurities in fine aggregates that are to be used in hydraulic cement mortar or concrete.

Procedure

1. Glass bottle was filled with water to the approximately 130-mL. level with the sample of the fine aggregate.
2. Sodium hydroxide was added to the solutions until the volume of the fine aggregate and liquid, indicated after shaking, is approximately 200 ml
3. The bottle, Shaked vigorously, and then allow to stand for 24 h.

Discussion

Fine aggregate tested for organic impurity according to ASTM C-40. Result indicated that liquid has no color. A colorless liquid indicates clean sand free from organic matter and this shows that it is suitable for concrete mix design.

- **Evaluation of Fine Aggregate Based on Standard Specification**

As we can in table A.5 the test result of different tests reviled that the sand sample taken for the experimental purpose meet the standard requirement for mortar and concrete making material. So, the material is suitable for the investigation in order to get reliable result.

Table A.6 Evaluation of Used Fine Aggregate

No.	Test Type	Test result	Standard specification	Range(limit)	Remark
1.	Gradation (FM)	3.0	ASTM C33	2.9 to 3.2	OK
2.	Specific Gravity	2.78	S.H. Kosmatka	2.4 and 2.9	OK
3.	Bulk Density	1636	S.H. Kosmatka	1200 - 1750 kg/m3	OK
4.	Water Absorption	1.5%	S.H. Kosmatka	0.2% to 2%.	OK
5	Silt content	2.04%	ASTM C33	5%	OK
			ES Standard	6%Max	
6	Organic content	Colorless	ASTM C 33	Colorless	OK

APPENDIX B

Chemical and Physical Test Result of SP and GP

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: -11/06/2021

Customer Name:-Kalab Amare Molla

Request No:- GLD/RQ/993/21

Report No:- GLD/RN/537/21

Sample type :-Powder

Sample Preparation: - 200 Mesh

Date Submitted :-17/05/2021

Number of Sample:- One(01)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
KA	48.42	15.96	5.64	17.12	5.16	3.20	2.08	<0.01	0.26	0.30	0.63	0.90

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

Analysts: Lidet Endeshaw, Yirgalem Abreham, Nigist Fikadu

Checked By: Tizita Zemene

Approved By: Yohannes Getachew

Quality Control: Gosa Haile

Figure B.1 Chemical Property of SP

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: -24/11/2021

Customer Name:-Kaleab Amare

Request No:- GLD/RQ/319/21

Report No:- GLD/RN/1012/21

Sample type : Glass Powder

Sample Preparation: - 200 Mesh

Date Submitted:-10/11/2021

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
1	77.72	3.11	<0.01	6.10	3.26	10.34	<0.01	<0.01	0.02	0.05	<0.01	0.59
2	75.92	3.35	0.14	6.26	3.18	10.22	<0.01	0.02	0.02	0.08	0.08	0.41

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

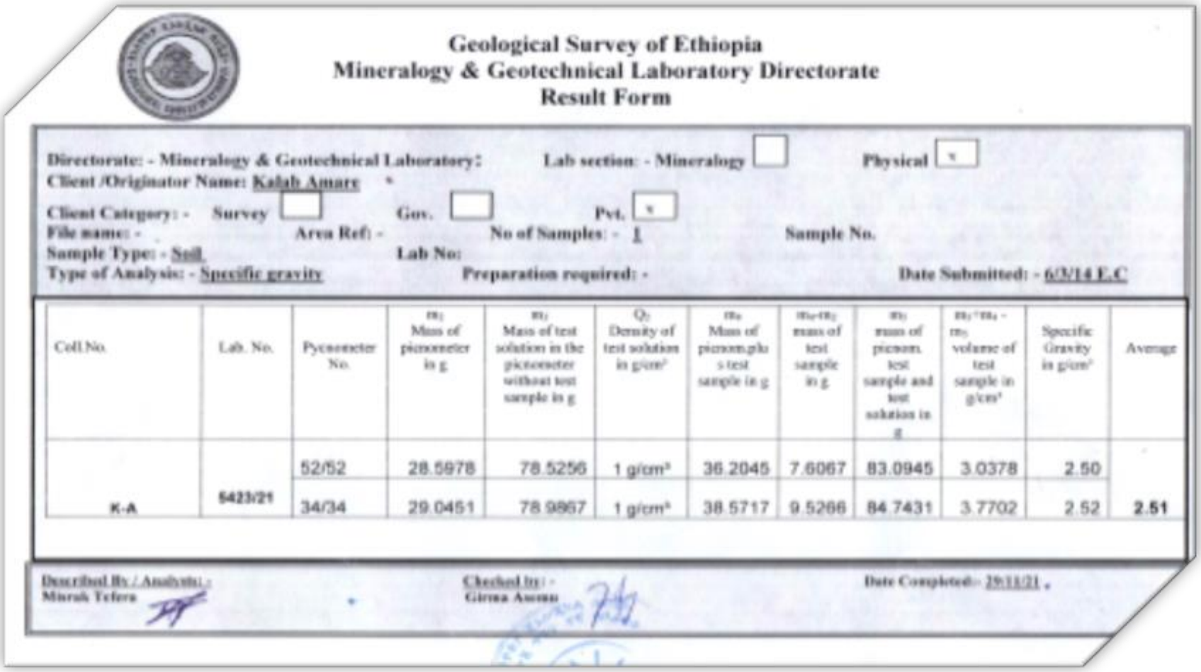
Analysts: Elisa Fiseha, Nigist Fikadu, Yirgalem Abraham

Checked By: Tizita Zemene

Approved By: Yohannes Getachew

Quality Control: Gosa Haile

Fig B.2 Chemical Property of Glass Powder



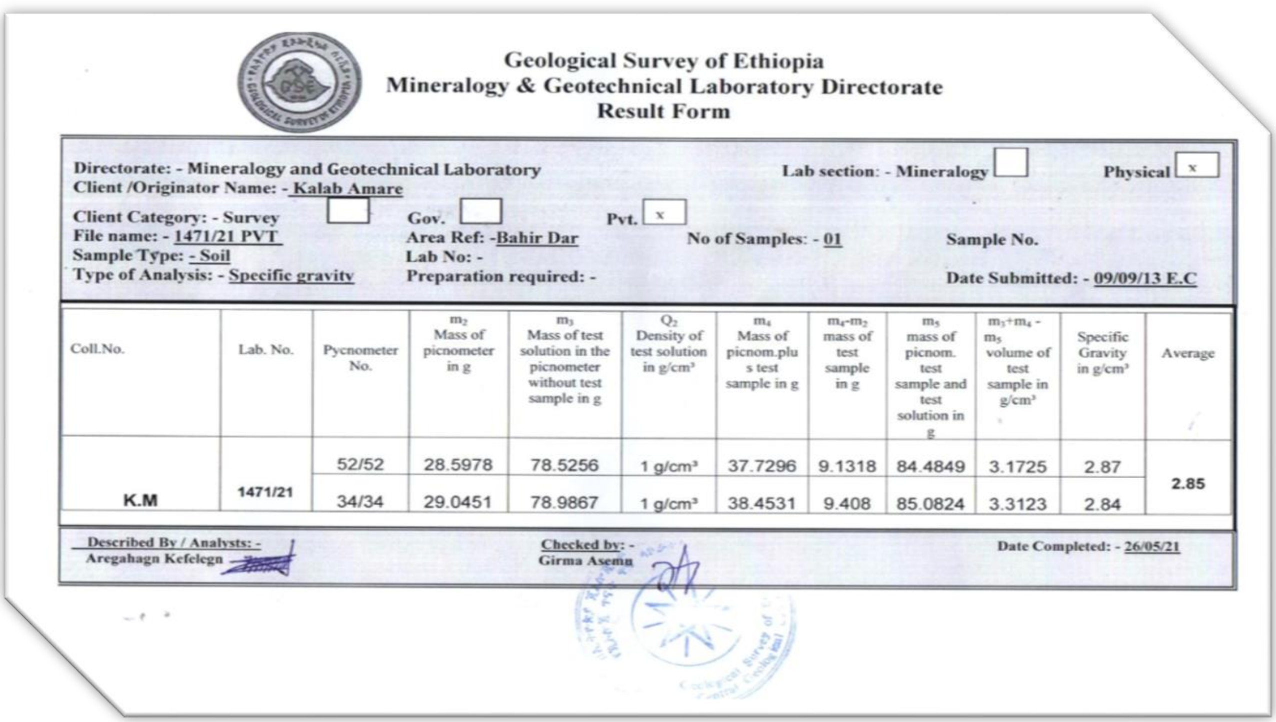
Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Mineralogy & Geotechnical Laboratory: Lab section: - Mineralogy ☐ Physical ☒
Client /Originator Name: Kalab Amare
Client Category: - Survey ☐ Gov. ☐ Pvt. ☒
File name: - Area Ref: - No of Samples: - 1 Sample No.
Sample Type: - Soil Lab No:
Type of Analysis: - Specific gravity Preparation required: - Date Submitted: - 6/3/14 E.C

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4 - m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
		52/52	28.5978	78.5256	1 g/cm³	36.2045	7.6067	83.0945	3.0378	2.50	
K-A	5423/21	34/34	29.0451	78.9867	1 g/cm³	38.5717	9.5266	84.7431	3.7702	2.52	2.51

Described By / Analysts: - Misrak Tefera
Checked by: - Girma Asemu
Date Completed: - 29/11/21

Figure B.3 Physical Property of Glass Powder



Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Mineralogy and Geotechnical Laboratory Lab section: - Mineralogy ☐ Physical ☒
Client /Originator Name: - Kalab Amare
Client Category: - Survey ☐ Gov. ☐ Pvt. ☒
File name: - 1471/21 PVT Area Ref: -Bahir Dar No of Samples: - 01 Sample No.
Sample Type: - Soil Lab No: -
Type of Analysis: - Specific gravity Preparation required: - Date Submitted: - 09/09/13 E.C

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4 - m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
		52/52	28.5978	78.5256	1 g/cm³	37.7296	9.1318	84.4849	3.1725	2.87	
K.M	1471/21	34/34	29.0451	78.9867	1 g/cm³	38.4531	9.408	85.0824	3.3123	2.84	2.85

Described By / Analysts: - Aregahagn Kefelegn
Checked by: - Girma Asemu
Date Completed: - 26/05/21

Fig B.4 Physical Property of Scoria

APPENDIX C
Cement Test

4. Strength Activity Index

Table C.1: Strength Activity

Strength Activity Index (SAI)								
	Cube-1		cube-2		Cube-3			
Mix-type	MPa	KN	MPa	KN	MPa	KN	Mean	SAI
CT	30.2	75.5	29.0	72.6	30.0	75.0	29.7	100.0
20%SP	24.3	60.8	23.2	57.9	24.0	60.0	23.8	80.1
20%GPSP	29.3	73.2	28.9	72.3	28.1	70.2	28.8	96.7

Table C.2: Evaluation of Blended Cement in ASTM C618

ASTM C 618 requirements		Class N	Glass powder	Scoria powder
Chemical requirement	SiO2+Al2O3+Fe2O3 min	70	79.41	70.02
	Sulphuric trioxide (SO3) max	4	-	-
	Moisture content max.	3	<0.01	0.63
	Loss on ignition (LOI) max.	10	0.59	0.9
Physical Requirement	Strength activity index at 7 days as percentage of control	75%	-	80.1

1. Fineness of OPC cement and scoria and Glass Powder (ASTM C184 – 94)

To determination of the fineness of hydraulic cement by means of the 150-µm (No. 100) and 75-µm (No. 200) sieves.

Procedure

1. Took a 100-g sample of the cement on the clean, dry75-µm sieve with the pan attached.
2. Sieved with a gentle wrist motion for 15 minutes.
3. Removed the sieve and weigh the residue carefully. The result expressed as percentage
4. Repeated step one to get 2 readings and would take the average at the end

Table C.3: Fineness of cement and Scoria Glass 1

Cement type	**Sample weight(gm.)**	trial-1		trial-2		Average Residue (%)
		Passing (gm.)	Residue (gm.)	Passing (gm.)	Residue (gm.)	
OPC	100	93.5	6.5	92.5	7.5	7%
Glass	100	94.5	5.5	93	7	6.3%
Scoria	100	90.5	9.5	92.5	7.5	8.5%

Fineness of the samples calculated as follows: $100 - \frac{Rs \times 100}{W}$

Where:

F = fineness of cement expressed as the percentage passing the 75-µm. sieve

Rs=Residue from sample retained on the 75-µm (No. 100)

W = weight of sample, g

- The standard value of fineness of cement should not be more than 10% as per IS recommendation. Used sample OPC and blended cement fulfill the requirement.

***2. Normal Consistency of Cement (ASTM C*187 – 16)**

- To determine the normal consistency of hydraulic cement

Procedure

1. 650 g of cement with a measured quantity of water following the procedure prescribed in the Procedure for Mixing Pastes of Practice C305 is done.
2. Having prepared cement paste was filled and leveled to a mold, plunger was lowered gently and brought to contact to the surface of the paste.
3. The screw was tightened by setting the movable indicator to the upper zero mark of the scale and the plunger was released immediately.
4. Thirty seconds after releasing the plunger, its penetration was recorded.
5. The paste is said to be of normal consistency when the rod settles 10±1 mm below the original surface within thirty seconds. The above procedures were repeated with varying the proportion of water until a normal consistency is obtained.

Calculation

$$\text{Percent of water (\%)} = \frac{weight\ of\ water(gm)}{weight\ of\ cement} \times 100 = \frac{169gm}{650gm} \times 100 = 26\%$$

- Different mixes of SP and GP cement paste was tested with varying the amount of water until normal consistency of cement was obtained

Table B.1: Normal Consistency Test Result

Mix-Type	**CT**	**10SP**	**15SP**	**20SP**	**25SP**	**22.5GP-7.5SP**	**15GP-15SP**	**7.5GP-22.5SP**
Consistency	26	26.2	26.3	26.3	26.5	26.4	26.4	26.7

Discussion

The usual range of water-cement ratio for normal consistency is between 26% and 33%. Since the percentage of water to make normal consistency of mixes is in the range of 26% to 33%.

3. Setting Time Test of Cement (ASTM C 191 – 08)

To determine the time of setting of hydraulic cement by means of the Vicat needle. The extent of set retardation depends on many factors including the fineness and compositional the SCM and the level of replacement used, amount and composition of the Portland cement or blended cement (particularly its alkali content), water-to-cementitious materials ratio (w/cm), and temperature of the concrete.

Procedure

1. New batch of paste by mixing 650 g of cement with the percentage of mixing water required for normal consistency is prepared
2. The paste was filled into conical mold and Excess cement paste trimmed off from mold.
3. The specimen was allowed to remain for 30 minutes after molding without disturbing
4. The needle was lowered until it rests on the surface of the specimen
5. The rod was released quickly and the needle was allowed to settle for 30 seconds
6. The penetration of the 1mm (diameter) needle after 30 min was determined
7. And the results of all penetration tests in every 15minutes thereafter until a penetration of 25mmor less is obtained and recorded

Time of setting Calculate as follows

$$\left[\frac{(H-E)}{(C-D)} \times (C-25)\right] + E$$

where:

E = time in minutes of last penetration greater than 25 mm,

H = time in minutes of first penetration less than 25 mm,

C = penetration reading at time E, and

D = penetration reading at time H

- Different trials made until 25mm or less mm found. Trial test result made after 15 minute was tabulated in table B.2 and initial and final setting time of cement with different proportion was tabulated in table B.3

Table B.1: Setting Time Trial Test Result

Trial NO.	**OPC (T_1=2.50AM)**		**10SP (T_1=3:08AM)**		**15%SP (T_1=3:20AM)**		**20%SP (T_1=2:30AM)**	
	Time -T_2	1mm needle Penetration (mm)	**Time -T_2**	1mm needle Penetration (mm)	**Time -T_2**	1mm needle Penetration (mm)	**Time -T_2**	1mm needle Penetration (mm)
1	3:20	36	3.38am	37	3:50am	38	3:00am	40
2	3:35	32	3.53am	34	4:05am	35	3:15am	37
3	3:50	28	4.08am	30	4:20am	31	3:30am	33
4	4:05	25	4:23am	27	4:35am	28	3:45am	29
5			4:38am	23	4:50am	24	4:00am	24
T= 75min/1:15hr			Using interpolation 25mm penetration is at Time T= **=82.5min/1:22hr**		Using interpolation 25mm penetration is at Time T= **86 min/min**		Using interpolation 25mm penetration is at Time T= **87min/3.10min**	

Trial NO.	**25SP (T_1=3:32AM)**		**22.5GP-7.5SP (T_1=3:42AM)**		**15GP-15SP (T_1=3:28AM)**		**7.5GP-22.5SP (T_1=3:57AM)**	
	Time -T_2	1mm needle Penetration (mm)	**Time -T_2**	1mm needle Penetration (mm)	**Time -T_2**	1mm needle Penetration (mm)	**Time -T_2**	1mm needle Penetration (mm)
1	4:02am	40	4:12	40	3:58	40	4:27	39
2	4:17am	37	4:27	37	4:13	36	4:42	36
3	4:32am	33	4:42	33	4:28	33	4:57	30
4	4:47am	29	4:57	300	4:43	28	5:12	29
5	5:02am	25	5:12	27	4:58	26	5:27	26
6			5:27	25	5:13	24	5:42	23
T= 90min/1:30hr			Time T= **105 min/1:45hr**		T= **97.5 min/1:37hr**		T= **95min/1:35hr**	

Table B.3: Cement Setting Time Test result with Different Percentage of SP and GPSP

Mix-ID	Initial setting time(min)	Final setting time(min)	Standard-setting time(min), ASTM C150		
			Initial(min)	Final(max)	Remark
CT	75	315	45	375	Ok
10SP	82.5	330	45	375	OK
15SP	86	330	45	375	OK
20SP	87	345	45	375	OK
25SP	90	345	45	375	OK
22.5GP-7.5SP	105	375	45	375	OK
15GP-15SP	97.5	360	45	375	OK
7.5GP-22.5SP	95	345	45	375	OK

Discussion

- ❖ Initial and final setting time test result revield that OPC Dangote cement and SP and GPSP blended cement meet the minimum and maximum requriment of ASTM C150.

4. Soundness Test of Cement (IS 4031 Part 3)

Soundness of cement may be determined by two methods, namely Le-Chatelier method and autoclave method. In this study Le-Chatelier method used.

Procedure

1. 500gm Cement bring to form a paste of standard consistency. Oiled placed lightly on a mold on and filled it with cement paste formed by gauging cement with 0.78 times the water required to give a paste of standard consistency.
2. The Mold was covered with another piece of lightly oiled glass sheet, place a small weight on this covering glass sheet and whole assembly immediately submerged the in water at a temperature of 27 ± 2°C and kept it there for 24 hours.
3. The distance separating the indicator needle points was measured to the nearest 0.5 mm (L1).
4. the mold Submerged again in water and bring the water to boiling, with the mold kept submerged, in25 to 30 minutes, and keep it boiling for three hours.
5. The assembly was removed from the water and it was allowed to cool in air, the distance between the indicator needle points was measured (L2).

Table B.4 Dangote OPC and Blended Cement Soundness Test Result

Mix-Proportion	**Test**	**Test result (L2- L1) in mm**	**Average (L2- L1) in mm**	**Remark**
OPC	1	5	4.5	OK
	2	4		
15SP	1	3	3	OK
	2	3		
25SP	1	2	2.5	OK
	2	3		
15GP-15SP	1	2	1.75	OK
	2	1		

Discussion

According to IS 269: 2013 (L2- L1) must not exceed 10 mm for ordinary Portland cement when tested according to Le-Chatelier method. Since All cement type, the expansion is less than 10 mm which fulfill the requirement.

APPENDIX D

Mix Design of Cement Mortar

1. ASTM C109

This test method provides a means of determining the compressive strength of Hydraulic cement and others mortars using 2inch or 50 mm cube specimen and maybe used to determine compliance with specifications.

Procedure

I. Composition of Mortars

The proportions of materials for the standard mortar shall be one part of cement to 2.75 parts of graded standards and by weight. Use a water-cement ratio of 0.485 for all Portland cements and 0.460 for all air-entraining Portland cement. The amount of mixing water for other than Portland and air-entraining Portland cements shall be such as to produce flow of 110 ±5 and shall be expressed as weight percent of cement.

The quantities of materials to be mixed at one time in the batch of mortar for making six and nine test specimens shall be as follows.

Table C.1 ASTM C109 Mix Proportion of Material For No. Of Cube

<table>
<tr><th colspan="2" rowspan="2">Ingredient</th><th colspan="2">Number of Specimens</th></tr>
<tr><th>6</th><th>9</th></tr>
<tr><td colspan="2">Cement, g</td><td>500</td><td>740</td></tr>
<tr><td colspan="2">Sand, g</td><td>1375</td><td>2035</td></tr>
<tr><td rowspan="2">Water, mL</td><td>Portland (0.485)</td><td>242</td><td>359</td></tr>
<tr><td>Air-entraining Portland (0.460)</td><td>230</td><td>340</td></tr>
</table>

II. Mixing Placing and compaction

Mechanically mix in accordance with the procedure given in Practice C 305. Place a layer of mortar about 1 in. or [25 mm] (approximately one half of the depth of the mold) in all of the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 s in 4 rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen, as illustrated in Fig. C.1. The tamping pressure shall be just sufficient to ensure uniform filling of the molds. The 4 rounds of tamping (32 strokes) of the mortar shall be completed in one cube before going to the next. When the tamping of the first layer in all of the cube compartments is completed, fill the compartments with the remaining mortar and then tamp as specified for the first layer

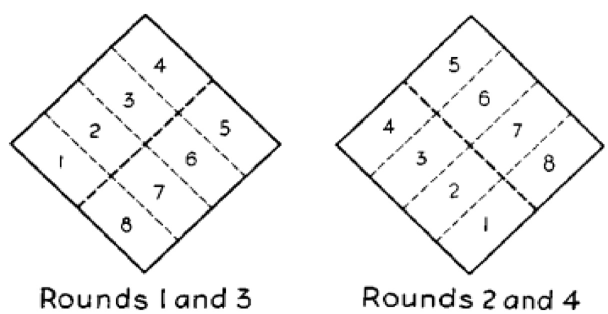


Fig C.1 Order Of Tamping In Molding of Test Specimens ASTM C 109

Apply the load rate at a relative rate of movement between the upper and lower platens corresponding to a loading on the specimen with the range of 200 to 400 lbs./s [900to 1800 N/s]

Record the total maximum load indicated by the testing machine, and calculate the compressive strength as follows:

$$FM = \frac{P}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (1)$$

where:

FM = compressive strength in psi or [MPa]

P = total maximum load in lb. or [N], and

A = area of loaded surface in2 or [mm2].

2. Mix proportion of test specimen

Table: C.2 Mix Proportion Of Specimen

Ingredient	***Cement(gm.)***	***Scoria(gm.)***	***Glass(gm.)***	***Sand(gm.)***	***Water(gm.)***	***No. Cube***
CT	740	*0*	*0*	2035	359	*9*
10SP	*666*	*74*	*0*	2035	*359*	*9*
15SP	*629*	*111*	*0*	2035	*359*	*9*
20SP	*592*	*148*	*0*	2035	*359*	*9*
25SP	*554*	*185*	*0*	2035	*359*	*9*
22.5GP-7.5SP	*518*	*55.5*	*166.5*	2035	*359*	*9*
15GP-15SP	*518*	*111*	*111*	2035	*359*	*9*

3. Number of Test specimen Produced

Total 480 cube was casted using 2inch mortar cube in accordance with as **ASTM C109** as the procedure described above

Table C.2 Shows the Total Number Of Molds

MIX=CODE	**compressive, sulfate, absorption test, UPV**					**Total Cube**
	Cube AGE					
	3rd-Day	*7th-Day*	*28th-Day*	*56th-Day*	*90th-Day*	
CT	12	12	12	12	12	60
10SP	12	12	12	12	12	60
15SP	12	12	12	12	12	60
20SP	12	12	12	12	12	60
25SP	12	12	12	12	12	60
22.5GP-7.5SP	12	12	12	12	12	60
15GP-15SP	12	12	12	12	12	60
7.5GP-22.5SP	12	12	12	12	12	60
Total no. cubes for compressive, sulfate, absorption & UPV test						**480 cubes**

APPENDIX E

5. Compressive Strength

Table E.1 Compressive Strength Test Result of Different Curing Age

	Compressive strength cured in water – 3rd day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
Mix-Id	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	357	362.5	360	17.77	44.4	19.03	47.6	17.96	44.9	18.3	45.6
10SP	356	354.5	354.5	17.00	42.5	15.95	39.9	16.52	41.3	16.5	41.2
15SP	351.5	353	354	16.93	42.3	15.25	38.1	14.22	35.6	15.5	38.7
20SP	350	349	349.5	14.96	37.4	13.11	32.8	14.83	37.1	14.3	35.8
25SP	345.5	349	350	13.58	34.0	11.21	28.0	12.18	30.5	12.3	30.8
22.5GP-7.5SP	330	332.5	335	13.58	34.0	14.39	36.0	13.99	35.0	14.0	35.0
15GP-15SP	339	340.5	345	12.68	31.7	13.96	34.9	14.26	35.7	13.6	34.1
7.5GP-22.5SP	342	340.5	339	10.01	25.0	10.33	25.8	12.96	32.4	11.1	27.8

	Compressive strength cured in water – 7th-day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
Mix-Id	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	361.5	365.5	363	28.5	71.3	29.43	73.6	29.7	74.2	29.2	73.0
10SP	360	361.5	357	27.22	68.1	27.56	68.9	28.92	72.3	27.9	69.8
15SP	354	350.5	357.5	25.42	63.6	24.33	60.8	25.85	64.6	25.2	63.0
20SP	355.5	352	349	23.93	59.8	22.18	55.5	23.19	58.0	23.1	57.8
25SP	345	347	353.5	18.96	47.4	20.22	50.6	20.82	52.1	20.0	50.0
22.5GP-7.5SP	331	342	336.5	22.24	55.6	23.12	57.8	23.64	59.1	23.0	57.5
15GP-15SP	336	332	335.5	21.21	53.0	20.1	50.3	21.09	52.7	20.8	52.0
7.5GP-22.5SP	344.5	343	338.5	15.31	38.3	17.49	43.7	18.5	46.3	17.1	42.8

Mix-Id	Compressive strength cured in water – 28th-day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	367.5	365.5	370.5	42.38	106.0	43.07	107.7	43.9	109.6	43.1	107.8
10SP	360.3	365.5	358.5	44.58	111.5	45.63	114.1	46.59	116.5	45.6	114.0
15SP	354.5	356	355.5	40.56	101.4	41.96	104.9	42.58	106.5	41.7	104.3
20SP	354	347	349	39.11	97.8	37.23	93.1	38.56	96.4	38.3	95.8
25SP	345.5	350	346	33.87	84.7	34.6	86.5	34.96	87.4	34.5	86.2
22.5GP-7.5SP	342	343	338	36.74	91.9	35.98	90.0	37.98	95.0	36.9	92.3
15GP-15SP	345	349	345	33.56	83.9	33.98	85.0	34.76	86.9	34.1	85.3
7.5GP-22.5SP	350	345	349	29.63	74.1	28.32	70.8	30.25	75.6	29.4	73.5

Mix-Id	Compressive strength cured in water – 56th-day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	368.5	369.5	367.5	46.92	117.3	47.08	117.7	47.74	119.4	47.2	118.1
10SP	361.3	363	359	52.78	132.0	53.81	134.5	52.14	130.4	52.9	132.3
15SP	357.5	358.5	355	48.22	120.6	48.01	120.0	47.38	118.5	47.9	119.7
20SP	354.5	352.5	349.5	45.81	114.5	42.26	105.7	43.76	109.4	43.9	109.9
25SP	347.5	350.5	354	39.23	98.1	40.34	100.9	41.93	104.8	40.5	101.3
22.5GP-7.5SP	341	346	335	45.62	114.1	42.35	105.9	44.03	110.1	44.0	110.0
15GP-15SP	341	342.5	346.5	40.35	100.9	41.23	103.1	39.02	97.6	40.2	100.5
7.5GP-22.5SP	344.5	344.5	340.5	36.54	91.4	40.06	100.2	37.10	92.8	37.9	94.8

Mix-Id	Compressive strength cured in water – 90th-day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	351.5	360	365	49.19	123.0	49.24	123.1	50.4	126.0	49.6	124.0
10SP	347	352	358.5	55.12	137.8	57.92	144.8	54.68	136.7	55.9	139.8
15SP	347.5	352	350	49.26	123.2	49.86	124.7	52.9	132.3	50.7	126.7
20SP	350	346.5	350	48.3	120.8	48.41	121.0	46.8	117.0	47.8	119.6
25SP	344.5	359.5	358.5	44.21	110.5	44.54	111.4	43.06	107.7	43.9	109.8
22.5GP-7.5SP	341.5	342	338.5	47.53	118.8	47.56	118.9	46.22	115.6	47.1	117.8
15GP-15SP	345	344	339.5	46.92	117.3	44.67	111.7	43.56	108.9	45.1	112.6
7.5GP-22.5SP	346	349.5	345	44.88	112.2	43.41	108.5	42.34	105.9	43.5	108.9

6. Sulphate Attack

Table E.2 Sulphate Attack Test Result of Different Curing Age

Mix-Id	Compressive strength cured in Sulphate(NaHSo4) – 3rd day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	372.0	367.0	357.5	19.17	47.9	17.87	44.7	18.99	47.5	18.7	46.7
10SP	358.5	359.5	360.0	15.95	39.9	17.89	44.7	16.83	42.1	16.9	42.2
15SP	357.5	349.5	356.0	16.32	40.8	14.98	37.5	15.90	39.8	15.7	39.3
20SP	347.5	347.5	348.0	14.56	36.4	14.98	37.5	13.99	35.0	14.5	36.3
25SP	341.5	346.0	343.0	12.58	31.5	12.20	30.5	12.38	31.0	12.4	31.0
22.5GP-7.5SP	335.5	342.0	342.5	15.05	37.6	14.13	35.3	13.17	32.9	14.1	35.3
15GP-15SP	336.5	339.0	341.5	13.21	33.0	14.78	37.0	13.25	33.1	13.7	34.4
7.5GP-22.5SP	344.0	342.5	341.0	10.50	26.3	11.30	28.3	11.90	29.8	11.2	28.1

Mix-Id	Compressive strength cured in Sulphate(NaHSo4) – 7th- day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	349.0	364.5	351.0	29.93	74.8	28.85	72.1	27.97	69.9	28.9	72.3
10SP	350.5	354.5	349.5	28.01	70.0	28.54	71.4	27.45	68.6	28.0	70.0
15SP	348.5	350.0	348.0	24.87	62.2	24.96	62.4	25.17	62.9	25.0	62.5
20SP	349.0	351.0	346.5	22.34	55.9	22.93	57.3	23.63	59.1	23.0	57.4
25SP	345.5	346.5	350.0	20.04	50.1	19.80	49.5	20.36	50.9	20.1	50.2
22.5GP-7.5SP	339.5	340.0	338.0	22.30	55.8	23.92	59.8	21.98	55.0	22.7	56.8
15GP-15SP	342.0	342.5	344.0	21.84	54.6	20.24	50.6	20.62	51.6	20.9	52.3
7.5GP-22.5SP	344.0	346.5	341.0	17.04	42.6	18.65	46.6	16.31	40.8	17.3	43.3

Mix-Id	Compressive strength cured in Sulphate(NaHSo4) – 28th- day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	358.5	369.5	355.0	41.59	104.0	42.91	107.3	43.03	107.6	42.5	106.3
10SP	360.5	364.5	353.5	45.56	113.9	44.07	110.2	45.77	114.4	45.1	112.8
15SP	358.5	356.0	362.0	41.28	103.2	42.46	106.2	40.66	101.7	41.5	103.7
20SP	349.0	351.0	346.5	37.79	94.5	37.63	94.1	38.98	97.5	38.1	95.3
25SP	350.5	346.0	347.5	33.98	85.0	33.26	83.1	34.97	87.4	34.1	85.2
22.5GP-7.5SP	338.0	346.5	324.0	36.92	92.3	35.12	87.8	36.76	91.9	36.3	90.7
15GP-15SP	349.5	348.0	342.0	33.17	82.9	35.27	88.2	34.06	85.2	34.2	85.4
7.5GP-22.5SP	344.5	351.0	348.5	30.14	75.4	28.63	71.6	29.13	72.8	29.3	73.3

Mix-Id	Compressive strength cured in Sulphate(NaHSo4) – 56th- day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	369.50	361.50	357.50	47.32	118.30	44.56	111.40	45.82	114.55	45.90	114.75
10SP	368.50	359.00	360.00	48.28	120.70	53.57	133.93	52.05	130.13	51.30	128.25
15SP	354.50	348.00	356.00	46.96	117.40	47.38	118.45	46.16	115.40	46.83	117.08
20SP	349.50	349.50	348.00	43.12	107.80	44.24	110.60	42.64	106.60	43.33	108.33
25SP	348.50	351.00	343.00	38.46	96.15	40.76	101.90	40.98	102.45	40.07	100.17
22.5GP-7.5SP	339.50	343.00	342.50	42.91	107.28	43.62	109.05	44.02	110.05	43.52	108.79
15GP-15SP	346.50	345.00	342.50	40.32	100.80	39.14	97.85	41.24	103.10	40.23	100.58
7.5GP-22.5SP	354.00	346.50	347.00	36.64	91.60	37.78	94.45	38.18	95.45	37.53	93.83

Mix-Id	Compressive strength cured in Sulphate(NaHSo4) – 90th- day test										
	Weight of Cube			Cube-1		Cube-2		Cube-3		Mean compressive	
	Cube-1	Cube-2	cube-3	Mpa	KN	Mpa	KN	Mpa	KN	Mpa	KN
OPC	359.00	361.50	366.50	47.76	119.40	45.43	113.58	46.78	116.95	46.66	116.64
10SP	360.50	359.00	365.50	52.22	130.55	52.80	132.00	53.94	134.85	52.99	132.47
15SP	359.50	355.00	359.50	50.42	126.05	48.55	121.38	48.22	120.55	49.06	122.66
20SP	350.00	356.50	349.00	45.23	113.08	46.68	116.70	46.97	117.43	46.29	115.73
25SP	348.50	351.00	349.50	42.30	105.75	43.55	108.88	41.91	104.78	42.59	106.47
22.5GP-7.5SP	340.00	345.40	338.50	45.96	114.90	47.54	118.85	45.10	112.75	46.20	115.50
15GP-15SP	349.50	342.50	344.00	43.27	108.18	44.02	110.05	44.78	111.95	44.02	110.06
7.5GP-22.5SP	346.00	349.50	348.00	41.12	102.80	41.99	104.98	43.00	107.50	42.04	105.09

Mix Codes (%)	Compressive Strength (Mpa) and curing condition														
	3rd Day			7th Day			28th Day			56th Day			90-Day		
	water	sulfate	(%)Loss	water	sulfate	(%)Loss	water	sulfate	(%)Loss	water	sulfate	(Loss)	water	sulfate	(%)Loss
OPC	18.3	18.7	2.3%	29.2	28.9	-1.0%	43.1	42.5	-1.4%	47.2	45.9	-2.9%	49.6	46.7	-6.0%
10SP	16.5	16.9	2.4%	27.9	28.0	0.4%	45.6	45.1	-1.0%	52.9	51.3	-3.0%	55.9	53.0	-5.2%
15SP	15.5	15.7	1.7%	25.2	25.0	-0.8%	41.7	41.5	-0.6%	47.9	46.8	-2.2%	50.7	49.1	-3.2%
20SP	14.3	14.5	1.5%	23.1	23.0	-0.6%	38.3	38.1	-0.4%	44.2	43.3	-2.0%	47.8	46.3	-3.2%
25SP	12.3	12.4	0.5%	20.0	20.1	0.3%	34.5	34.1	-1.2%	40.5	40.1	-1.1%	43.9	42.6	-3.1%
22.5GP-7.5SP	14.0	14.1	0.9%	23.0	22.7	-1.2%	36.9	36.3	-1.7%	44.0	43.5	-1.1%	47.1	46.2	-1.9%
15GP-15SP	13.6	13.7	0.8%	20.8	20.9	0.5%	34.1	34.2	0.2%	40.2	40.2	0.1%	45.1	44.0	-2.3%
7.5GP-22.5SP	11.1	11.2	1.2%	17.1	17.3	1.4%	29.4	29.3	-0.3%	37.9	37.5	-1.0%	43.5	42.0	-3.5%

7. Water absorption

Table E.3 Water Absorption Test Result of Different Curing Age

Water absorption test -3- DAY										
	Saturated weight (w2)			Oven-dry weight (w1).			water absorption %			Mean water Absorption
Mix-type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube-1	cube-2	cube-3	3-Day
OPC	351	348.5	350.5	315.5	313.5	315	11.25%	11.16%	11.27%	11.2%
10SP	348	349.5	347.5	311.5	312.5	311	11.72%	11.84%	11.74%	11.8%
15SP	346.5	346	347.5	309.5	309.2	310.5	11.95%	11.90%	11.92%	11.9%
20SP	344.5	345	347	307	305.5	307.5	12.21%	12.93%	12.85%	12.7%
25SP	346.5	339.5	342	306.5	300	303.5	13.05%	13.17%	12.69%	13.0%
22.5GP-7.5SP	344	339	342	304	299.5	305	13.16%	13.19%	12.13%	12.8%
15GP-15SP	356	349.5	345	317	310	306	12.30%	12.74%	12.75%	12.6%
7.5GP-22.5SP	351	342	352	311.5	303.5	313.5	12.68%	12.69%	12.28%	12.5%

Water absorption test -7- DAY										
	Saturated weight (w2)			Oven-dry weight (w1).			water absorption %			Mean water Absorption
Mix-type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube-1	cube-2	cube-3	7-Day
OPC	362	352	338	326.5	317	305	10.87%	11.04%	10.82%	10.9%
10SP	351.5	343	345.5	315	308	310.5	11.59%	11.36%	11.27%	11.4%
15SP	339	347	340.5	304	311.5	306	11.51%	11.40%	11.27%	11.4%
20SP	334.5	331	348	299.5	297	311.5	11.69%	11.45%	11.72%	11.6%
25SP	336.5	330	335	302	295	299.5	11.42%	11.86%	11.85%	11.7%
22.5GP-7.5SP	335	346	343	298.5	309	306	12.23%	11.97%	12.09%	12.1%
15GP-15SP	368.5	359.5	345	329	320.5	307.5	12.01%	12.17%	12.20%	12.1%
7.5GP-22.5SP	357	356.5	341	319	318	305	11.91%	12.11%	11.80%	11.9%

Water absorption test -28- DAY										
	Saturated weight (w2)			Oven-dry weight (w1).			water absorption %			Mean water Absorption
Mix-type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube-1	cube-2	cube-3	28-Day
OPC	342	352.5	356	311	320	325	9.97%	10.16%	9.54%	9.9%
10SP	341	339.5	349	308.5	307	316.5	10.53%	10.59%	10.27%	10.5%
15SP	351.5	346	344.5	317	312	310.5	10.88%	10.90%	10.95%	10.9%
20SP	333	339	341.5	300	305	307.5	11.00%	11.15%	11.06%	11.1%
25SP	364.5	344.5	352	329	309.5	315	10.79%	11.31%	11.75%	11.3%
22.5GP-7.5SP	339.5	334.5	338.5	304	300.5	302	11.68%	11.31%	12.09%	11.7%
15GP-15SP	354.5	349.5	346.5	317.5	313	310.5	11.65%	11.66%	11.59%	11.6%
7.5GP-22.5SP	354.5	349	351	319	313	314.5	11.13%	11.50%	11.61%	11.4%

Water absorption test -56- DAY										
	Saturated weight (w2)			Oven-dry weight (w1).			water absorption %			Mean water Absorption
Mix-type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube-1	cube-2	cube-3	56-Day
OPC	354	348.5	344	322.5	317.5	315.5	9.77%	9.76%	9.03%	9.5%
10SP	347.5	350	348.5	317.5	318.5	316.5	9.45%	9.89%	10.11%	9.8%
15SP	353	340.5	340.5	322.5	309.5	308.5	9.46%	10.02%	10.37%	9.9%
20SP	347	344	338	313.5	310.5	304	10.69%	10.79%	11.18%	10.9%
25SP	346	343.5	335.5	311.5	310.5	302	11.08%	10.63%	11.09%	10.9%
22.5GP-7.5SP	326.5	343.5	324.5	292.5	308.5	290.5	11.62%	11.35%	11.70%	11.6%
15GP-15SP	352.5	340.5	349.5	316	306.5	313.5	11.55%	11.09%	11.48%	11.4%
7.5GP-22.5SP	338.5	336	329	304.5	301.5	295.5	11.17%	11.44%	11.34%	11.3%

Water absorption test -90- DAY										
	Saturated weight (w2)			Oven-dry weight (w1).			water absorption %			Mean water Absorption
Mix-type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube-1	cube-2	cube-3	90-Day
OPC	340	348.2	345	310.4	317.2	315.2	9.54%	9.77%	9.45%	9.6%
10SP	340.2	340.8	341	309.6	310.4	312	9.88%	9.79%	9.29%	9.7%
15SP	345	341.6	339.4	313.6	311.5	310.2	10.01%	9.66%	9.41%	9.7%
20SP	358.2	347.6	342	324.6	314.4	310	10.35%	10.56%	10.32%	10.4%
25SP	362.2	343	361.2	328.2	310	326	10.36%	10.65%	10.80%	10.6%
22.5GP-7.5SP	324.8	344.4	338	293.6	311.6	305.2	10.63%	10.53%	10.75%	10.6%
15GP-15SP	347.8	342.8	336	313.2	309.6	303.2	11.05%	10.72%	10.82%	10.9%
7.5GP-22.5SP	361.8	354.6	349.8	327.4	319.4	315.8	10.51%	11.02%	10.77%	10.8%

Water absorption test					
	Mean water absorption capasity(%)				
Mix-type	3rd-Day	7th-Day	28th-Day	56th-Day	90th-Day
CT	11.2%	10.9%	9.9%	9.5%	9.6%
10SP	11.8%	11.4%	10.5%	9.8%	9.7%
15SP	11.9%	11.4%	10.9%	9.9%	9.7%
20SP	12.7%	11.6%	11.1%	10.9%	10.4%
25SP	13.0%	11.7%	11.3%	10.9%	10.6%
22.5GP-7.5SP	12.8%	12.1%	11.7%	11.6%	10.6%
15GP-15SP	12.6%	12.1%	11.6%	11.4%	10.9%
7.5GP-22.5SP	12.5%	11.9%	11.4%	11.3%	10.8%

8. Ultrasonic-pulse velocity

Table E.4 Water Absorption Test Result of Different Curing Age

Ultra-sonic pulse velocity (UPV) – 3rd day test							
Mix-ID	Weight Of Specimen In Gm.			UPV Reading (micro-second)			
	Cube -1	Cube -2	Cube -3	Cube -1	Cube -2	Cube -3	Average
OPC	353.0	348.0	354.5	20.2	20.8	20.5	20.5
10SP	349.0	349.5	348.5	22.2	22.1	22.2	22.2
15SP	347.5	350.0	347.5	22.6	22.4	21.9	22.3
20SP	344.5	345.5	346.5	22.2	22.7	22.7	22.5
25SP	342.5	340.5	342.0	22.3	22.9	22.2	22.5
22.5GP-7.5	335.5	340.0	339.0	22.3	22.6	21.9	22.3
15GP-15SP	343.0	344.0	342.0	22.4	22.6	22.5	22.5
7.5GP-22.5	347.0	347.0	348.5	22.6	22.3	22.8	22.6

Ultra-sonic pulse velocity (UPV) – 7th-day test							
Mix-ID	Weight Of Specimen In Gm.			UPV Reading (micro-second)			
	Cube -1	Cube -2	Cube -3	Cube -1	Cube -2	Cube -3	Average
OPC	349.0	352.5	356.0	18.7	18.9	19.2	18.9
10SP	345.0	345.5	351.0	19.0	19.1	19.3	19.1
15SP	346.0	342.0	351.5	19.1	19.8	18.6	19.2
20SP	347.5	339.5	340.0	18.8	19.6	19.1	19.2
25SP	346.0	342.0	342.5	19.6	19.2	19.6	19.5
22.5GP-7.5	333.0	330.5	332.0	19.2	19.7	19.9	19.6
15GP-15SP	340.0	337.5	341.5	19.9	19.3	19.5	19.6
7.5GP-22.5	343.0	343.5	340.0	19.8	19.7	19.8	19.8

Ultra-sonic pulse velocity (UPV) – 28th-day test							
Mix-ID	Weight Of Specimen In Gm.			UPV Reading (micro-second)			
	Cube -1	Cube -2	Cube -3	Cube -1	Cube -2	Cube -3	Average
OPC	362.0	359.0	357.5	16.5	16.3	16.3	16.4
10SP	361.0	358.0	353.0	16.3	16.1	16.6	16.3
15SP	352.0	353.0	357.0	16.4	16.8	16.3	16.5
20SP	347.0	358.0	350.0	16.8	16.6	16.5	16.6
25SP	348.0	348.9	351.0	16.7	17.0	16.9	16.9
22.5GP-7.5	341.0	339.5	340.0	17.0	16.9	17.3	17.1
15GP-15SP	341.0	344.0	345.0	16.9	17.1	17.3	17.1
7.5GP-22.5	346.0	347.0	349.5	17.3	17.6	17.2	17.4

Ultra-sonic pulse velocity (UPV) – 56th-day test							
Mix-ID	Weight Of Specimen In Gm.			UPV Reading (micro-second)			
	Cube -1	Cube -2	Cube -3	Cube -1	Cube -2	Cube -3	Average
OPC	347.0	350.5	353.0	16.7	16.3	16.2	16.4
10SP	340.0	345.5	338.0	16.4	16.2	16.1	16.2
15SP	347.0	342.5	351.0	16.5	16.2	16.3	16.3
20SP	345.5	331.5	347.0	16.5	16.3	16.4	16.4
25SP	349.0	342.5	348.0	16.8	16.2	16.5	16.5
22.5GP-7.5	337.0	329.5	339.0	16.1	16.3	16.1	16.2
15GP-15SP	343.0	339.5	341.0	16.3	16.5	16.4	16.4
7.5GP-22.5	348.0	345.5	347.0	16.6	16.4	16.3	16.4

Ultra-sonic pulse velocity (UPV) – 90th-day test							
Mix-ID	Weight Of Specimen In Gm.			UPV Reading (micro-second)			
	Cube -1	Cube -2	Cube -3	Cube -1	Cube -2	Cube -3	Average
OPC	358.0	364 .5	366.0	16.2	16.1	16.0	16.1
10SP	358.0	349.0	368.0	16.1	15.8	16.1	16.0
15SP	353.5	352.0	357.5	16.0	16.2	15.9	16.0
20SP	344.5	453.5	349.5	16.4	16.1	16.3	16.3
25SP	350.0	348.5	341.5	16.4	16.5	16.3	16.4
22.5GP-7.5	339.5	336.5	340.0	16.0	16.2	16.1	16.1
15GP-15SP	348.0	339.5	348.5	16.4	16.5	16.4	16.4
7.5GP-22.5	345.0	349.5	345.0	16.3	16.7	16.4	16.5

Mean UPV test result					
Mix-ID	3rd-Day	7th-Day	28th-Day	56th-Day	90th-Day
OPC	2439.0	2640.8	3055.0	3048.8	3105.6
10SP	2255.6	2613.2	3061.2	3080.1	3125.0
15SP	2242.2	2608.7	3030.3	3061.2	3118.5
20SP	2218.9	2608.7	3006.0	3048.8	3073.8
25SP	2225.5	2568.5	2964.4	3030.3	3048.8
22.5GP-7	2245.5	2551.0	2929.7	3092.8	3105.6
15GP-15S	2222.2	2555.4	2924.0	3048.8	3042.6
7.5GP-22	2215.7	2529.5	2879.1	3042.6	3036.4

APPENDIX F

1. Power cost and Energy

For the production of each 10 kg of Scoria and glass powder; the following machine power and milling time taken from machinery specification and the actual production of scoria and glass powder.

A. Disk mill machine power required = 2050watt
B. Time for milling = 3 hr.
C. Current cost of electric power for business in Ethiopia 1.019 ETB/kwh. (Source, Ethiopian Electric Power Corporation)

$$\text{Energy required} = \text{Machine Power} \times \text{Time required for production of scoria \& Glass powder}$$

Disk mill Power consumption per 10kg = $2050watt \times 3hour = 6.15kwh$

Energy required for 10kg powder

$$= 6.15kwh \times 3500sec/hr.$$

$$= 21{,}525\ kilojoule$$

$= 21.5\ Mega\ joules\ for\ production\ of\ 10\ kg\ scoria\ and\ glass$ Powder

Energy required for 1kg of Glass and scoria

$$= 21.5 \div 10$$

$$= 2.15\ Mega\ joules$$

Energy Cost of powder per 10kg

$$= 6.15\ kWh \times 1.019ETB = 6.27\ ETB$$

Energy cost of powder for 1kg

$$= 0.627\ ETB.$$

2. Cost Estimation

According to Amar Pratap (Singh, 2014), the major cost elements that are associated with the production of cement include power and fuel costs, raw material costs, selling expenses and other expenses. Power and fuel, material, and transportation, costs accounts for 30%, 30%, and 10% of the price of the cement when it is sold respectively. Selling and other expenses such as employee cost administration cost, repair and maintenance cost accounts up to 20% of the price of the cement when it is sold. Material and transportation of scoria costs estimated based on interviewing local suppliers in the markets. The Power cost for the production of scoria and glass is estimated based on the milling time and laboratory machinery power consumption. Selling and other costs such as labor, administration cost, repair and maintenance cost estimated based on the above percent from the price of current OPC cement for scoria powder. The cost of glass is taken as the same cost of scoria.

Current price of 1 Quintal OPC cement price is 700ETB.

Table F.1 Cost Estimation of OPC and Scoria

No.	Costs of cement	% per price of cement	OPC cost	Cost scoria
1.	Power cost& fuel cost	30%	210.0 ETB	62.7 ETB
3.	Material cost	30%	210.0 ETB	50.0 ETB
4.	Transportation cost	10%	70.0 ETB	
5.	Selling and other expenses	20%	140.0 ETB	140.0 ETB
6.	Benefit	10%	70.0 ETB	70.0 ETB
7	**Total price of cement**	**100%**	**700.0 ETB**	**323.0 ETB**

Table: Cost saving per Quintal of cement

Cement type	Cost of cement per Quintal
CT	700 ETB
10SP	662 ETB
15SP	643 ETB
20SP	624 ETB
25SP	606 ETB
30GPSP	587 ETB

3. SPSS Output

1. Between-Subjects Factors

Between-Subjects Factors

		Value Label	N
Curing-Age	1	3rd-Day	24
	2	7th-Day	24
	3	28th-Day	24
	4	56th-Day	24
	5	90th-Day	24
Mix-Type	1	CT	15
	2	10SP	15
	3	15SP	15
	4	20SP	15
	5	25SP	15
	6	22.5GP-7.5SP	15
	7	15GP-15SP	15
	8	7.5GP-22.5SP	15

2. Homogeneous Subsets

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
Compressive Strength	1.161	39	80	.283
Sulphate Attack	4.618	39	80	.000
Water Absorption	2.415	39	80	.000
UPV	1.688	39	80	.025

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + MixType + Curingage + MixType * Curingage

Sulphate Attack

Tukey HSD

Mix-Type	N	Subset
		1
25SP	15	.07367
15GP-15SP	15	.44333
20SP	15	.55467
15SP	15	.74467
22.5GP-7.5SP	15	.75733
CT	15	.89733
10SP	15	1.18667
7.5GP-22.5SP	15	1.71133
Sig.		.448

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 4.732.

a. Uses Harmonic Mean Sample Size = 15.000.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

c. Alpha = .05.

Compressive Strength

Tukey HSD

Mix-Type	N	Subset				
		1	2	3	4	5
7.5GP-22.5SP	15	27.66667				
25SP	15		30.26667			
15GP-15SP	15		30.80000			
22.5GP-7.5SP	15			33.06667		
20SP	15			33.46667		
15SP	15				36.13333	
CT	15				37.40000	
10SP	15					39.93333
Sig.		1.000	.923	.983	.085	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 1.425.

a. Uses Harmonic Mean Sample Size = 15.000.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

c. Alpha = .05.

Water Absorption

Tukey HSD

Mix-Type	N	Subset			
		1	2	3	4
CT	15	.10227			
10SP	15		.10622		
15SP	15		.10775		
20SP	15			.11329	
25SP	15			.11499	.11499
7.5GP-22.5SP	15			.11596	.11596
15GP-15SP	15				.11719
22.5GP-7.5SP	15				.11761
Sig.		1.000	.727	.096	.108

Means for groups in homogeneous subsets are displayed.Based on observed means. The error term is Mean Square(Error) = 6.56E-006.

a. Uses Harmonic Mean Sample Size = 15.000.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

c. Alpha = .05.

UPV

Tukey HSD

Mix-Type	N	Subset				
		1	2	3	4	5
CT	15	17.65333				
10SP	15		18.04000			
15SP	15		18.08667	18.08667		
20SP	15		18.20000	18.20000	18.20000	
22.5GP-7.5SP	15		18.28667	18.28667	18.28667	18.28667
25SP	15			18.34000	18.34000	18.34000
15GP-15SP	15				18.40000	18.40000
7.5GP-22.5SP	15					18.52000
Sig.		1.000	.112	.094	.327	.157

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .059.

a. Uses Harmonic Mean Sample Size = 15.000.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

c. Alpha = .05.

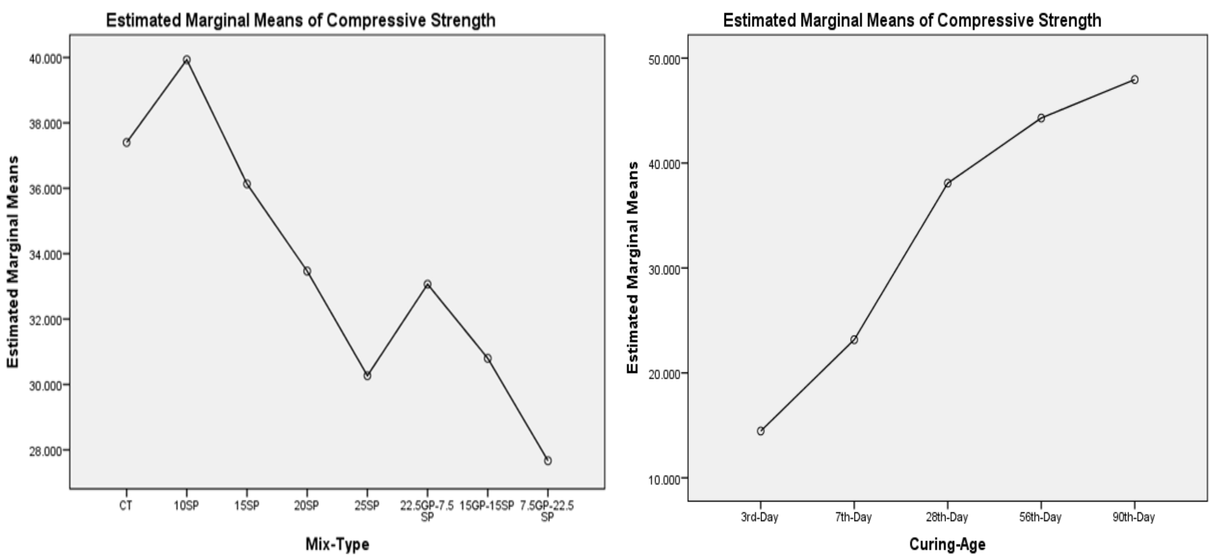


Figure F.1 Marginal Means of Compressive Strength

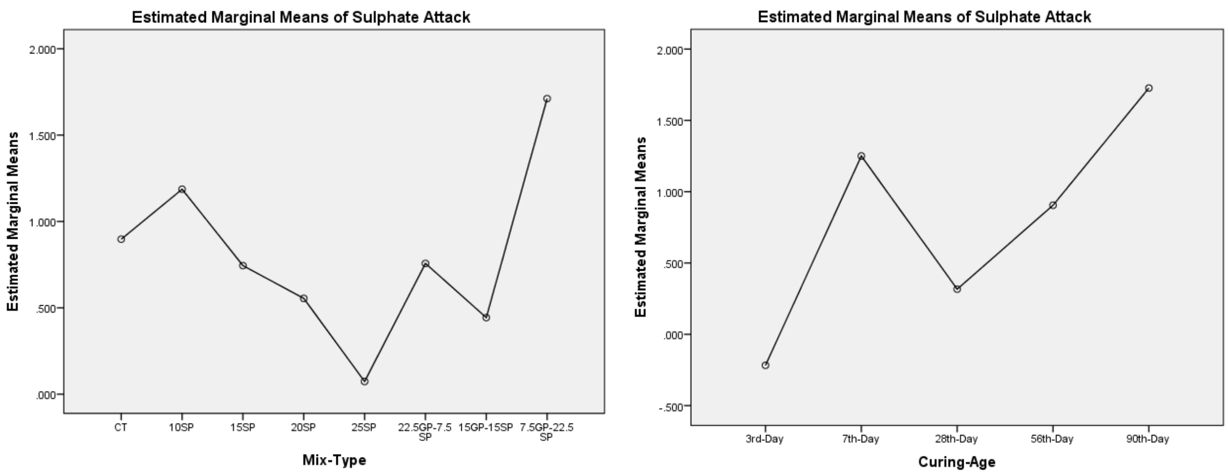


Figure F.2: Marginal Means of Sulphate Attack

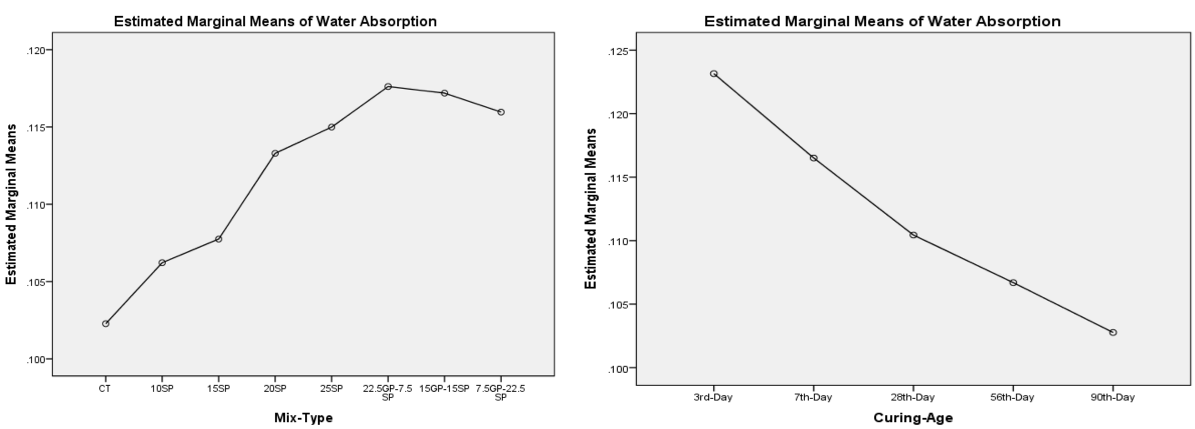


Figure F.3 Marginal Means of Water Absorption

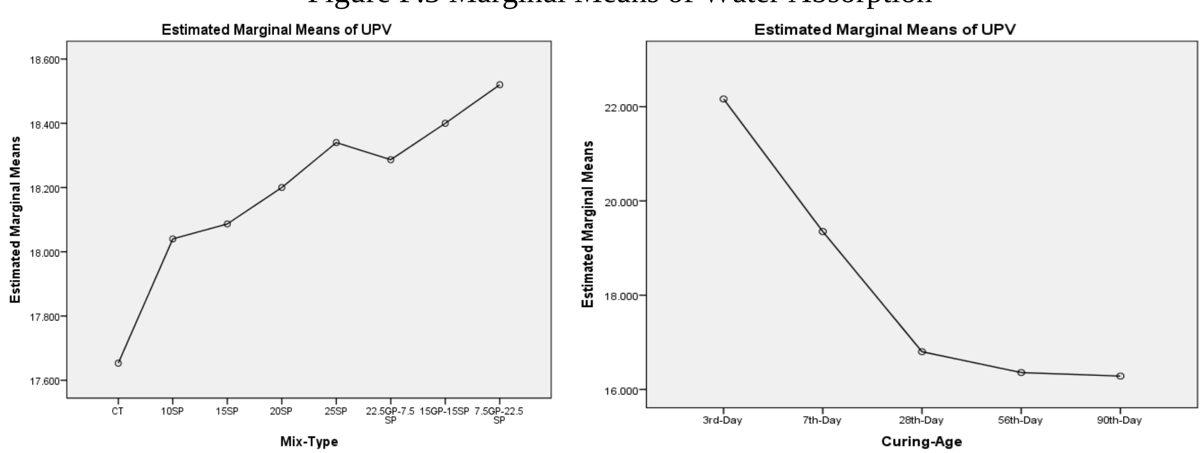


Figure F.4 Marginal Means of UPV

Figure F.5 Some Photo during Work