EXPERIMENTAL INVESTIGATION OF PUMICE POWDER AND BAMBOO LEAF ASH AS A PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

Haris Hassen Adem

A Thesis Submitted to the Department of Civil Engineering School of Civil Engineering and Architecture

Presented in fulfilment of the Requirement for the Degree of Master's in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies
Adama Science and Technology University

June, 2023

Adama, Ethiopia

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DECLARATION

I declare that this thesis entitled "**Experimental Investigation of Pumice Powder and Bamboo Leaf Ash as a Partial Replacement of Cement in Concrete**" is my own work and has not been submitted to any university for similar purposes. Proper citations duly recognize the references used in this thesis.

Haris Hassen ________________________ ________________

Signature Date

RECOMMENDATION OF ADVISOR

I, the principal advisor of this thesis, hereby certify that I have closely advised/supervised the student while developing this thesis and read the draft thesis entitled **"Experimental Investigation of Pumice Powder and Bamboo Leaf Ash as a Partial Replacement of Cement in Concrete"** prepared under my guidance by Haris Hassen Adem.

Therefore, I recommend submitting the thesis to the department for further review and evaluation.

Fikreyesus Demeke (PhD)	______________________	_______________
Major Advisor	Signature	Date

APPROVAL PAGE

I, the advisor of the thesis entitled "**Experimental Investigation of Pumice Powder and Bamboo Leaf Ash as a Partial Replacement of Cement in Concrete**" and developed by Haris Hassen, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Fikreyesus Demeke (PhD)	______________	______________________
Advisor	Signature	Date

APPROVAL OF BOARD REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by Haris Hassen Adem have read and evaluated the thesis entitled "**Experimental Investigation of Pumice Powder and Bamboo Leaf Ash as a Partial Replacement of Cement in Concrete**" and examined the candidate during the open defence. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Construction Engineering and Management.

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ABSTRACT

Concrete has been used in construction industry for centuries with flexibility, making it the most-used substance globally. Cement is the basic ingredient of concrete, which is costly and environmentally unfriendly. Its production result in high carbon emissions, require large capital costs and production energy, and consumes a lot of raw materials. However, this could be decreased by utilizing local and inexpensive supplementary cementitious materials. Therefore, this research objective is to investigate the potential of blending Pumice Powder and Bamboo Leaf Ash as partially replacing cementitious material on mechanical and durability properties of concrete. In this study, the capability of Ethiopian rift valley Pumice Powder and highland Bamboo Leaf Ash as a partial substitute for cement in C-25 concrete production with 5%, 10%, 15% and 20% replacement of OPC with Mix-1(100, 0, 0): Mix-2 (90, 5, 5): Mix-3(85, 10, 5): Mix-4 (85, 5, 10): Mix-5 (80, 10, 10) of (OPC: PP: BLA) % respectively investigated. The chemical composition of VPP and BLA was examined and the summation of major oxide (SiO_2, Al_2O_3, and Fe_2O_3) is 84.59 %, 74.4% and classified as class N, F pozzolan respectively. C-25 Concrete mix design is designed according to the ACI standards. The result also exposed that workability of concrete decreases as the Pumice Powder and Bamboo Leaf Ash replacement increases. On the 28th day, Mix-2 and Mix-3 attains the target mean compressive strength (33.5Mpa) of C-25 concrete according to the ACI standards. The flexural strength of concrete made with partial replacement of mix-2 satisfied the required strengths 3.5Mpa for C25 IS standards. The water absorption of the Pumice Powder and Bamboo Leaf Ash blended concrete was lower than the control at mix-2 and the blended concrete improved its resistance to sulphuric acid attack and Mix-3 had the least strength reduction of 9.59%. In contrast, the control mix has a 33.34% strength reduction. The cost-effectiveness advantages of incorporating Pumice Powder and Bamboo Leaf Ash into concrete are more prominent when compared to conventional concrete.

Keywords/terms: *Cement; Bamboo Leaf Ash; Pumice Powder; Supplementary Cementitious Materials; Concrete.*

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LIST OF ACRONYMS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BL	Bamboo Leaf
BLA	Bamboo Leaf Ash
BFSC	Blast Furnace Slag Cement
EDS	Energy dispersive spectroscopy
GHG	Green House Gas
GDP	Gross Domestic Product
IS	International Standard
LOI	Loss of Ignition
LHC	Low Heat Cement
OPC	Ordinary Portland Cement
PCC	Plain Cement Concrete
PC	Portland Cement
PPC	Portland Pozzolana Cement
SCM	Supplementary Cementitious Material
SEM	Scanning Electron Microscope
RCC	Reinforced Cement Concrete
PP	Pumice Powder
XRD	X-Ray Diffraction
XRF	X-Ray Florescence
GJ/t	Gigajoule per ton
KWH	Kilowatt hour
C-25	Concrete characteristic compressive strength of 25 Mpa
MPa	Mega Pascal

LIST OF CHEMICAL FORMULAS

Al	Aluminum	C_4AF	TetraCalcium Alumino Ferrite
Al_2O_3	Aluminum Oxide	C-S-H	Calcium Silica Hydrate
Ca	Calcium	CH	Calcium Hydroxide
CaO	Calcium Oxide	CO_2	Carbon Dioxide
$CaCO_3$	Calcium Carbonate	Fe	Iron
Ca_3SiO_5	Alite	Fe_2O_3	Iron Oxide
Ca_2SiO_5	Belite	K_2O	Potassium Oxide
Ca_2AlFeO_5	Ferrite	MgO	Magnesium Oxide
Ca_3Al12O_6	Aluminate	Na_2O	Sodium Oxide
H_2SO_4	Sulpharic acid	Si	Silicon
SO_3	Sulfur Trioxide	SiO_2	Silicon Oxide

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The construction industry is one of the largest and most important sectors in the global economy as it provides an essential service, constructing buildings and infrastructure for various purposes such as residential, transportation, education, health, and different sectors (Ball, 2014). Concrete is the most widely used material in the construction industry, due to its durability and strength (Valente et al., 2019).

Concrete has been used for centuries with flexibility, though it has been widely used for years, its basic ingredient remains cement, accounting for about 15% of the total weight of concrete (Li et al., 2022). This basic material continues to be in high demand all over the world for construction purposes. According to Mehta & Monteiro, (2014), the annual global cement production is predicted to be 11 billion tonnes. At the same time, the demand for cement worldwide is expected to increase by 4.7% annually (Hossain, 2004). A significant quantity of waste, capital expenditure, consumption of energy, and traditional raw materials would be produced, needed, and used annually as a result of this growth rate of production (Gebremariam & Marchetti, 2018).

The high rates of cement production result in significant waste production, high capital expenditures, high carbon emissions, and energy-intensive processes (Gashahun, 2020; Worrell et al., 2001). Portland cement must be produced at high temperatures and with a lot of energy, which makes it particularly expensive. In addition to polluting the atmosphere, this process causes the release of harmful gases (Mohamad et al., 2022). However, it is possible to minimize the environmental impact of cement production by partially replacing cement with materials that are readily available locally. This method aids in minimizing overall energy needs and minimizing negative environmental effects. Additionally, utilizing alternative materials can aid in conserving conventional raw materials and advancing environmentally friendly practices in the construction sector (Abebaw et al., 2021).

In this regard, getting suitable replacements or ways to use less of alternative materials per unit volume of construction materials for conventional materials like cement while keeping the required quality are consequently important as the price of these resources continues to rise. In the production of concrete, Portland cement is utilized more commonly. A decrease in Portland cement consumption and cost could result into more cost-effective concrete production (Kolawole et al., 2021).

The cement industry consistently strives to reduce the expense and resource usage of Portland cement production while preserving the environment and enhancing the cement and concrete's quality (strength and durability). This can be commonly accomplished by utilizing pozzolans as a partial substitute for Portland cement during concrete manufacturing (Askarian et al., 2018; Temitope et al., 2015).

A pozzolan is a siliceous or siliceous and aluminous substance that by itself has very limited binding capacity (Mohan et al., 2020). A variety of pozzolanic materials, including rice husk ash, bamboo leaf ash, burnt clay waste, sawdust ash, corn cob ash, fly ash, silica fume, metakaolin, pumice powder, blast furnace slag, clinoptilolite, and periwinkle shell ash, have been explored for their potential use in manufacturing blended cement concrete (Sanusi et al., 2014; Temitope,, 2015). From those materials, volcanic pumice powder and bamboo leaf ash were investigated by past studies for their potential to substitute cement in concrete production partially.

Pumice can serve as a valuable resource for creating cement and concrete, particularly in volcanic regions, and contributes to cost-effective construction (Hossain, 2004). Incorporating PP as cement replacement led to reduced strength in the initial stages, but similar strength in later stages when compared to conventional concrete. Additionally, PP enhanced the concrete's workability and diminished its absorption and porosity levels (Kabay et al., 2015).

Scholars investigated that bamboo leaf ash possesses pozzolanic properties that able to utilize bamboo leaf ash as a replacement material for cement. Bamboo leaves are often considered as a waste from agricultural activities and their disposal becomes an ecological crisis especially around bamboo growing centres causes' water pollution, and it has associated health effects (Abebaw et al., 2021). The potential for agricultural crop byproducts to partially substitute cement offers an opportunity to decrease the environmental contamination and energy consumption associated with cement manufacturing. (Zerihun et al., 2022). Abebaw et al., (2021) found that using bamboo leaf ash as a cement substitute can potentially reduce cement usage by up to 10%. This result may help to mitigate rising cement prices and increase the affordability of housing without negatively affecting quality. Moraes et al. (2019) also reported that incorporating bamboo leaf ash into cementitious matrices decreased workability and enhanced mechanical behavior and durability.

The construction industry is seeing a rapid increase in the usage of blended cements, driven by factors such as cost savings and environmental conservation. Some studies have demonstrated the effective use of bamboo leaf ash and volcanic pumice powder as partial substitutes for cement in concrete production, However, none has dealt with a ternary combination of the three (Portland cement, bamboo leaf ash and pumice powder). And investigating the workability, mechanical and durability properties, microstructural characteristics, and cost benefits of C-25 concrete.

The study conducted on the use of the ternary blending of PP and BLA as a partial replacement of cement in concrete production. To realize this, physical properties of concrete ingredients and the chemical characterization of pumice powder and bamboo leaf ash are experimentally investigated. The effect of blending volcanic pumice powder and bamboo leaf ash together with cement on fresh and hardened concrete also determined. In addition, economic implications of using the blend volcanic pumice powder and bamboo leaf ash together as a partial replacement of cement also explored.

1.2 Statement of the Problem

Cement production requires a lot of energy, depletes natural resources, and releases a large amount of CO_2 into the atmosphere. This has led to the search for alternative binder materials such as pozzolan, also called supplementary cementitious materials to partially replace Ordinary Portland cement (OPC) as a binder. Many scholars throughout the world are finding a way to replace cement with SCMs to minimize resource depletion, CO_2 emissions, and cement costs (Kolawole et al., 2021).

Numerous pozzolans have been evaluated for their appropriateness in creating blended cement concrete. Some of these include rice husks ash and bamboo leave ash, incinerated clay waste, sawdust ash and corn cobs ash, fly ash, silica fume, metakaolin, blast furnace slag, and periwinkle shells ash (Kolawole et al., 2021; Sanusi et al., 2014). The use of volcanic pumice powder and bamboo leaf ash as supplementary cementitious materials in concrete has been explored in previous studies, but there is no study conducted on ternary blends of PP, BLA and cement and there is a need for further research on their combined effects.

Ethiopia ranks as the world's fourth-largest producer of pumice and scoria aggregates, coming after Italy, Chile, and Ecuador (Hossain & Lachemi, 2007), disposal of Bamboo leaf becomes an ecological crisis and considerable causes for contamination of water sources associated with health impact (Abebaw et al., 2021). It is essential to investigate partial replacement of those locally available (volcanic pumice powder and bamboo leaf ash) properties while blending with cement with the aim of using this locally available low cost materials and thereby minimizing the cost of construction.

According to the research by Alake et al. (2018), bamboo leaf ash has a low percentage of alumina (5.08%) but a high percentage of silica (83.33%), which is typical for any pozzolan, while, according to Kabay et al., (2015), volcanic pumice powder has a silica percentage of 67.05% and a comparatively greater alumina level (18.57%). A high silica pozzolan tends to be more pozzolanic, whereas a high alumina pozzolan is more resistant to acidic attack, according to a review of the literature (Kolawole et al., 2021; Temitope, 2015). Therefore, this study's findings help to bridge the gap between sustainability and construction by taking the advantage of both properties (high pozzolanicity and acidic resistant) by blending bamboo leaf ash, volcanic pumice powder and Portland cement to investigate workability, Mechanical, durability, micro-structural properties of C-25 normal grade concrete in addition to its cost implication.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of the study is to investigate the mechanical and durability property of C-25 concrete by partially replacing the cement with a blended pumice powder and Bamboo Leaf Ash.

1.3.2 Specific Objectives

The specific objectives of the study are: -

1. To characterize the physical and chemical composition of PP and BLA.
2. To investigate the workability, compressive and flexural strength of cement blended with PP and BLA concrete.

3. To investigate water absorption and acid attack resistance of cement blended with PP and BLA concrete.
4. To compare the cost of conventional concrete with concrete blended with PP and BLA.

1.4 Significance of the Study

The study contribute a new knowledge area on the effect of using ternary blended PP and BLA to be added as a partial replacement of cement in C-25 concrete production. Furthermore, this research play a significant role in reducing environmental and health problem come due to disposal of bamboo leaf. Additionally, this investigation open the way for utilizing the local cheap and available volcanic pumice and bamboo leaf material. Finally, use of PP and BLA with cement provide secondary data for researchers to further investigation.

1.5 Scope of the Study

The study examine the chemical characterization of PP and BLA as well as the physical property of concrete materials. The workability of fresh concrete is tested using a slump test to examine the impact of blended PP and BLA with cement on workability. Additionally, concrete specimens casted as (150mm x 150mm x 150 mm) cubes for compressive strength test and (500mm x 100mm x 100 mm) beams for flexural strength test. Compressive strength and flexural strength test is performed after curing the concrete samples 7, 14 and 28 days with the varying combinations of PP and BLA and (150mm x 150mm x 150 mm) cubes specimens are casted for durability test including water absorption and acid attack test. The effect of PP and BLA replacement in concrete microstructure conducted by SEM and XRD for control and blended concrete on shape, size and crystal formation of concrete. Results compared to the controlled concrete specimen's sample. This investigation cover C-25 normal concrete.

1.6 Organization of the Document

The thesis is presented in five chapters and organized as follows.

The first chapter is an introductory section that covers the study's background, problem, objective, scope and significance of the study.

Chapter 2 presents the literature review, with special reference to the topic that provides a concise review of concrete composing materials, pozzolanas, PP and BLA, property of concrete as well as the fresh and hardened properties of concrete containing volcanic pumice powder and Bamboo Leaf ash and finally provide the literature summary and research gap.

In Chapter 3, materials and methods is discussed. It explains the properties of materials, mix proportions, mixing, casting, and curing procedures. After presenting the study's overall research methods, the methods adopted in individual objectives is discussed in this chapter then finally provide the specific methods to achieve each objectives.

Chapter 4 aims to discuss the results of different concrete composing material and interpreted the hardened and fresh concrete property test results to realize this aim, the study presents the findings and associated discussion in relation to concrete composing material property and hardened and fresh concrete containing PP and BLA.

Chapter 5 provides an overview of the methodologies utilized and the results obtained from the different sections of the study, leading to the conclusions drawn. The chapter concludes by highlighting the study's contributions to the existing body of knowledge, outlining its limitations, and offering recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In order to achieve a better understanding of the research objective, an extensive literature review has been conducted. The purpose of this review was to identify the study gap and investigate the effects of partially replacing cement with blend volcanic pumice powder and bamboo leaf ash in normal concrete production. This chapter provides an in-depth review of various aspects related to concrete composing materials, pozzolanic materials, volcanic pumice powder, bamboo leaf ash, and their physical and chemical properties. Moreover, examine the effects of blending pumice powder and bamboo leaf ash with cement in concrete production and review different concrete properties, including compressive strength, flexural strength, water absorption, acid attack, and microstructural property of concrete. Finally, an economic evaluation of pozzolanic blend cement concrete is presented. The literature review is structured and presented in subsequent sections.

2.2 Concrete and Concrete Composing Materials

Concrete is primarily composed of cement, aggregates (such as fine and course), water, and optional additives. Concrete is an essential material used in construction industry around the world, especially in developing countries. As construction industries expand, so does the demand for concrete due to its advantageous properties such as high compressive strength, fire resistance, water-tightness and durability (Bandodkar et al., 2011). Under this sub topic different concrete materials were presented.

2.2.1 Aggregates

Aggregates serve as the primary elements of concrete that can withstand compressive forces. In the case of concrete, aggregates make up about 75% of its total volume, making it crucial for them to meet industry specifications to ensure the concrete is workable (Temitope, 2015). Aggregates are inert granular materials used in concrete production. They can be natural, manufactured, or recycled and include items like gravel, crushed stone, and sand, slag, and geosynthetic aggregates. Classifying aggregates is based on size (fine/coarse) and other factors such as shape and unit weight per ASTM- C33/C33M standards. It's important to know the characteristics of standard aggregates when producing concrete.

2.2.1.1 Fine Aggregate

The fine aggregate should be made up of natural sand, manufactured sand, or a blend of the two. It must not exceed 45% when passing through a single sieve and being held on the subsequent consecutive sieve. The fine aggregate's fineness modulus should be no less than 2.3 and not greater than 3.1, with a maximum allowable variation of 0.20 (C33/C33M, 2014).

2.2.1.2 Coarse Aggregates

The coarse aggregate used in concrete shall be made up of materials such as gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic-cement concrete, or a combination of these materials. When exposed to moisture through wetting, prolonged contact with humid air, or interaction with damp ground, the aggregate should not contain any substances that would react negatively with the alkalis in the cement and cause excessive expansion of the mortar or concrete. The aggregate's nominal size is described in terms such as 40mm, 20mm, 16mm, and 12mm, as per ASTM-C33/C33M standards.

2.2.2 Water

Water is an essential component in concrete production, as it not only enables the chemical reactions that lead to setting and hardening but also acts as a lubricant for the aggregates and cement mix, making it easier to place. Standards dictate that water suitable for human consumption is suitable for making concrete. The quality of water is generally consistent, while the quantity used, as determined by the water-cement ratio, is critical in controlling the consistency, strength, and durability of the concrete (Neville & Brooks, 2010). The ASTM C1602M guidelines permit the use of potable water without testing and list methods to verify non-potable water sources after considering their effect on setting time and strength.

2.2.3 Cement

Portland cement is a fundamental ingredient in the production of concrete. When combined with water, it creates a paste which sets and hardens when bound together with aggregates like sand and rock. To create Portland cement, several components must be heated to 2,500 - 2,800 degrees Fahrenheit in a rotating kiln: lime, iron ore, silica, and alumina. Once cooled, this mixture is then turned into a fine powder for use in construction projects (Cement et al., 2017).

2.2.3.1 Type of Cement

The cement manufactured varies due to the differences in its chemical composition and the final products. The unique kinds of Portland cement are identified through the (ASTM C150, 2016) Standard Specification for Portland cement, which categorizes them based on their application (C33/C33M, 2014).

Portland cements are categorized according to the ASTM classification system. This designates cement types as Type I, Type II, Type III, Type IV, Type V, along with some less common varieties such as Type IA, IIA, and IIIA. The Table 2.1 outlines the various types and provides a brief explanation of their applications.

Table 2.1: Types and Uses of Cements

Types of cement	**Use**
I	For use in general concrete production where the special properties specified for Types II, III, IV and V are not required (ordinary Portland cement).
II	For use in general concrete construction exposed to moderate sulphate attack or moderate heat of hydration is required.
III	When high early strength is desired (Rapid Hardening Cement).
IV	When low heat of hydration is desired (Low Heat Cement).
V	When high sulphate resistance is required (Sulphate Resisting Cement).
IA	A type I cement containing an integral air-entraining agent
IIA	A type II cement containing an integral air-entraining agent
IIIA	A type III cement containing an integral air-entraining agent

2.2.3.2 Physical and Chemical Property of Cement

Cement is fundamental to the construction industry, boasting a range of beneficial physical properties such as fineness, consistency, setting time, soundness and compressive strength (as shown in Table 2.2)

Table 2.2: Physical Property of Cement, Description, Test Method, Standard Requirement

Physical Property	**Description**	**Test Method**	**Standard Requirement**
Fineness	Measure of particle size	ASTM C 115, C 786, C 204, C 430	Ethiopian standard: not less than 2250 cm2/g; ASTM C 150: minimum fineness of 2800 cm2/g
consistency	Water content of neat cement paste	(ASTM C187, 2004)	Normal consistency: 26% to 33% by weight of dry cement
Setting time	Time from mixing to hardening	(ASTM C192, 2016)	The initial setting period should be no less than 45 minutes, and the final setting period should not surpass 10 hours.
soundness	Ability to retain volume after setting	ASTM C 151, Le Chatelier Test	Maximum autoclave expansion of 0.80%; expansion not exceeding 10mm for Le Chatelier Test
strength	Compressive, tensile, and flexural strength	Various factors affecting strength	Depends on the application and design requirements

Source: ASTM Standards

Ordinary Portland cement is produced by heating a specific ratio of naturally occurring argillaceous and calcareous materials to partial fusion temperatures (about 1450 0C). It may contain minor amounts of iron oxide or magnesia (Dalton et al., 2004). Its major and minor compounds, classified by quantity, are presented in Table 2.3 as oxides.

Table 2.3: Approximate Oxide Composition limits of ordinary Portland cement

Oxide	Common name of oxide	Weight by % in PC
CaO	Lime	60 to 67
SiO_2	Silica	17 to 25
Al_2O_3	Alumina	3 to 8
Fe_2O_3	Ferric oxide	0.5 to 6
MgO	Magnesia	0.1 to 0.4
K_2O, Na_2O	Alkali	0.4 to 1.3
SO_3	Sulphur trioxide	1.3 to 3

Source: Dalton et al., (2004)

2.2.3.3 Ordinary Portland Cement Production

Ordinary Portland Cement (OPC) is produced by heating oxide-rich raw materials like limestone, clay or shale, and an iron-based component at temperatures ranging from 1300°C to 1500°C. These materials typically consist of around 80% limestone (rich in calcium carbonate) and 20% clay or shale (providing silica, alumina, and iron oxide). The process of manufacturing cement involves four main stages: quarrying, preparing the raw materials, clinker production, and cement grinding (Temitope, 2015).

2.3 Pozzolanic Supplementary Cementitious Materials

Supplementary Cementitious Materials (SCMs) are soluble siliceous, alumina siliceous, or calcium alumina siliceous powders used as partial replacements for clinker in cement or as partial replacements of Portland cement in concrete combinations. Supplementary cementitious materials are materials that can partially replace Portland cement in concrete and enhance its properties. SCMs can be classified into two types: pozzolanic and hydraulic. Pozzolanic SCMs (fly ash, silica fume and metakaolin) react with calcium hydroxide, a by-product of cement hydration, to form additional cementitious compounds. Hydraulic SCMs (slag, natural pozzolans and calcined clay) can harden and gain strength in the presence of water, similar to cement (Arvaniti et al., 2015). It is used in conjunction with Portland cement, Portland limestone cement, or blended cement

The impact of replacing clinker partially with SCMs is frequently influenced by industry pressure to minimize CO_2 emissions from cement production (Juenger & Siddique, 2015). Many of the materials now employed as SCMs are by-products of other industries. Fly ash, ground granulated blast furnace slag, silica fume, calcined clays, and natural pozzolans from coal-fired power plants are the most commonly used waste products. The process of converting these wastes for usage needs less energy than the energy required for cement manufacturing (Juenger et al., 2019).

According to ASTM C618, (2014), a pozzolan comprises siliceous or siliceous-aluminic components that naturally lack cementitious properties. Nevertheless, when these pozzolans are finely ground and exposed to moisture, they can react with the calcium hydroxide produced by Portland cement during its hydration process at regular temperatures, resulting in cement-like characteristics.

Amorphous silica present in pozzolanic materials can interact with lime to create cementitious substances, which boost the durability of concrete and improve its strength development rate while decreasing heat release. This characteristic is especially beneficial for mass concrete applications (Hossain, 2005). Neville, (1996) noted that the reactivity of pozzolans results in a higher concrete strength, emphasizing one of the main purposes of incorporating pozzolans into concrete to increase its quality, durability, and longevity as a commonly used construction material.

The use of pozzolans in concrete has been practiced for as long as construction itself. Studies have shown that the long-term strength and durability of concrete that contains slag is superior to that of regular Portland cement concrete (Khatib & Hibbert, 2005; Ramezanianpour & Malhotra, 1995). Türkmen et al., (2003), reported that by replacing only five percent of Portland cement with silica fume, the resulting concrete becomes impermeable to harmful chemicals, thereby extending the lifespan of the concrete. Qian & Li, (2001) observed that utilizing metakaolin as a pozzolan can enhance the concrete's resistance to alkali-silica reaction. Additionally, Siddique, (2004), reported that class F fly ash is a suitable pozzolan for replacing up to 50% of cement in concrete, making it applicable for precast elements and reinforced concrete construction.

Pozzolanic cements are a blend of Portland cement and natural or artificial pozzolans. In addition to being suitable for use underwater, the alkalinity of pozzolans makes it highly resistant to common types of sulfate corrosion. (McCann, 1994). When fully cured, pozzolanic cement made by blending Portland cement with pozzolan may be stronger than traditional Portland cement, as it has a lower porosity. This also makes it more resilient to water absorption and spalling (Sahmaran et al., 2007). The utilization of pozzolans in mortars and concrete has been shown to mitigate the effects of sulfates and alkali-silica reaction, which can be particularly harmful to concrete structures. This is achieved through the acceleration of the pozzolanic reaction. (Sahmaran et al., 2007). The compressive strength of concrete is not improved during the early stages by adding pozzolan to Portland cement. However, if the concrete is properly cured in moist conditions for an adequate duration, strengths comparable to those of ordinary Portland cement can be achieved at later ages (Bhanja & Sengupta, 2002).

Currently, the use of waste materials as a pozzolanic substitute in concrete has become increasingly common, with mechanical treatment such as grinding being employed to enhance the pozzolanic properties of waste ashes (Kiattikomol et al., 2001; Shi & Day, 2001). The enhancement of pozzolanic characteristics relies on a greater strength activity index value (ASTM C 311, 1998), primarily attributed to two key factors: the pozzolanic reaction and the particle packing effect of finer materials. Pozzolans provide a valuable contribution to concrete by significantly improving its strength and longevity while being utilized. These materials are typically silicate or aluminosilicates, which go through a high-temperature process in a furnace or combustion chamber. After undergoing rapid cooling under particular conditions, they transform into amorphous or glassy phases. This structure allows them to easily react during the curing of concrete, making pozzolans extremely useful in cement and concrete applications today. Notably, it is essential for pozzolans to possess low alkali levels (Na_2O and K_2O) since increased alkali levels could lead to durable issues caused by the alkali-silicate reaction (ASR) (Neville & Brooks, 2010).

There are numerous pozzolans, each with different compositions that vary from one type to another. The composition of even a single pozzolan can have variations due to factors such as the source region, processing methods, and the specific type of pozzolan (Pekmezci & Akyüz, 2004; Shetty, 2006). To be accepted universally as a construction material, pozzolan must meet certain standards designed to guarantee uniformity. This ensures that the concrete created from pozzolans in different areas has consistent properties, including strength. Furthermore, physical and chemical criteria need to be fulfilled for a material to be classified as a pozzolan.

2.3.1 Physical Requirement of Pozzolans

The assessment of pozzolanic materials relies on various physical properties, including particle size, specific gravity, pozzolanic activity, durability, initial and final setting time, and water requirement. These factors provide insight into the level of interaction that will influence the strength of the hydrated mixture in the long run. Table 2.4, based on ASTM C618., (2014), contains a compilation of the most critical physical attributes of a pozzolan for reference and comparison purposes. Other aspects of the pozzolan, such as its fineness and crystalline structure, also affect its reactivity (Ansari et al., 2000).

Table 2.4: Physical Requirements for Pozzolans as per ASTM C 618: 2014

S/N	Property of pozzolan	ASTM requirements		
		Class		
		N	F	C
I	Fineness:			
	Amount retained when wet-sieved on 45µm (No. 325) sieve, max. %	34	34	34
II	Strength activity index:			
	With Portland cement, at 7 days, min. percent of control	75	75	75
	With Portland cement, at 28 days, min. Percent of control	75	75	75
III	Water requirement, max. percent of control	115	105	105
IV	Soundness:			
	Autoclave expansion or contraction, max. percent	0.8	0.8	0.8
V	Uniformity requirements:			
	Density, max. variation from average, %	5	5	5
	Percent retained on 45µm (No. 325), max. variation % points from average	5	5	5

Source: ASTM C 618: 2008

2.3.2 Chemical Requirements of Pozzolans

To be classified as a pozzolan, various standards outline the necessary chemical composition and characteristics. Table 2.5, presents chemical requirements for pozzolans as per, according to ASTM C 618 (2014), materials must have a minimum content of silica (SiO_2) and alumina (Al_2O_3), with an iron oxide (Fe_2O_3) percentage ranging from 50-70%. The maximum sulfur trioxide (SO3) content should be restricted to 5%, and the loss on ignition should range between 6-12%. Indian standard IS 3812-1(2003) stipulates that the combined silica, alumina, and ferric oxide content in a pozzolan should exceed 70%. Kenyan KS 02-1261: 1994 advises incorporating at least 35% silica in the constituents. Consequently, it is clear that to qualify as a pozzolan, a material must contain substantial amounts of reactive silica and alumina, with silica alone representing more than 40% - contributing no less than 70% in total for these three specified elements. In summary, the capacity of pozzolans to react with calcium hydroxide is crucial for them to exhibit their intended effects (Knofel, 1983).

Table 2.5: Chemical Requirements for Pozzolans as per ASTM C 618: 2014

S/N	Property of pozzolan	ASTM requirements Class		
		N	F	C
I	(SiO_2) + (Al_2O_3) + (Fe_2O_3) (min. %)	70	70	70
I	Sulphur trioxide, max. %	4.5	5.0	5.0
III	Water requirement, max. percent of control	115	105	105
IV	Moisture content, max. %	3.0	3.0	3.0
V	Loss on Ignition (LOI), max. %	10.0	6.0	6.0

Source: ASTM C 618: 2008

2.3.3 Pozzolanic Reaction Activity

The pozzolanic reaction takes place when pozzolans interact with calcium hydroxide, a common occurrence in concrete mixing. This reaction offers several technical benefits, including a relatively slow reaction pace, which results in minimal heat release and gradual strength development. Further, it utilizes lime rather than generating it, leading to a paste that is more resistant to chemical attacks. Additionally, the hydrated paste produced exhibits higher strength and durability potential compared to regular pastes (Al-Dulaijan et al., 2003).

Study by Shi & Day, (2001), show that the pozzolan content significantly influences pore size distribution, as the reaction products can fill capillary spaces, thereby improving the system's strength and impermeability. Notably, they can supply reactive alumina, which helps form cementitious compounds such as C_4 HA_{13} by interacting with calcium hydroxide and sulfate ions. These substances substantially enhance the strength and durability of the hydrated paste.

2.3.4 Pozzolan in Blended Cement

Blended cement according to (ASTM C618., 2014), is a combination of Portland cement and pozzolan. Pozzolans are generally utilized as mineral admixtures in concrete, but they can also serve as an admixture by partially substituting the Portland cement, either in volume or weight, based on the specific gravity value of the pozzolan and a certain percentage. The selection of pozzolan depends on the requirements of the cement and its availability. Blended cement produces less hydration heat and offers better resistance against the harmful chemical compared to Ordinary Portland Cement. This makes it especially useful for dams and reservoirs construction projects involving mass concrete (Derucher & Korfiatis, 1988).

The development of mixed or pozzolanic cement emerged from the need to conserve energy and manage waste materials in numerous countries (Bakker, 1999). The majority of pozzolan materials are derived from waste products in the industrial and agricultural sectors. Fly ash and blast furnace slag are the two primary materials used as pozzolan in devloped countries' blended cement. Bakker, (1999), states that the Netherlands has the highest utilization of mixed or pozzolanic cement among other countries. Approximately 60% of the cement produced in the country is estimated to be blast furnace cement, which consists of around 25% clinker and 25% fly ash, while only 20% of the cement produced is pure Portland cement. Besides blast furnace cement and fly ash cement, other pozzolan types that have been researched include silica fume, rice husk ash, sawdust ash, corn cob ash, and periwinkle shell ash. In this particular research, volcanic pumice powder and bamboo leaf ash are explored as pozzolanic materials.

2.4 Pumice

Pumice, which can also be referred to as pumicite when it is in the form of powder or dust, is a type of volcanic igenious rock that is characterized by a highly vesicular and rough-textured volcanic glass, with or without crystals. It usually has a light color. Pumice powder is a natural pozzolan and can be found in various regions of the world. Italy, Chile, and Ecuador are among the leading producers of pumice, and Ethiopia is the fourth-largest producer (Hossain & Lachemi, 2007).

2.4.1 Property of Pumice Powder

Physical characteristics of rocks play a significant role in determining their type and exploring their properties. Pumice, a type of rock, has various physical properties such as hardness, grain size, fracture, streak, porosity, luster, and strength that define its characteristics. These physical properties of pumice are crucial in determining its texture and potential applications (Hossain & Lachemi, 2007).

The distinct physical attributes of pumice stone play a vital role in understanding its features and potential applications, which are linked to its formation process. The streak of pumice powder or crushed pumice determines its color, which can range from white, greenish-white, or grey. Pumice exhibits perfect cleavage, while its specific gravity, which compares the density of a substance to that of water. These physical attributes ultimately help in identifying the possible applications of pumice across various industries (Zeyad & Almalki, 2021).

2.4.2 Chemical Composition of Pumice Powder

The chemical composition percentage of PP is determined using X-ray fluorescence (XRF) analysis. The Table 2.6, shows the combined proportion of primary oxides (SiO_2, Al_2O_3, and Fe_2O_3) in VPP surpassed 70%, fulfilling the ASTM criteria for categorization as pozzolanic substances (Bakker, 1999).

Table 2.6: Chemical Composition of PP by Past Studies

No.	Oxide	(Zeyad & Almalki, 2021)	(Hossain, 2004c)	(Sarıdemir, 2013)	(Kabay et al., 2015)
1	SiO_2	47.70	60.82	71.80	77.52
2	Al_2O_3	18.57	16.71	12.40	12.90
3	Fe_2O_3	10.04	7.04	1.05	1.5
4	CaO	7.90	4.44	1.10	0.1
5	MgO	2.58	1.94	0.34	0.4
6	K_2O	1.07	2.25	4.51	0.12
7	MnO	0.123	---		
8	Na_2O	2.58	5.42	5.20	0.12
9	P_2O_5	0.64	---		
10	TiO_2	1.62	---		
11	SO_3	0.34	0.14	0.08	0.52
12	LOI	2.21	1.62	3.52	5.42
13	SiO_2+ Al_2O_3+ Fe_2O_3	76.01	84.5	85.25	92.01

Source: Kabay et al., (2015), Zeyad & Almalki, (2021), Hossain, (2004)

2.4.3 Effect of Pumice Powder on Concrete

The inclusion of pumice powder led to a reduced mechanical strength in the initial stages. However, it eventually reached a similar strength to that of the conventional concrete. By partially replacing cement with PP, the resulting concretes exhibited increases water absorption, sorptivity, and void content, while offering increased resistance to magnesium sulfate compared to the conventional concrete (Kabay et al., 2015).

Samples containing a 10% substitution of cement with PP and a 0.20% polyethylene fiber concentration showed a modest enhancement in compressive strength compared to the conventional concrete at more advanced ages. Various standard assessments on the blends demonstrated promising outcomes and excellent potential for incorporating PP into high strength concrete constructions (Zeyad et al., 2020). Using volcanic pumice as cement replacement material show that the PP has sufficient strength and adequate density to be accepted as partial replacement in structural lightweight concrete (Hossain, 2004d).

Study by Zeyad & Almalki, (2021), discovered that adding more PP content to mixtures decreases workability. Their study found that a 10% PP inclusion in the mix resulted in the best compressive strength. Utilizing PP as a partial replacement demonstrated a positive impact on the concrete's efficiency, and decreased porosity and absorption resistance across diverse mixtures.

Table 2.7: Optimum Percentage Replacement with Compressive Strength of PP by Past Studies

		Optimum percentage replacement of PP				
Authors		(Zeyad et al., 2020)	(Zeyad & Almalki, 2021)	(Hossain, 2004b)	(Kabay et al., 2015)	(Sarıdemir, 2013)
PP		10%	10%	15%	10%	10%
Compressive strength at 28 day(MPa)	control	71.6	32.3	37.5	72.5	74.90
	Optimal replacement	74.7	34	34.9	66.2	79.56

Source: Kabay et al., (2015), Zeyad & Almalki, (2021), Hossain, (2004)

2.5 Bamboo Leaf

The bamboo plant, which belongs to the Gramineae family, thrives in tropical and mildly temperate areas across continents like Africa, Asia, and South America. Based on existing data, more than 20 million tons of bamboo are utilized every year in diverse sectors, including food, brewing, building, farming, fiber, paper, textiles, and boards (Lobovikov et al., 2007).

Ethiopia is home to approximately one million hectares of natural bamboo forest, the largest on the African continent. Although bamboo has a wide range of uses globally and has the potential to improve socio-economic and ecological development significantly, this potential has not yet been fully realized in Ethiopia (Mekonnen et al., 2014). Bamboo leaf ash (BLA) is a fine waste derived from the combustion of bamboo leaves in a controlled or uncontrolled burning process (Abebaw et al., 2021).

2.5.1 Physical Property of Bamboo Leaf

The color of bamboo leaves can vary between green and brown based on their level of dryness, they possess linear veins accompanied by filled mesophyll cells, their form resembles that of a finger, once dried, they can burn and produce brown smoke (Umoh & Odesola, 2015).

2.5.2 Chemical Composition of Bamboo Leaf Ash

The chemical composition percentage of bamboo leaf ash is determined using X-ray fluorescence (XRF) analysis. The Table 2.8, shows for any material to qualify as a pozzolan, it must satisfy the requirements stipulated in the standards examined. $SiO_2 + Al_2O_3 + Fe_2O > 70\%$ that categorized under Class F pozzolanic materials as per ASTM C- 618 specifications (Zeyad & Almalki, 2021). BLA have a silica content higher than 25 % (Kolawole et al., 2021).

Table 2.8: Chemical Composition of BLA by Past Studies

No.	Oxide	(Mekonnen et al., 2014)	(Abebaw et al., 2021)	Dwivedi et al., (2006)	(Kolawole et al., 2021)	Alake et al., (2018)	(Umoh & Odesola, 2015)	(Temitope ,et al., 2013)
1	SiO_2	74.23	65.66	75.90	72.97	83.33	72.25	75.00
2	Al_2O_3	2.27	6.41	4.13	2.85	1.03	4.08	4.13
3	Fe_2O_3	2.34	4.28	1.22	2.31	1.95	1.97	1.22
4	CaO	3.30	15.22	7.47	4.98	4.44	4.23	7.47
5	MgO	1.46	2.48	1.85	1.23	1.02	1.01	1.85

6	K_2O	2.31	4.84	5.62	6.07	3.09	3.15	5.62
7	MnO	0.15	---	---	0.41	0.22	0.22	0.016
8	P_2O_5	1.02	---	---	2.37	0.73	0.74	3.22
9	TiO_2	0.46	---	0.20	0.41	0.34	0.35	---
10	SO_3	0.84	---	1.06	0.55	0.10	0.15	---
11	LOI	11.34	9.65	---	4.20	0.40	2.93	---
12	SiO_2+ Al_2O_3+ Fe_2O_3	78.84	76.35	81.25	78.13	86.33	78.3	80.33

Source: Abebaw et al., (2021), Umoh & Odesola, (2015), Kolawole et al., (2021).

2.5.3 Effect of Bamboo Leaf Ash on Concrete

The Bamboo Leaf Ash has been found to be an excellent pozzolanic material, meeting all the criteria set by standard specifications and showing great potential for inclusion in cement production for use in concrete, mortars, and pastes (Tavares et al., 2020). Adding BLA to cement binders in concrete can result in satisfactory mechanical strength and resistance to chemical degradation. Suggested Supplementary Cementitious Material (SCM) formulations with acceptable performance include 5% and 10% BLA. With its optimal 10% BLA content, there is a possibility for an approximately 10% reduction in cost. Therefore, increasing the use of low-cost SCMs like BLA can lead to a further decrease in the overall cost of concrete (Kolawole et al., 2021).

Abebaw et al., (2021) found that using bamboo leaf ash as a cement substitute can potentially reduce cement usage by up to 10%. This result may help to mitigate rising cement prices and increase the affordability of housing without negatively affecting quality. Moraes et al. (2019) also reported that incorporating bamboo leaf ash into cementitious matrices enhanced mechanical behavior and durability. Additionally, pastes containing 20% and 30% bamboo leaf ash had fewer connected pores compared to the control paste, suggesting the suitability of bamboo leaf ash for sustainable high-performance matrices. According to Olanrewaju et al., (2018), when bamboo leaf ash is employed as a pozzolanic material for concrete production, optimal improvements in compressive strength occur at ratios between 20% and 25%.

According to Umoh & Odesola, (2015), blended cement concrete with a combined 10% cement replacement using PSA and BLA has demonstrated increased compressive and tensile strength while exhibiting increased water absorption and porosity when compared to the standard. As a result, a 10% cement replacement mixture is considered the ideal proportion for a ternary blended cement concrete.

A study by Temitope, (2015), found that both BLA and PBCW can be effectively used as pozzolans in the manufacturing of concrete. The researchers determined that the optimal replacement level for cement in structural concrete is 10% PBCW, while for mass concreting, a mixture of 10% BLA and 10% PBCW is appropriate. The use of BLA and PBCW can enhance the durability of concrete, with a 10% PBCW and 10% BLA substitution working well in mild conditions. However, in severe conditions, 10% of PBCW as replacement performs better.

Table 2.9: Optimum Percentage Replacement Compressive Strength, Water Absorption of BLA by Past Studies

Authors		Optimum percentage replacement of BLA					
		(Kolawole et al., 2021)	(Nduka et al., 2022)	(Hnin et al., 2018)	(Umoh & Femi, 2013)	(Ubachukwu et al., 2018)	(Abebaw et al., 2021)
BLA		5%	10%	10%	5%	15%	10%
Compressive strength at 28day(MPa)	control	21	46.32	41.8	14.92	28.96	**37.70**
	OR (%)	18.6	47.56	35.7	19.10	26.22	**35.96**

% Water absorption	Control (%)	-	4.3%	-	4.18%	3%	3%
	OR (%)	-	5.2%	-	4.825	7%	3.1%

Source: Abebaw et al., (2021), Umoh & Odesola, (2015), Kolawole et al., (2021).

2.6 Pumice Powder and Bamboo Leaf Ash Concrete Properties

Concrete is one of the most widely used construction materials in the world. It has many advantages such as high strength, durability, fire resistance and low cost. However, concrete also has some limitations and challenges that need to be addressed by proper design and quality control. Therefore, it is essential to understand the properties of concrete and how they affect its performance and serviceability

Concrete properties can be majorly grouped into two categories: fresh and hardened. Fresh concrete properties include workability, setting time, bleeding, and segregation. Hardened concrete properties include compressive strength, flexural and tensile strength, modulus of elasticity, shrinkage, creep and durability. These properties determine the load-bearing capacity, deformation behavior and resistance to environmental factors of concrete (Malhotra & Mehta, 1996a).

Concrete strength refers to its ability to withstand fracture caused by external forces. This can be evaluated in various ways, including compression strength, tension strength, shear strength, or bending strength (Umoh & Odesola, 2015). The capacity of concrete to resist compressive, tensile, and flexural (bending) forces is identified as compressive strength, tensile strength, and flexural or bending strength, respectively (Alsayed & Amjad, 1996).

2.6.1 Fresh Property of Concrete

Fresh concrete is the mixture of cement, aggregates, water and admixtures that has not yet hardened. The fresh properties of concrete are important for its workability, durability and strength. Some of the fresh properties of concrete are workability, consistency, setting time bleeding. Plastic shrinkage, unit weight, air content and temperature. These properties can be influenced by the type and proportion of the ingredients, the mixing method, and the environmental factors (Ubachukwu et al., 2018).

Workability is important characteristics of fresh concrete as it determines the amount of effective internal work needed for complete compaction (Neville, 1996). Hoffman and Gustafson (2001) note that ensuring adequate water content allows concrete to be positioned and consolidated without forming honeycomb structures or excessive water rise. This also makes it possible for the concrete to be pumped if necessary and enables the creation of a properly finished surface for different structures.

The workability of concrete is an important factor to consider in construction, as it depends on a number of elements. These include water content, mixture composition, aggregate type and quality, cement fineness, water-cement ratio, mixing process duration based on the nature of the work and material thickness, the addition of additives, and external environmental influences such as temperature, humidity and wind speed (Neville, 1996; Shetty, 2006). The water content in the mixture has the most substantial impact on workability among all these factors, as stated by Neville, (1996). Consequently, the water-to-cement ratio in any mixture is a crucial aspect to consider for structural concrete.

The slump test, compacting factor test, Vee Bee consistometer test and flow test are all useful ways to measure the consistency and stability of concrete. The slump test is particularly suitable for richer mixes, while the compacting factor test is best for dry mixes. The Vee Bee consistometer measures vibration time, which is beneficial for dry mixtures with no slump. Last but not least, the flow test gives an indication of quality of concrete in terms of consistency and segregation resistance - perfect for high or very high workability mixes (Asha et al., 2014).

2.6.2 Compressive strength of Concrete

Concrete's compressive strength is arguably its most desirable quality in the hardened state. This is because concrete is commonly used to resist compressive stresses for many structural applications. Derucher & Korfiatis, (1988), confirms that concrete is at its strongest when it is subjected to compression, which is why measuring its compressive strength is the most widely used method for evaluating the quality of hardened concrete.

The compressive strength of concrete can be measured using either cube or cylindrical-shaped specimens. Cubes are typically 100 x 100 x 100mm in size, but if the maximum aggregate size exceeds 20mm, larger cubes with dimensions of 150 x 150 x 150mm can be used instead (Shetty, 2006). Compressive strength serves as a valuable indicator for estimating other properties of concrete, and it should be noted that the material's tensile strength is typically around 10% of its compressive strength (Mosley et al., 1999), while the flexural strength of plain concrete is about 15 – 20% of the compressive strength (Derucher & Korfiatis, 1988).

The most significant factor influencing the compressive strength of concrete is the water-to-cement ratio. According to Bhanja & Sengupta, (2002)there is an inverse correlation between the compressive strength of concrete and its water-to-cement ratio. However, at a specific water-to-cement ratio, the percentage of pozzolan replacing cement also influences the compressive strength. In general, higher pozzolan replacement percentages lead to lower compressive strength, particularly during the early stages of curing (Bhanja & Sengupta, 2002; Siddique, 2004). The curing process and its duration are also important factors to consider when examining compressive strength. Concrete performs better when it is hydrated, reducing shrinkage and absorbing the heat produced during hydration to create a favorable environment for strength development. The longer the curing period, the greater the strength developed.

Concrete containing pozzolanic materials tends to gain strength gradually, especially during the early stages of curing. This is due to the slow pozzolanic reaction that occurs at room temperature, necessitating an extended curing period to observe its beneficial effects. In the present study, concrete cube specimens were cured for up to 120 days to allow for a longer duration of pozzolanic reaction (Kolawole et al., 2021).

2.6.3 Flexural Strength of Concrete

Flexural strength is used to determine the bending resistance of concrete. It helps to measure tension stress on unreinforced concrete at the point of failure in a bending test and can be calculated through standard test methods ASTM C78 or ASTM C293 by taking into account span length, depth, and loading. In tests from 0% to 10% replacement of BLA, flexural strength increased from 3.5 MPa to 3.9 MPa accordingly.

2.6.4 Durability of Concrete

According to ACI Committee 318 & American Concrete Institute, (2014), Portland cement concrete is considered durable if it can withstand weathering, chemical attacks, abrasion, and other forms of deterioration, while retaining its original form, quality, and serviceability in the given environment. Neville & Brooks, (2010)further emphasize the significance of durability in concrete, stating that it is crucial for concrete to endure the conditions for which it was designed throughout the lifespan of a structure. In other words, concrete must function in accordance with its intended level of serviceability and functionality throughout its expected life cycle.

The last few decades have been marked by the inadequate durability of construction projects. This has forced a reallocation of infrastructure budgets for repair and maintenance, forming a large part (from 30 to 50%) of the overall budget. With an emphasis on long-term life-cycle costs over initial costs, government, and private developers are shifting their focus toward strength and longevity in concrete structuring. However, it is important to note that multiple factors contribute to the durability of concrete, such as its physical and chemical properties, service environment, and design life. Thus, one must be mindful that what performs satisfactorily under extreme conditions may not necessarily be suitable for moderate ones; this is due to potential differences in failure mechanisms as exposed to different environmental exposures (Kolawole et al., 2021).

2.6.4.1 Water Absorption

Water absorption of concrete is an important property that affects its durability and performance Water absorption of concrete can be measured by different methods, such as capillary absorption, sorptivity, and water permeability. Capillary absorption is the process of water uptake by unsaturated concrete through capillary suction. Sorptivity is the rate of capillary absorption per unit area of exposed surface. Water permeability is the ease with which water can flow through saturated concrete under a pressure gradient (Neville, 1996).

Concrete made from pozzolanic material, such as fly ash or slag, has different water absorption behaviour than concrete made from ordinary Portland cement. pozzolanic material also affects the water absorption of concrete by changing its microstructure and pore size distribution. Several factors influence the water absorption of concrete, such as water-to-binder (W/B) ratio, curing age, aggregate type, and mineral admixture (Alsayed & Amjad, 1996).

2.6.4.2 Acid Attack

Concrete has an alkaline nature, making it vulnerable to acid damage (Neville, 1996). When exposed to acids, especially those with a pH lower than 6, the concrete components tend to break down, resulting in the dissolution of calcium hydroxide. The severity of the acid attack is influenced by factors such as the cement paste's porosity, the acidity levels, the solubility of acid calcium salts, and the fluid movement through the concrete. Aggressive acids like sulfuric, nitric, hydrochloric, and acetic acids cause significant damage because their calcium salts dissolve easily and are removed from the affected area. In contrast, less harmful acids like phosphoric and humid acids have calcium salts with low solubility, which hinders the attack by forming interconnected cracks, voids, and porosity. While quality concrete can withstand occasional exposure to mild acids, it is not resistant to strong acids or compounds that change into acids (Hewayde et al., 2007; Neville & Brooks, 2010).

In general, Portland cement does not possess strong resistance to acids, although it can withstand some weak acids, especially if the exposure is infrequent (ACI Committee 318 & American Concrete Institute, 2014).). Sulfuric acid is particularly damaging as it not only initiates a sulfate attack on the aluminate phase but also an acid attack on the calcium hydroxide and calcium silicate hydrate phase. Consequently, decreasing the cement content in the concrete is advantageous, as long as the concrete's density remains unaffected (Neville, 1996).

2.6.5 Microstructural Property of Concrete

The mechanical strength of concrete depends on its microscopic structure. The concrete microstructure can be analysed through modern techniques such as Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD). The former presents an image of the concrete surface, pointing out details such as the size, shape and distribution of pores, aggregates, and cementitious materials. On the other hand, the XRD provides information about the cement phases present in the composition: hydrated and anhydrous products as well as crystalline or amorphous silica (Garboczi & Bentz, n.d.).

In a recent study, the microstructure of different types of concrete was investigated using SEM and XRD. The results of the SEM analysis showed that the microstructure of the concrete varied depending on its composition, curing conditions, and age. The XRD analysis revealed that the main crystalline phases present in the concrete were calcium silicate hydrate (C-S-H) and calcium hydroxide (CH). The study concluded that SEM and XRD are powerful tools for characterizing the microstructure of concrete and providing valuable information for the design and optimization of concrete mixtures (Zhang et al., 2023).

In another study, the microstructure of high-performance concrete was analysed using SEM and XRD. The SEM images showed that the high-performance concrete had a dense and homogeneous microstructure, with a low porosity and a high content of fine particles. The XRD analysis confirmed the presence of C-S-H and CH, as well as the absence of any deleterious minerals such as ettringite or monosulfate. The study concluded that the microstructural characteristics of high-performance concrete were responsible for its superior mechanical properties and durability (Ye et al., 2003).

2.7 Availability of BLA and PP in Ethiopia

The Food and Agriculture Organization (FAO) of the United Nations has released its Global Forest Resource Assessment 2020 (FRA), which indicates that there are over 35 million hectares of bamboo across the globe. The FRA 2020 reveals that there has been a 50% rise in bamboo area between 1990 and 2020, mainly due to recent expansion in China and India. Ethiopia boasts over one million hectares of highland and lowland bamboo resources, comprising about 67% of African bamboo resources and over 7% of the total area covered by bamboo worldwide (Mekuriaw et al., 2022). The formation of the East African Rift Valley is when massive lava outpourings and pyroclastic flows resulted in the creation of pumice and pumice-like ash in the Main Ethiopian Rift Valley (MERV). Numerous pumice deposits are found throughout the MERV, but the most well-known are located at Gari Baldi Pass, Koka, Dere, Bishoftu, Modjo, Alemtena, and Meki Fentale (WILKERSON & SANTIAGO, 2002).

2.8 Literature Review Summary and Gap

The literature review in the previous sections on the partial replacement of Cement in Concrete by pumice powder and bamboo leaf ash summarized by Table 2.10, reveals that several researchers have carried out studies on the individual effect of those pozzolanic material on concrete property.

Table 2.10: Summary of Literature Review on PP and BLA by Past Studies

Year	Title	Authors	% replacement of PP	Test conducted	Findings0
2019	Durability and strength characteristics of high-strength concrete incorporated with volcanic pumice powder and polypropylene fibers	(Zeyad et al., 2020)	Incorporating VPP (at concentrations of 10% and 20%) with polypropylene fiber (PF) at varying levels (0.20%, 0.35%, and 0.50%).	Including slump, Compressive strength, indirect Tensile strength, Flexural strength, Water absorption, Initial surface absorption, and Sorptivity,	A minor enhancement in compressive strength was observed when 10% of cement was replaced with VPP and the PF content was at 0.20%. The optimal tensile and flexural strengths were achieved when 10% VPP was used as a replacement and the PF content was 0.50%. However, the slump experienced a reduction.
2004	Development of volcanic pumice based cement and lightweight concrete	(Hossain, 2004a)	By substituting 0-50% of cement by weight.	Test on workability, strength, shrinkage, and permeability have been conducted.	PC containing volcanic pumice has an increased setting time and reduced heat of hydration when using up to 15% of VPP
2021	Role of particle size of natural pozzolanic materials of volcanic pumice: flow properties,	(Zeyad & Almalki, 2021)	Utilized as a 10%, 20%, and 30% partial substitution for cement by mass	Various tests were conducted, including flow, strength activity, compressive strength, water absorption,	This partial replacement of cement enhance workability while decreasing absorption and porosity in concrete.

	strength, and permeability			porosity, and initial surface absorption	
2015	Characteristics of Bamboo Leaf Ash Blended Cement Paste and Mortar	(Umoh & Odesola, 2015)	The proportion of BLA rises from 5% to 25% by mass,	Compressive and flexural strength, water absorption, and apparent porosity conducted.	A mix containing 15% BLA by mass performs comparably to the reference mixture at 28 days.
2021	Experimental Investigation on Effect of Partial Replacement of Cement with Bamboo Leaf Ash on Concrete Property	(Abebaw et al., 2021)	A 0%, 5%, 10%, 15%, and 20% substitution of cement with bamboo leaf ash was examined	**Assessing properties such as workability, compressive strength, water uptake, density, and resistance to sulfate attack**	The findings indicate that bamboo leaf ash can effectively replace cement up to a maximum of 10%..
2021	Effect of Open Air Burnt Bamboo Leaf Ash Blended Cement Concrete	(Olanrewaju et al., n.d.)	Bamboo leaf ash (BLA) of 0%, 10%, 20%, 25%, 50%, 75% and 100%	Tested for its effectiveness in various aspects, such as workability and strength.	Bamboo leaf ash (as a pozzolanic material) is to be used for concrete production as between 20% and 25% of 1:2:4 mix must be used
2018	Experimental Investigation on Effect of Bamboo Leaf Ash Replacing	(Hnin et al., 2018)	The proportion of OPC replaced by BLA ranges from 0% to 15% by weight,	Compressive strength	An optimal replacement for medium-grade concrete lies between 5% and 10% BLA

	Cement on Compressive Strength		specifically in increments of 5%.		

Source: Abebaw et al., (2021), Umoh & Odesola, (2015), Kolawole et al., (2021), Hnin et al., (2018).

Various scholars have undertaken several investigations on the applicability of various supplementary cementitious materials in the production of concrete. Bamboo leaf ash has a low percentage of alumina but a high percentage of silica, while volcanic pumice powder has a moderate silica percentage and a comparatively greater alumina level. High silica pozzolan tends to be more pozzolanic which form a strong slow-hardening, whereas a high alumina pozzolan is more resistant to acidic attack that will improve durability of concrete. Therefore, there is a gap in using of those special property and utilization of blending volcanic pumice powder and bamboo leaf ash as partial replacement of cement in concrete production. So, it is valuable to assess the VPP and BLA and to conduct experimental study to fill the currently existing gap regarding using VPP and BLA as cement replacement at specified percentage to investigate workability, mechanical, durability, microstructural property, and to evaluate cost benefits of C-25 concrete.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The Materials and Methods section of this research paper aims to provide a detailed account of the procedures adopted to achieve the research objectives set in Chapter 1. As discussed in the previous chapter, the literature review has highlighted the existing knowledge gaps and past studies related to the blending of pumice powder and bamboo leaf ash as a partial replacement of cement in concrete. Building upon this background, this section will elaborate on the methodology implemented in this study to address the research gaps and achieve the research objectives.

3.2 Materials

This research study focused on the utilization of locally available materials, namely ordinary Portland cement, pumice powder and bamboo leaf ash as partial replacement of cement in concrete production as presented in Figure3.1.

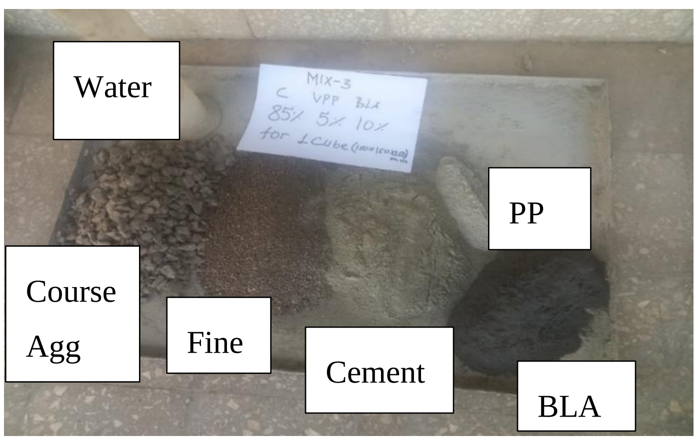

Figure 3.1: Concrete composing materials

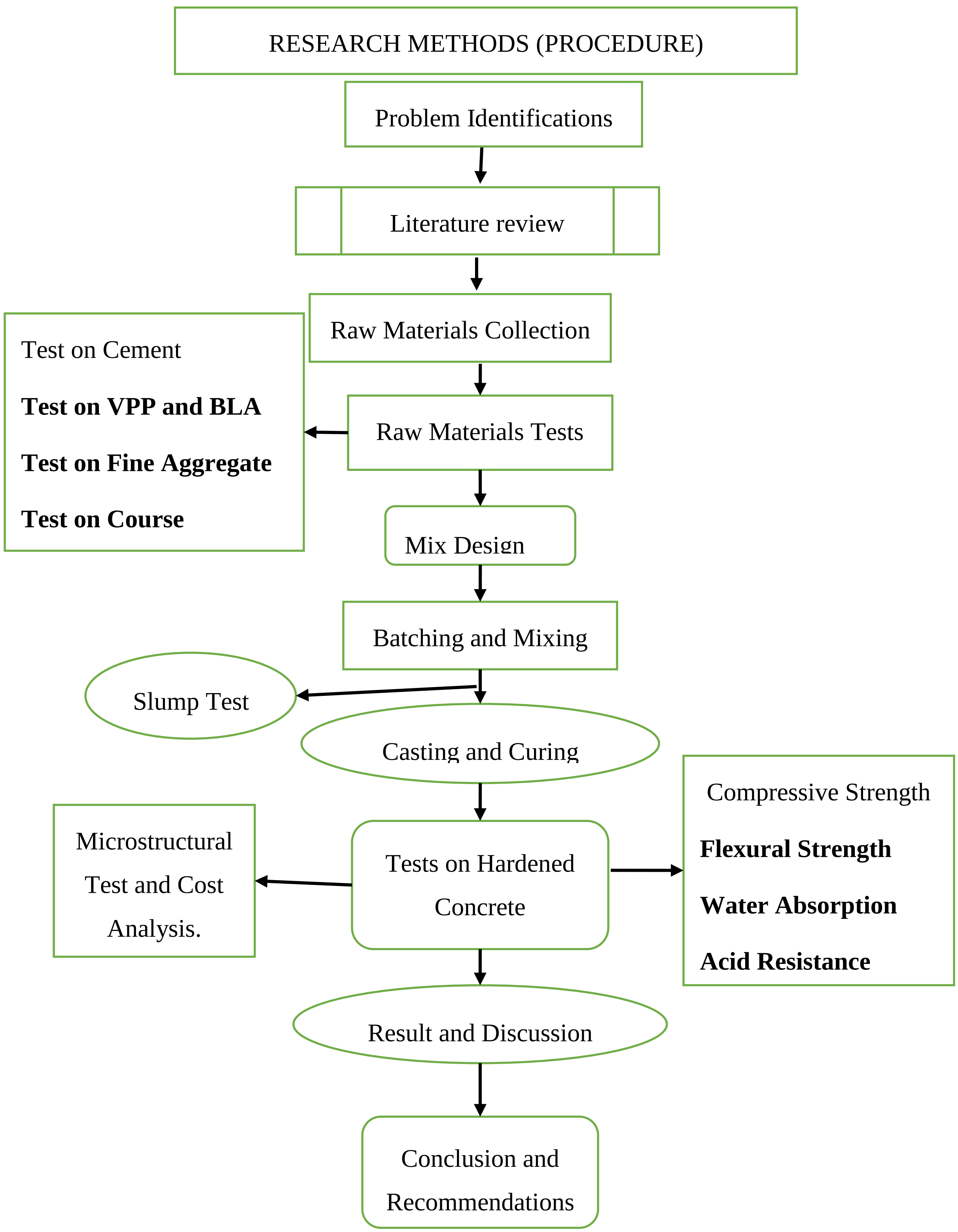

Figure 3.2: Schematic Diagrams for Research Procedure

3.2.1 Cement

The experiment employed locally available ordinary Portland cement, which is a finely powdered material comprising argillaceous, siliceous, and calcareous components, as well as chemically mixed iron oxide, gypsum, and other chemicals. OPC is widely used in construction due to its excellent mechanical properties, early stripping, and high grade. The chosen OPC for the study was obtained from shops in Adama, Ethiopia, and was carefully stored in an airtight container to protect it from moisture and atmospheric agents, in compliance with the ASTM C150 standard. The cement used was OPC of Strength Class CES 28, CEM I 42.5 N, manufactured by the National cement factory and available in the local market of Adama, Ethiopia.

3.2.2 Fine Aggregate

For this study, the fine aggregate was obtained from construction site found in ASTU in accordance with the ASTM C33 (2003) standards. As per the ASTM specification, the fine aggregate should not absorb more than 5% of water.

3.2.3 Course Aggregate

For this study, crushed gravel was used as the coarse aggregate for the concrete samples, which was obtained from a construction site found in ASTU that meets the requirements of ASTM C33. The coarse aggregate used in the experiment must be durable, strong, free from vegetable matter, with less than 5% water absorption, and not sharp and angular in accordance with the ASTM C33 standard.

3.2.4 Water

To test the pH of water pH meter is used. Collect a water sample in a clean container. Using a pH meter, immerse the electrode into the water sample and wait for the reading to stabilize. The pH meter display the pH value directly. Potable water, which meets ASTM C1602 (2006) standard was utilized for the current research.

3.2.5 Pumice

Pumice for this research was sourced from Meki, East Shawa, Oromia regional state, Ethiopia, about 136 Km from the capital city Addis Ababa. The used pumice was obtained from Dangote cement factory (as Dangote cement factory uses pumice from meki quarry site for production of Portland pozzolona cement) The source location was chosen because of the high availability of volcanic pumice in the area and its closeness to the Adama, where the experimental work was carried out.

3.2.5.1 Preparation of Pumice Powder

A sample was collected from the bulk storage using a sampling tube while it was being discharged. To obtain the sample at the discharge point into a rail car or tanker, it is necessary to first remove the top layer to a minimum depth of 200 mm (8 inches) as per the guidelines of ASTM 311. The sample dried on oven dry, after that grind to powder in the ASTU chemical department laboratory using ball milling machine and sifting to 150 micrometres (μm) size which was done at ASTU construction material laboratory.

[a) Oven drying of pumice b), Grind to powder by ball milling machine c), VPP]

Figure 3.3: Volcanic pumice processing.

3.2.6 Bamboo Leaf

Bamboo leaf for this research was sourced from kofele near shashamne, Oromia regional state, Ethiopia, about 261 Km from the capital city Addis Ababa. The source location was chosen because of the high availability of bamboo leaf around the area and its closeness to the Adama, where the experimental work was carried out

3.2.6.1 Preparation of Bamboo Leaf Ash

Bamboo leaf used in this study was collected from source and washed by potable water to remove dust impurities on bamboo leaf then dried in sun. Grinding machine (Wofcho) was used for grinding the washed and dried bamboo leaf. Then the grinded bamboo leaf obtained was taken to Ethiopian defence university laboratory and heated in muffle furnace under controlled Temperature of 600 0C for two hours to remove extra carbon in the ash and to get amorphous material containing amorphous silica. The ash generated was taken and used as bamboo leaf ash sample after sieved on 45 µm (No. 325) and checked the percent of passed BLA as per ASTMC 618 Specification.

[A) Collected Bamboo leaf   B) washed by tap water C) dried in sun   D) Grinded bamboo

E) BLA after burned in furnace under controlled Temperature of 600 ^{0}C for two hours]

Figure 3.4: Bamboo leaf processing

3.3 Research Methods

The methods encompassed the examination of concrete composing materials and their respective tests, followed by concrete mix design. Moreover, delve into the processes of concrete batching, mixing, casting, and curing to comprehend the methods utilized in achieving the desired output. Lastly, both hardened and fresh concrete properties procedure were conducted. By consolidating these elements, the overall research methods applied for this specific research were discussed below.

3.3.1 Test on Concrete Materials

3.3.1.1 Test for Cement

Series of tests conducted on cement to evaluate its quality and suitability for this study. The tests performed include the normal consistency test and specific gravity test, which are essential in determining the standard water-cement ratio and the cement's inherent density. By evaluating these properties, we can ensure that the cement mix will exhibit the desired performance characteristics.

A) Normal Consistency Test for Cement

The consistency of cement test is used to evaluate how much water should be added to cement in order to achieve standard consistency or normal consistency. The normal consistency test of cement is recommended to be measured using the (ASTM C 187) method. As a result, a vicat apparatus was used to determine the typical consistency. This test was performed according to the instructions in (ASTM C 187). Detailed Procedures for normal consistency of cement paste test are presented in Appendix: A3.

B) Specific Gravity Test

The specific gravity of cement was determined using a non-reactive medium such as water-free kerosene and a pycnometer. This applied to dust, sand, and other fine particulate materials, including PP and BLA. In accordance with ASTM C188 (2009) standards, this process accurately determined specific gravity ranging from 3.1 to 3.16 g/cc. Kerosene was preferred over water due to its inability to trigger a reaction that could potentially affect the test results. Detailed instructions on the procedure were available in appendix A4 for reference.

3.3.1.2 Test for Pumice Powder and Bamboo Leaf Ash

This section presents tests conducted on volcanic pumice powder and bamboo leaf ash.that focused on chemical composition, specific gravity and fineness test. It’s essential to ensure their suitability for use.

A) Chemical Composition Analysis

This type of examination helped in identifying the proportions of diverse oxides present within the sample. This analysis was done through different methods such as LIBO, fusion, HF attack, gravimetric, colorimetric, and AAS. The analysis was conducted at the laboratory of the Ethiopia Geological Survey.

B) Specific Gravity Test

One method of determining the specific gravity was to use a liquid that did not react with cement, such as water-free kerosene, by using a specific gravity pycnometer. Due to this reason, the specific gravity of PP and BLA was also determined by this method. The test was conducted according to ASTM C188 (2009) standard. Kerosene was used to determine the specific gravity because when water was used while testing, it started to react. This reaction could have affected the experiment, but kerosene did not react with cement and ash, and did not affect the test. Detailed procedures for the Specific Gravity Test were presented in Appendix: A4.

C) Fineness of PP and BLA

Sieve analysis of the PP and BLA was undertaken, as the same as cement sieve analysis, since particle size distribution of PP and BLA should be similar to the cement.

3.3.1.3 Test for Fine Aggregate

This section highlights experiments conducted on fine aggregate, focusing on aspects such as silt content, sieve analysis, unit weight, specific gravity, and water absorption testing. These experiments aim to ensure the suitability of the aggregates for their intended use.

A) Silt Content of Fine Aggregate

For this experiment, sample sand, clean water, a graduated jar, a spoon, a dish for taking a sand sample, and a funnel were used. Detailed Procedures for silt content are presented in Appendix: A5 based on ASTM C 117.

B) Sieve Analysis of Fine Aggregate

The test was to determine the fineness modulus of fine aggregate with the help of a series of IS sieves having (4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15, and pan) sizes from top to bottom, respectively, 500 g of fine aggregate, a balance, sieve shaker, shovel, and sieve brush. The test procedure was in accordance with (ASTM C136). The range of fineness modulus is between 2.3-3.1 intervals (ASTM C33). Detailed Procedures for sieve analysis of fine aggregate test are presented in Appendix: A6.

C) Unit Weight, Specific Gravity, and Water Absorption of Fine Aggregate

The procedure for determining the unit weight, specific gravity, and water absorption of fine aggregate was presented in Appendix. These measurements were used to calculate the unit weight and specific gravity of the fine aggregate using the appropriate formulas. The procedure followed relevant standards, such as ASTM C128 and ASTM C127, ensuring accurate and reliable results for the unit weight, specific gravity, and water absorption of fine aggregate.

3.3.1.4 Test for Course Aggregate

This section emphasizes the experiments carried out on course aggregate, concentrating on tests such as sieve analysis, unit weight, specific gravity, and water absorption testing. The purpose of these experiments is to guarantee the appropriateness of the aggregates for their designated use.

A) Sieve Analysis

The process of determining gradation involves sifting the material through a series of stacked sieves with increasingly smaller openings from top to bottom, the IS sieves are 20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan, respectively. Because the material that passed through the sieve opening 4.75mm was initially excluded, aggregates than 4.75 mm were not used. Sieve analysis apparatus used for the current study includes a set of IS sieves, a pan, shovel, balance, a mechanical sieve shaker, and a sample splitter. The test was undertaken according to ASTM C13 (2006) standard.

B) **Specific Gravity and Water Absorption Tests**

To carry out this test, sample was taken by using a sample splitter and sieved with 20 and 4.75 mm sieves to ignore materials retained on sieve opening 20 mm and passed through a sieve opening 4.75 mm. Then the sample was washed to remove dust particles and put in the oven at 110$_o$C for 24 hours. After that, the sample was allowed to cool after being removed from the oven and its weight was measured. The sample was submerged in the water for 24 hours. After the sample was removed from the water, it was rolled in a large absorbent cloth until all visible films of water were removed, and the required weight of the saturated surface dry sample was taken. After being weighted, immediately S.S.D sample was placed in the wire basket, and its weight in the water was determined. Finally, the sample dried to constant weight at a temperature of 110$_o$C, and cooled in the air for 2 hours. Overall calculations were done using equations 3.1 to 3.3. Density, specific gravity and water absorption tests were done according to ASTM C127 (2007) standard.

Bulk specific gravity = A/ (A+S-C)…………………………….…..Equation 3.1

Apparent specific gravity = A/ (B+A-C)…………………………...Equation 3.2

Absorption capacity = ((S-A)/A) * 100…………………………..…Equation 3.3

Where,

A: Weight of oven dry specimen in oven, (g)

B: Weight of wire basket with water, (g).

S: Weight of saturated surface dry specimen, (g).

C: Weight of wire basket with specimen in the water, (g).

C) Unit Weight Test

This test was carried out in the same way that the procedure for determining the unit weight of fine aggregate was carried out in the previous section.

3.3.1.5 Test for Water

The pH level of the mixing and curing water has an impact on the properties of concrete. Therefore, to determine the pH level, a pH meter was utilized. The process involved preparing a sample of water, immersing the electrode in the buffer solution, submerging the electrode in the water sample, and taking a reading of the pH level.

3.3.2 Concrete Mix Design

In this study, ACI 211.1 method used to design mix proportion for Characteristics strength C-25 concrete grade. The target or mean compressive strength based on characteristic strength of 25 MPa which gives; fck = f'ck +8.5 = 25 + 8.5 = 33.5 MPa is used for this study. As show in Table 3.2, the mix proportion adopted in this work was 1:2.337:2.678 (cement: sand: aggregate) with the water/cement ratio (w/c) of 0.491 for ordinary mix used for general reinforced/structural concrete. Detailed Procedures for concrete mix design are presented in Appendix: B.

Table 3.1: Average Compressive Strength Conversion

Characteristics strength (f'ck, MPa)	Mean strength (fck, MPa)
< 21	F'ck +7
21-35	F'ck +8.5
>35	1.1 x F'ck +5

Table 3.2: Mix Ratio for C-25 Concrete Grade

Ingredients	Cement	Fine aggregate	Coarse aggregate
Amount/m^3	376.78/376.78	880.859/376.78	1008.15/376.78
Ratio	1	2.337	2.675

3.3.3 Concrete Batching and Mixing

3.3.3.1 Concrete Batching

Batching refers to the procedure of measuring the appropriate amounts or ratios of materials, such as cement, fine and coarse aggregates, and water, for creating a concrete mix. This can be completed either through weight or volume-based measurements. Batching by weight method will be used for this specific study, because it is found more accurate than batching by volume. Volcanic pumice powder (VPP) and Bamboo leaf ash (BLA) will used to replace OPC at dosage of 10%, 15% and 20% by weight of binder (cement). Additionally, 0% of VPP and BLA will be used as a control mix.

Based on above literature review, study done by different scholars provide the average of optimum percent for VPP is 10% and for BLA 10% could acceptable for partial replacement of cement without affecting concrete properties. Taking this as a bench mark 5% - 10% replacement for VPP and BLA is conducted for this experimental investigation to assess the effect of blending those two material with cement on concrete production by partial replacing up to 20% of blended VPP and BLA.

Table 3.3: Optimum Percentage Replacement of VPP by Past Studies

Authors	(Zeyad et al., 2020)	(Zeyad & Almalki, 2021)	(K. Hossain, 2004)	(Kabay et al., 2015)	(Sarıdemir, 2013)
VPP	10%	10%	15%	10%	5%

Table 3.4: Optimum Percentage Replacement of BLA by Past Studies

Authors	(Kolawole et al., 2021)	(Temitope & Olubunmi, 2015)	(Moraes et al., 2019)	(Umoh & Femi, 2013)	(Olanrewaju et al.)	(Abebaw et al., 2021)
BLA	10%	10%	15%	10%	5%	10%

3.3.3.2 Concrete Mixing

For this experiment, five mix samples were made by mixing cement, bamboo leaf ash, and volcanic pumice powder. Mixing done by using drum mixer. Once the fine and coarse aggregates have been fully mixed with the blended cementitious material, water added gradually to the dry mixture while stirring continuously to create a homogenous mix.

Table 3.5: Percentage Replacement of Cement with VPP and BLA

Batch	Mix samples	Cement (OPC)	Volcanic Pumice Powder (VPP)	Bamboo Leaf Ash (BLA)
1	Mix -1 (100,0,0)	100%	0%	0%
2	Mix -2 (90,5,5)	90%	5%	5%
3	Mix -3 (85,10,5)	85%	10%	5%
4	Mix -4 (85,5.10)	85%	5%	10%
5	Mix-5 (80,10,10)	80%	10%	10%

3.3.4 Test for Fresh Concrete

The concrete slump test was conducted according to the ASTM C143 (2010) standard as a way to determine the consistency of freshly-prepared concrete. This assessment is used to evaluate the workability of newly made concrete and serves as an early warning signal for improper mixing. If the results yield an excessively low slump, there may be issues with consolidation, while an overly high result can lead to mortar loss and increased formwork pressure. The necessary materials for this test include a slump cone (with dimensions 200 mm in diameter at its base, 10 mm in diameter at its top, 300 mm in height), a tamper rod (16 mm in diameter and 600 mm long), a ruler, flat pan, and other tools.

In this study, the methods for conducting Slump, Compacting Factor, Vee Bee, and Flow tests are thoroughly detailed in their respective ASTM standards. Due to constraints related to equipment availability, only the Slump test was utilized to assess workability in the present analysis.

3.3.4.1 Workability (slump) Test

In this study, the Slump, Compacting Factor, Vee Bee, and Flow tests have distinct ASTM standards detailing their respective execution procedures. Nonetheless, due to constraints such as equipment availability, only the Slump test was performed to assess workability.

According to ACI for C-25, a concrete slump of 2-10 cm is recommended. The slump test was conducted according to the procedure outlined in ASTM standards. The slump cone was washed and placed on a flat pan before being filled with three layers of fresh concrete. Each layer accounted for roughly one-third of the cone's capacity and was compacted with 25 tamper rod strokes equally distributed across the cross-section. Upon completion of filling and compaction, the cone was gently raised and its slump value was measured via ruler. This process was repeated three times to acquire reliable results, with mean values being calculated for each mix code.

3.3.5 Concrete Casting and Curing

Activities of cleaning of the mold, oiling the surface, casting after thoroughly mixing the inner cubes molds cleaned and lubricated with mold oil to facilitate easy molding and smoother surface. Three (150mmx150mmx150mm) concrete cube samples for each sample number (Mix-1, Mix -2, Mix -3, Mix -4, Mix -5) is casted and Water tank curing method adopted as all the specimens wholly submerged in water tank for continuous water curing and cured in the open tank for 7th, 14th and 28th and test for compression strength of concrete.

Table 3.6: Number of Sample Preparation

	Compressive strength			Water absorption	Acid attack	Flexural strength		
	7 day	14 day	28 day			7	14	28
Mix-1 (control)	3	3	3	3	6	3	3	3
Mix -2	3	3	3	3	6	3	3	3
Mix -3	3	3	3	3	6	3	3	3
Mix -4	3	3	3	3	6	3	3	3
Mix -5	3	3	3	3	6	3	3	3
Total	15	15	15	15	30	15	15	15

Three (500mmx100mmx100mm) concrete beam samples for each sample number (Mix-1, Mix -2, Mix -3, Mix -4, Mix -5) is casted and Water tank curing method adopted as all the specimens wholly submerged in water tank for continuous water curing and cured in the open tank for 7th, 14th and 28th and test for flexural strength of concrete. Three concrete cube samples for each mix casted then cured in the open tank for 28th day and tested for water absorption. Finally, one concrete cube samples for each mix casted and cured in the open water tank for 7 day. Then socked in 10% sodium sulphate up to 28th curing age and tested for effects of VPP and BLA on concrete sulphate attack resistance analysis and one concrete cube sample for each mix level casted for microstructural test of concrete then cured in water tank for 28 days. Generally 90 concrete cubes sample and 45 beam sample casted for this experimental investigation.

3.3.6 Test for Hardened Concrete

3.3.6.1 Compressive Strength Test

Concrete with 150 x 150 x 150mm cube sample casted for compressive strength measurement and tested at the ages of 7, 14 and 28 days, with respect to the volcanic pumice powder and bamboo leaf ash replacement levels. This test conducted by using Compressive Testing Machine at ASTU, Construction Material Laboratory and done in accordance with ASTM C39/C39M standard. Load should be applied gradually at the rate of 140 kg/cm2 per minute, having a load capacity of 3000 KN till the Specimens fails. The maximum load was recorded, and finally, the compressive strength was calculated. The results obtained reported as an average of three tests.

3.3.6.2 Flexural Strength Test

The flexural strength test was carried out on the concrete beams as ASTM D790 description, at varies curing age (7^{th}, 14^{th} and 28_{th} day) to determine the flexural strength. The specimens are tested in a flexural testing machine at standard loading rates. Concrete beam of 500mmx10mmx10mm sizes was used.

3.3.6.3 Water Absorption Test

According to ASTM, C1585, The water absorption test procedure followed was: after 28 days of curing, the samples were taken out of the curing water and dried at a temperature of 105°C for 24 hours, weighed, then immersed in curing water for 72 hours, weighed again, based on (ASTM, C1585), and the highest water absorption limit is 10%. The percentage of weight increase relative to the initial weight is represented as water absorption (Umoh et al., 2013).The water absorption and percent reduction can be computed by Equation 3.4.

Water absorption % = (A-B/B) x 100% …………..Equation 3.4

Where; A = Weight of saturated surface dry concrete, B = Weight of oven-dry concrete.

3.3.6.4 Acid Attack Test

To examine the acid attack (durability) through testing the compressive strength loss, the casted concrete cubes cured for 30 day that in water tank for 7 days , then the sample are taken from pure water thank and soaked in 5% $H_2.SO_4$ for 30 days. Then concrete cube cured in potable water and 5% $H_2.SO_4$ are compared and compressive strength losses due to acid attack are determined (Abebaw et al., 2021; Al-Dulaijan et al., 2003).

3.3.6.5 Microstructural Test

The test conducted for the optimal and control concrete. The sample were taken from samples prepared for compressive strength test after cured for 28 day in water tank and the sample taken from the middle of the cube.

3.3.7 Cost Comparison between Conventional and PP and BLA Concrete.

The cost of one cubic meter of concrete without and with 5% of PP and 5% of BLA was computed to compare cost of Conventional and PP and BLA Concrete. The current market price of materials and the cost of PP and BLA production were used to calculate the concrete cost.

3.4. Method of Data Analysis

The data obtained from the laboratory experiments was carefully analyzed using statistical measures such as mean, percentage, and standard deviation to ensure robust data interpretation. The findings were presented in an easy-to-understand manner through tables, graphs, figures, and charts. These visual representations were used to provide a clear and concise overview of the data, making it easier for readers to understand the research results.

3.5. Validity and Reliability

To ensure the accuracy and reliability of the data, the instruments used in the experiments were thoroughly checked for calibration and verification. The laboratory test results were meticulously recorded to minimize any potential errors. Moreover, each set of tests was conducted using three samples, and the average values were calculated to enhance the reliability and representativeness of the data.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Introduction

The previous chapter discussed the research materials and methods adopted in this study to achieve the objective of the research. This chapter deals with results and discussion. The chapter containing introduction about the main findings of a research and interprets the results. This section presented and analysed the results of various experimental tests. The chemical analysis of VPP and BLA was mentioned, including the properties cement, VPP, BLA, fine aggregate, course aggregate and water used in this study. Cement, VPP and BLA Blended paste consistency were also observed. Workability, compressive strength, flexural strength, water absorption, concrete acid resistance and microstructural property of the concrete were also discussed. Finally, the economic implications of using blended VPP and BLA as a partial replacement of cement in concrete production were also explored and presented.

4.2 Physical and Chemical Properties Materials

In this study, the results and discussion of the material properties investigated were presented, focusing on the main findings related to the experimental tests and their interpretations. The chemical analysis of PP and BLA, as well as the properties of cement, PP, BLA, fine aggregate, coarse aggregate, and water used in this study, form the basis of discussion. A critical examination of the blended paste consistency of cement, PP, and BLA provides further insight into the effectiveness and properties of these materials. Through a comprehensive analysis of the experimental results, enhance the understanding of these materials and their potential applications in concrete production.

4.2.1 Cement, PP and BLA

The test results obtained from the analysis of Cement, PP, and BLA are presented and discussed in the following sections.

4.2.1.1 Chemical Characterization of National OPC Cement, PP and BLA

The chemical characterization of the materials used for the blended cements are presented in Table 4.1.

Table 4.1: Oxide Composition of National OPC Cement, PP and BLA

Oxide Composition	National OPC Cement	PP [Appendix A1]	BLA [Appendix A2]
SiO_2	26.02	61.06	68.12
Al_2O_3	5.09	18.13	4.92
Fe_2O_3	3.48	5.4	1.36
CaO	60.4	2.12	6.02
MgO	1.76	0.34	1.52
Na_2O	0.34	3.9	0.66
K_2O	0.56	4.04	0.16
MnO	0.04	0.16	0.12
P_2O_5	0.1	0.32	1.46
TiO_2	0.16	0.1	0.01
H_2O	0.39	0.63	2.39
LOI	1.89	4.68	14.25
$SiO_2 + Al_2O_3 + Fe_2O_3$		84.59	74.4

The result indicates that the combined oxide components ($SiO_2 + Al_2O_3 + Fe_2O_3$) of BLA and VPP exceeded the 70% minimum requirement for classes F and N pozzolans, as specified by ASTM C 618-08 (2008). ASTM C 618-08 (2008) classifies BLA as a class F pozzolan, whereas VPP falls under class N. Moreover, the Table 4.1 highlights that BLA exhibits a higher silica composition than PP, while PP possesses a greater concentration of alumina and ferrite, thus providing a superior resistance to acid attack (Kolawole et al., 2021; Zeyad & Almalki, 2021).

Likewise, the same standard limits maximum loss on ignition (LOI) of class F and N pozzolans to 6% and 10%, respectively. PP satisfied this specification since exhibited 4.68% which is lower than ASTM C618's maximum value of 6%, while BLA has LOI of 14.25% which is higher than ASTM C618's maximum value of 10%. The reason for occurrence of high LOI in BLA is presence of carbon in the ash due to low combustion temperature. According to Barrack and Sylvester (2021), the value of LOI increases when compounds are burned at a low temperature.

Furthermore, the PP was discovered to contain alkali content, such as Na_2O (3.9%) and K_2O (4.04%), signalling a high potential for the alkali-silica reaction when utilized in concrete with silica reach aggregate. As a result, combining PP with silica reach aggregate has a negative impact on the long-term durability of concrete. It is recommended to handle this problem with a silica-free aggregate.

The chemical composition of PP (Al_2O_3 of 18.13%) for this research conforms to previous study with higher in alumina of 18.57, 16.71 and 12.90 (Hossain, 2004c; Zeyad & Almalki, 2021) and (Kabay et al., 2015) BLA contains higher silica content of 68.12% which conforms with previous research with silica content of 65.66%, 74.23%, and 75% (Abebaw et al., 2021; Mekonnen et al., 2014), and (Temitope, 2015). The minor variations in the composition of both PP and BLA, as noted by various researchers, could be due to the source location, geological factors, and processing techniques (Shetty, 2006; Umoh et al., 2013).

4.2.1.2 Fineness of Cement, PP and BLA

Fineness is an important property of cementitious materials that affects their hydration rate, strength development and durability. Fineness can be measured by various methods, such as sieving, air permeability, laser diffraction and image analysis. The fineness of the bamboo leaf ash retained on 45 µm (No. 325) sieves is 30% and 70% passed which is less than the maximum value of 34% retain as specified per ASTMC 618. Increasing the fineness of BLA increases the amount of mixing water required to achieve a given consistency and reduces the amount of bleeding by the concrete(Abebaw et al., 2021; Kolawole et al., 2021). The fineness of the volcanic pumice powder retained on 45 µm (No. 325) sieves is 29.3% which is less than the maximum value of 34% retain as specified per ASTMC 618.

4.2.1.3 Specific gravity of Cement, PP and BLA

Specific gravity is a fundamental property of materials that is used to determine the density of a substance relative to the density of water. The specific gravity of a material is an important factor that influences its physical and chemical properties, including its strength, durability, and workability.

Table 4.2: The Result of Specific Gravity of PP and BLA

Particulars	**Denotations**	**Samples in gram**	
		PP	**BLA**
Weight of empty flask (g)	**A**	**46.81**	**46.81**
Weight of pycnometer with VPP or BLA (g)	**B**	**74.95**	**73.65**
Weight of pycnometer with VPP or BLA and kerosene (g)	**C**	**145.01**	**143.55**
Weight of pcynometer with kerosene (g)	**D**	**124.75**	**124.75**
Specific gravity	**SG**	**2.32g/cc**	**2.24g/cc**

According to ASTM standards, the specific gravity of OPC must be between 3.10 and 3.16 g/cc. The fact that the specific gravity of OPC falls within this range indicates that it meets the required ASTM standards as it can be seen from Table 4.2. The specific gravity of BLA (2.24 g/cc) and volcanic pumice powder (2.32 g/cc) are both less than the specific gravity of OPC (3.15 g/cc). The reason why BLA and PP have lower specific gravity than OPC is because they contain more air voids and pores within their particles. These voids and pores reduce the density and weight of the materials, but also increase their water absorption capacity (Kurt et al., 2016; Umoh et al., 2013).

4.2.2 Water

The water was tested for PH measurement at Adama Science and Technology University. The PH value of water used for mixing concrete in the current study is 7.56, which is within the range (6 to 8.5) specified by ASTM (2006) standard. This means that the water quality meets the requirements for concrete production.

4.2.3 Fine Aggregate

4.2.3.1 Sieve Analysis of Fine Aggregate

The sieve analysis requirement for fine aggregate according to ASTM C136 (2006) and the grain size distribution of the fine aggregate should meet the standards for better quality of concrete, The laboratory test was carried out to identify the physical properties of the original sand sample was meeting the grading requirement to determine the fineness modulus of the fine aggregate. Table 4.2, shows the fine aggregate grading requirements according to ASTM C136 (2006) and the fine aggregate grain size distribution.

Table 4.3: Sieve Analysis Results and Standard for Fine Aggregate.

Sieve size (mm)	Weight of sample retained	Cumulative weight retained	Cumulative % retained	Cumulative % pass	ASTM Min (%)	ASTM Mix (%)
9.5	0	0	0	100	100	100
4.75	10	10	2.03	97.97	95	100
2.36	55.9	65.9	13.37	86.63	80	100
1.18	95.65	181.55	36.85	63.15	50	85
0.6	120	281.55	57.65	42.35	25	60
0.3	126	407.55	82.73	17.27	5	30
0.15	64.25	471.8	95.78	4.22	0	10
Pan	16.77	492.57	100			
Total	492.57		289.04			

The calculation shows that the fineness modulus of sand is 2.89. The results are shown in Table 4.3 below and Figure 4.1 respectively.Fineness Modules of sand = summation of cumulative % weight retained/100

= 289.04/100

= 2.89

The fine aggregate used in this study met the necessary requirements and standards. Specifically, the fineness modulus value fell within the range specified by ASTM C33 (2003), which is between 2.3 to 3.1. Additionally, the gradation curve of the fine aggregate was between the ASTM lower and upper limits, as shown in Figure 4.1, indicating that the fine aggregate met the ASTM C136 (2006) requirement for sieve analysis of fine aggregates.

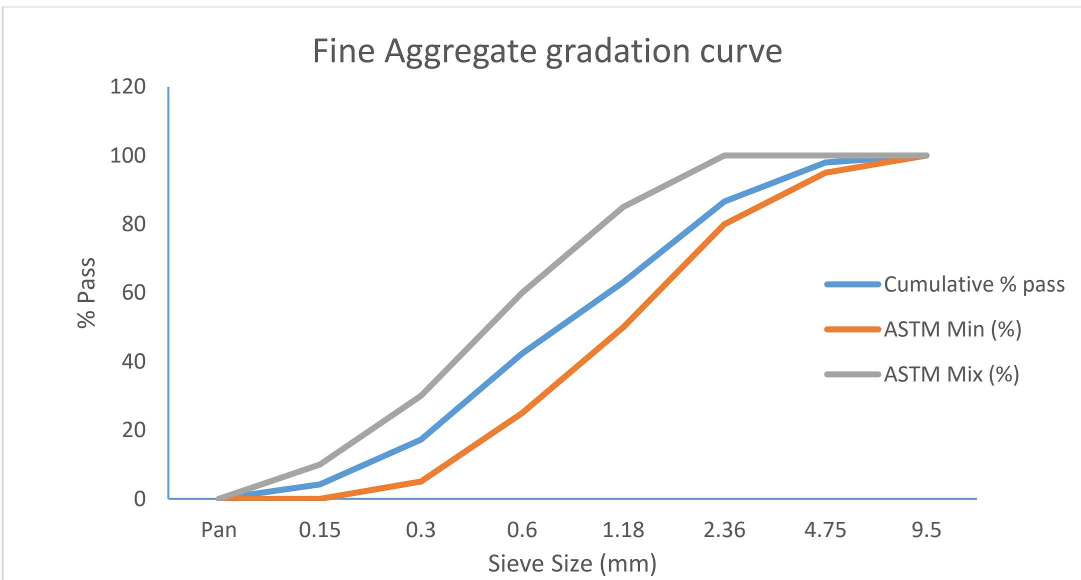

Figure 4.1: Gradation Curve of Fine Aggregate and ASTM lower and upper limit

4.2.3.2 Silt Content of Fine Aggregate

Before using fine aggregate for concrete production, it was necessary to determine the silt content in the laboratory. According to Ethiopian standards, silt content should not be greater than 6% (Dinku, 2002). The sand silt content was found 2.33 % which is less than 6% and suitable for use.

A: Silt deposited above the sand = 7ml

B: Amount of clean sand = 300ml

Silt content (%) = $\frac{Silt\ deposited\ above\ the\ sand\ (A)}{Amount\ of\ clean\ sand\ (B)} x10$

Silt content (%) = 700/300*100= 2.33 %

4.2.3.3 Specific Gravity and Water Absorption of Fine Aggregate

Table 4.4: Result of Specific Gravity and Absorption Capacity of Fine Aggregate

	Formulas	Calculations	Results
Bulk specific gravity	BGS = A/ (B+D-C)	Bsg= 490/ (1507.5+500-1829.9)	2.76
Bulk Specific gravity	(SSD) = D/ (B+A-C)	BSSD=500/ (1507.5+490-1829.9)	2.98
Apparent Specific gravity	ASG = A/(B+ A-C)	Asg=490/ (1507.5 + 490-1829.9)	2.91
Absorption %	WA = B/ (B-A) * 100	WA = (500 - 490)/490* 100	2.04%

Specific gravity evaluates the density of a composite material by comparing its weight to the weight of an equal volume of water. The porous nature of aggregates impacts their specific gravity, as measurements can include or exclude these pores. The apparent specific gravity pertains to the solid components of the aggregate, excluding the pores, while the bulk specific gravity encompasses the entire volume of the aggregate, including its pores.

A: weight of oven-dried test sample in air 490 g

B: weight of the pycnometer filled with water to the calibration mark 1507.5 g

C: weigh of pycnometer filled with sample and water to the calibration mark 1829.9 g

D: weight of SSD sample in air 500 g

The fine aggregates' specific gravity typically falls between 2.6 and 2.8. As present on Table 4.4, result of specific gravity and absorption capacity of fine aggregate, sample with a 2.76 bulk specific gravity is suitable for creating concrete. Absorption refers to the total open volume that can be occupied by water and is essential for adjusting the moisture in a mixed design. An absorption rate of 2.04% is comfortably below the 4% maximum threshold.

4.2.3.4 Unit Weight of Fine Aggregate

Unit weight, also known as density or specific weight, refers to the weight of a material per unit volume. It is a fundamental property that characterizes the mass distribution within a given volume. Unit weight is commonly expressed in kilograms per cubic meter (kg/m^3)

A= Volume of the container 0.01 m3 UWFA= (s-N)/I

B= Aggregate plus container weight 20.760 Kg

C= Weight of the empty container 5.605 Kg

Unit Weight of Fine Aggregate = (B-C)/A

Unit Weight of Fine Aggregate = (20.760-5.605)/0.01

Unit Weight of Fine Aggregate = 1515.5 kg/m3

This indicates that the calculated unit weight of the fine aggregate meets the standard requirements and demonstrates a satisfactory density level. The material can be considered suitable for use.

4.2.3.5 Moisture Content of Fine Aggregate

The moisture content in fine aggregates was measured by drying a 500 gram sample in an oven at 110°C for 24 hours and calculating the weight difference relative to the oven-dried weight. The evaluation of the water content in fine aggregate adhered to the ASTM-C 566 standard, and the observed results of 1.01% complied with the standard, indicating that the fine aggregate is appropriate for use. Physical properties of fine aggregate results are summarized in Table 4.5

Table 4.5: Summary Physical Properties of Fine Aggregate

No.	Types of Tests	Test Result	Test Standard
1.	Finesse modulus	2.89	ASTM -C136
2.	**Silt content**	**2.33%**	**-**
3.	Bulk unit weight	1515.5 kg/m3	ASTM -C29
4.	Bulk Specific gravity	2.76	ASTM -C128

5.	Absorption	2.04 %	ASTM -C128
6.	Moisture content	2%	ASTM -C566

4.2.4 Coarse Aggregate

4.2.4.1 Sieve Analysis of Coarse Aggregate

The coarse aggregates used for this research were crushed rock. A maximum aggregate size of 20 mm was used in all the concrete work. In a similar manner like the fine aggregate, laboratory tests were carried out gradation of the coarse aggregate using sieve analysis based on the ASTM C-136 standard. The results are shown in Table 4.6 below and Figure 4.2 respectively.

Table 4.6: Sieve Analysis Results and Standard for Course Aggregate

Sieve size (mm)	Weight of sample retained (g)	Percent of retained (%)	Cumulative percent retained (%)	Percent finer (%)	ASTM Min (%)	ASTM Mix (%)
20	0	0	0	100	100	100
19	410	8.25	8.25	91.75	95	100
12.5	1405	28.29	36.54	63.46	40	80
9.5	1670	33.63	70.17	29.83	20	55
4.75	1480	29.80	99.95	0.05	0	10
Pan	0	0	-	0	-	-

Materials used in the study were tested and evaluated according to ASTM standards The coarse aggregate used in a study met the ASTM lower and higher limits for gradation, as demonstrated by the gradation curve in Figure 4.2. Coarse aggregate is an essential component of concrete and its size distribution can have a significant impact on the strength and durability of the concrete. By meeting the ASTM standards for gradation, the coarse aggregate used in the research is likely to perform well and provide the desired characteristics for the concrete (Zeyad & Almalki, 2021).

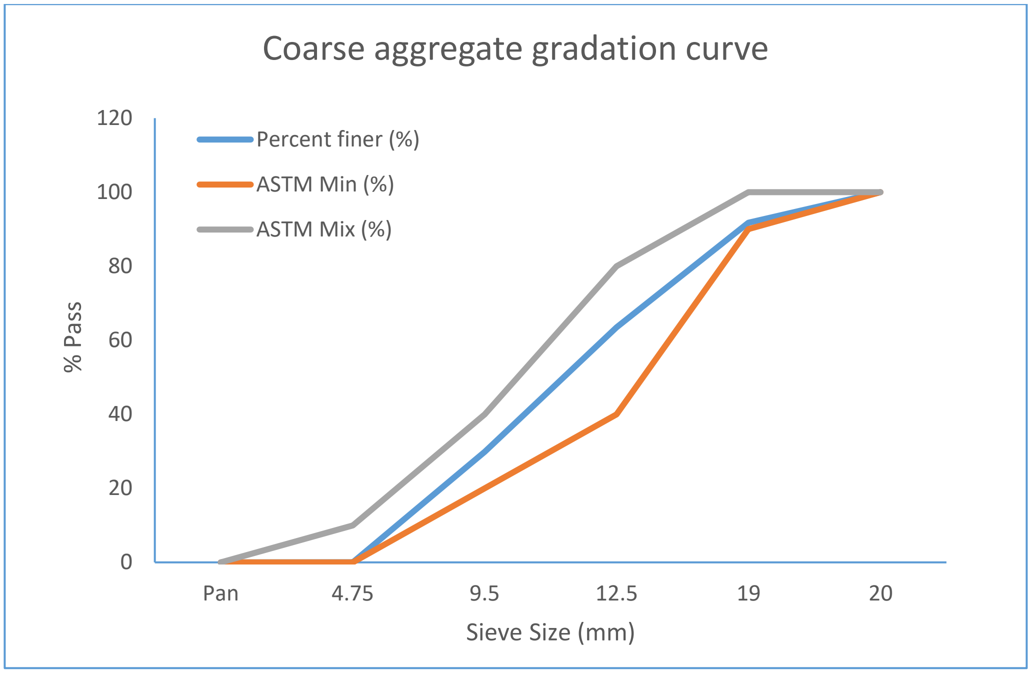

Figure 4.2: Gradation Curve of Coarse Aggregate and ASTM lower and upper limit

4.2.4.2 Specific Gravity and Water Absorption of Coarse Aggregate

Table 4.7: Result of Specific Gravity and Absorption Capacity of Coarse Aggregate

	Formulas	Calculations	Results
Bulk specific gravity	BSG= B/(B-C)	Bsg= 5094/ (5094 - 3300)	2.83
Apparent Specific gravity	ASG= A/(A-C)	Asg=4960/ (4960 - 3300)	2.98
Water absorption (WA) in %	WA=((B-A)/A)*100	WA = (5094 - 4960)/4960* 100	2.7%

Specific gravity is the ratio of the mass of a material to the mass of an equal volume of water, and it indicates the density and quality of the aggregate. Water absorption is the measure of the amount of water that can penetrate into the pores of the aggregate, and it affects the workability and strength of the concrete.

According to ASTM C127-15, the standard test method for relative density (specific gravity) and absorption of coarse aggregate, the specific gravity of coarse aggregate should range from 2.5 to 3, and the water absorption should not exceed 3%. The test result from Table 4.7, for specific gravity is 2.83 and water absorption is 2.7%, which are within the acceptable limits of the ASTM standard is used for this specific study.

Weight of oven dry specimen in oven (A) was 4960 gram.

Weight of saturated surface dry specimen (B) was 5094 gram.

Weight of specimen in the water with the wire basket (C) was 3300 gram.

4.2.4.3 Unit Weight of Coarse Aggregate

The rodded unit weight of coarse aggregates test (ASTM C29) is used to determine the unit weight of coarse aggregates in a compacted condition. This test method is applicable to aggregates not exceeding 15 cm in nominal size.

A= Volume of the container 5L

B= Aggregate plus container weight 11.690 Kg

C= Weight of the empty container 3.440 Kg

Unit Weight of Coarse Aggregate = (B-C)/A

Unit Weight of Coarse Aggregate = (11.690-3.440)/5

Unit Weight of Coarse Aggregate = 1650 kg/m3

Based on this result, the unit weight of coarse aggregate 1650 kg/m3 was laid between the ranges (1200 to 1750) kg/m3 that specified by ASTM C29. Therefore the coarse aggregate used for the current study was fulfilled the requirements in terms of unit weight.

4.2.4.4 The Moisture Content of Coarse Aggregate

The moisture content of coarse aggregate is determined in the same way as for fine aggregate. The ASTM-C 566 standard specifies the method for measuring the moisture content of coarse aggregate by drying it in an oven. The sample result value of 0.98% indicates the percentage of water in the aggregate mass. This value is within the acceptable range of 0.5% to 1% for coarse aggregate according to the ASTM-C 33 standard.

4.2.5 Cement, PP and BLA Blended Paste

4.2.5.1 Consistency of Cement, VP and BLA Blended Paste

Table 4.8: Result of Normal Consistency of Blended Paste

Mix- code	% Replacement			Normal consistency %
	Cement	PP	BL	
Mix-1	100	0	0	26
Mix-2	90	5	5	28
Mix-3	85	10	5	30
Mix-4	85	5	10	31
Mix-5	80	10	10	33

In this research, the impact of PP and BLA on the normal consistency of cement paste was examined. Normal consistency refers to the proportion of water needed to create a paste with a standard fluidity level. This consistency is reached when the plunger goes through 10 ± 1 mm from the paste's initial surface. This aspect is crucial, as it influences the workability and strength of the concrete.

The consistency of cement paste was evaluated using the Vicat equipment, following the ASTM C-187 standard. Different mixtures were prepared, including the control mix (OPC Mix-1) and mixes with partial replacements of volcanic pumice powder and bamboo leaf ash, namely Mix-2 (90% OPC, 5% PP, 5% BLA), Mix-3 (85% OPC, 10% PP, 5% BLA), Mix-4 (85% OPC, 5% PP, 10% BLA), and Mix-5 (80% OPC, 10% PP, 10% BLA). The normal consistency, expressed as a percentage, was measured for each mix. OPC Mix-1 had a normal consistency of 26%, while Mix-2, Mix-3, Mix-4, and Mix-5 exhibited normal consistencies of 28%, 30%, 31%, and 33% respectively. The results, presented in Table 4.8 & Figure 4.3, demonstrate the influence of partial replacement on the consistency of the cement paste for the different mix compositions.

The results on Figure 4.3, show that the normal consistency of cement paste increases with the increase of PP and BLA content. This is because PP and BLA have finer particles than OPC and can fill the voids between cement grains and also due to the rough and porous structure of PP reducing the water demand for a given fluidity. Moreover, PP and BLA have higher water absorption capacity than OPC and can retain more water in the paste, increasing its consistency (Kurt et al., 2016).

The results are consistent with previous studies that reported similar effects of PP and BLA on the consistency of cement paste. Several previous studies have reported similar findings on the effect of volcanic pumice powder and bamboo leaf ash on the normal consistency of cement pastes. Study by Kabay et al., (2015), investigated the effect of volcanic pumice powder on the properties of cement pastes and mortars, and found that the normal consistency increased from 26% to 32% when the replacement level increased from 0% to 30%. (Abebaw et al., 2021), studied the effect of bamboo leaf ash on the properties of cement pastes found that the normal consistency increased from 25% to 35% when the replacement level increased from 0% to 20%.

Figure 4.3: Normal Consistency of Blended Paste

The standard consistency experienced a 12% reduction when the PP content ranged from 0% to 50%. This decline in consistency can be attributed to the decreased cementitious binder present in the fresh mix as the PP content increases. Additionally, the lower specific gravity of PP compared to cement leads to a larger PP volume when replacing cement by mass. This causes the total volume to expand, requiring more water to produce a paste of the same consistency with varying PP percentages in the mix (Kurt et al., 2016).

4.3 Fresh Concrete Properties

4.3.1 Workability

Table 4.9: Result of Slump Value of Fresh Concrete

Mix- code	% Replacement			Slump in mm	% Redaction
	Cement	PP	BLA		
Mix-1	100	0	0	26	0
Mix-2	90	5	5	24	7.6
Mix-3	85	10	5	22	15.38
Mix-4	85	5	10	21	19.23
Mix-5	80	10	10	19	26.92

To better understand the effects of varying percentages of PP and BLA on the workability of concrete, slump tests were conducted on five different mixes. Mix-1, which served as the control mix, had a slump value of 26mm. As shown in Table 4.9 and Figure 4.4, as the percentage replacement of cement by PP and BLA increased, the slump value decreased in all subsequent mixes (mix-2 to mix-5). For instance, mix-2 achieved a slump value of 24mm, mix-3 had 22mm, mix-4 had 21mm, and mix-5 had the lowest slump value of 19mm. The water-cement ratio was held constant at 0.491 for all mixes.

In terms of percentage reduction in slump from the control mix, mix-2 showed the least change with a reduction of 7.6%, whereas mix-5 had the highest reduction of 26.92%. Mix-4 showed a reduction of 19.23%, and mix-3 deviated from the control mix by 15.38%, but with a 3.85% improvement over mix-4. This improvement can be attributed to the presence of 5% BLA and 10% PP in mix-3. The fineness of BLA and its larger specific surface area likely contributed to this effect, as finer particles require more water to wet their larger specific surface area (Abebaw et al., 2021).

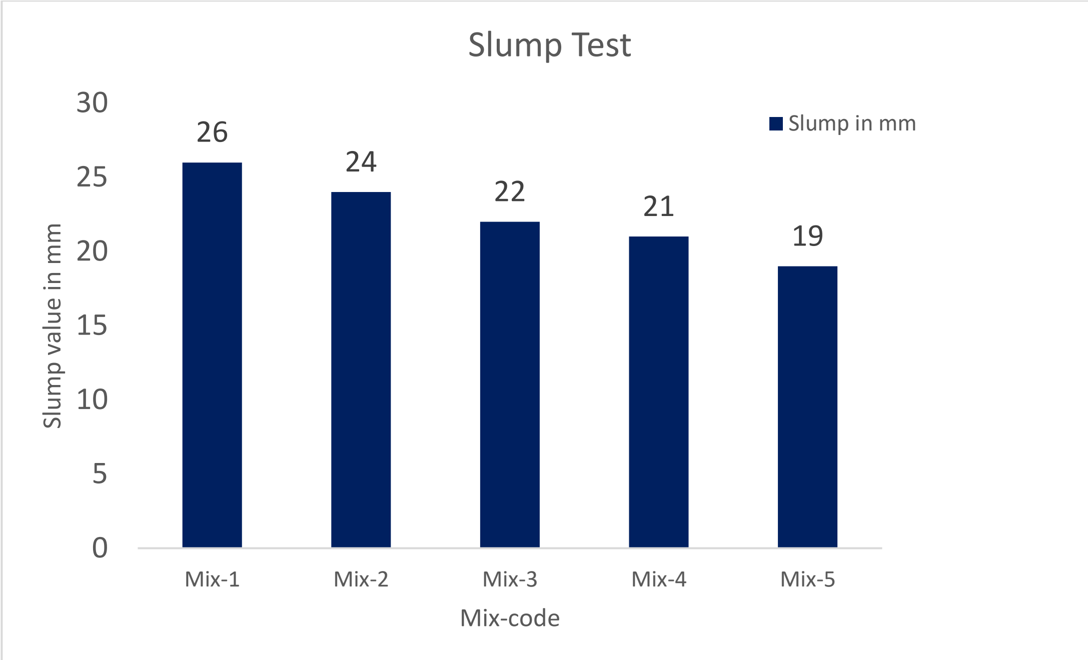

Figure 4.4: Slump Value of Concrete at Different Percentage of Replacement

4.4 Compressive and Flexural Strength of PP and BLA Concrete

Hardened concrete possesses various properties that determine its overall strength, durability, and resistance to external factors. Compressive strength is a crucial property that indicates the concrete's ability to withstand compressive forces without deformation. Flexural strength, on the other hand, measures the concrete's ability to resist bending or cracking under applied loads. Water absorption is an important property that indicates the concrete's permeability and susceptibility to moisture-related issues. Acid attack resistance is a vital property that reflects the concrete's ability to withstand chemical corrosion and deterioration caused by acidic substances. Lastly, microstructural properties, such as porosity and pore structure, play a significant role in determining the concrete's overall durability and performance. These properties result were presented and discussed in the following section.

4.4.1 Compressive Strength

The results of the compressive strength tests conducted on concrete cubes containing a blend of pumice powder and bamboo leaf ash, along with the corresponding curing days and percentages of replacement, are presented in Table 4.10. This table includes the compressive strengths of three replicate samples of blended cement concrete cubes, as well as the mean compressive strength values and the percentage attainment of the target strength (33.5 N/mm^2) after 28 days of curing in water tank.

Table 4.10: Compressive Strength of the Concrete with Different Replacement Percentage at 7, 14, and 28 Day's Age

Curing Days	Compressive strength					
	Mix code	1	2	3	Target Mean Strength (Mpa)	% Target strength of 33.5(Mpa)
7 day	Mix-1	23.73	23.62	23.59	23.64	70.5672
	Mix-2	22.46	21.98	23.1	22.48	67.1045
	Mix-3	21.69	21.28	21.4	21.46	64.0597
	Mix-4	20.28	20.81	21.04	20.71	61.8209
	Mix-5	13.94	14.92	14.96	14.62	43.6418
14 day	Mix-1	28.5	26.86	27.83	27.73	82.7761
	Mix-2	27.99	27.54	26.79	27.44	81.9104
	Mix-3	26.32	27.2	26.65	26.71	79.7313
	Mix-4	23.87	25.47	24.3	24.57	73.3433
	Mix-5	21.8	22.24	20.42	21.28	63.5224
28 day	Mix-1	34.25	34.21	35.82	34.79	103.851
	Mix-2	36.34	35.17	36.01	35.84	106.985
	Mix-3	33.81	34.65	32.49	33.55	100.149

	Mix-4	32.12	29.98	31.26	31.12	92.8955
	Mix-5	29.18	27.19	28.74	28.36	84.6567

*Replacement levels Mix (OPC: PP: BLA) %

Mix-1(100, 0, 0): Mix-2 (90, 5, 5): Mix-3(85, 10, 5): Mix-4 (85, 5, 10): Mix-5 (80, 10, 10)

In general, the compressive strength of the concrete increases with longer curing periods but decreases with higher proportions of bamboo leaf ash and volcanic pumice powder. After 7 days of curing, the control mix (Mix-1) achieved 70.56% of the target strength, followed closely by Mix-2 (90% OPC, 5% PP, 5% BLA) with 67.10% of the target strength. However, Mix-5 (80% OPC, 10% PP, 10% BLA) had a lower target strength, reaching only 43.64% of the target value. According to Domone & Illston, (2010), concrete is expected to reach 65% - 80% of its target strength at 7 days of curing, and only Mix-1 and Mix-2 satisfied this condition.

The test results at 14 days of curing, as shown in Table 4.10, indicate that the control mix (0% BLA and 0% PP) achieved 82.77% of the target strength, meeting the requirement of normal concrete strength development specified by BS 8110-2 (1985) for 14 days of curing (80%). Mix-2 had 81.9% of the target strength, followed closely by Mix-3 (85% OPC, 10% PP, 5% BLA) with 79.73% and Mix-4 (85% OPC, 5% PP, 10% BLA) with 73.34% of the target strength and mix-3 is greater than mix-4 this may imply PP exhibits more pozzolanic nature than BLA and also The BLA presented a high value of loss on ignition (LOI, 14.25%), which is attributed to the organic remove the organic content of the leaves. The high value of LOI might interfere in the hydration reactions, reduce the workability of the cementitious matrices which leads to an increase of water demand and probably a decrease of the compressive strength. Mix-5, which contained 80% OPC, 10% PP, and 10% BLA, achieved 63.52% of the target strength at 14 days of curing. Mix levels 1 and 2 satisfied the 80% - 95% percentage attainment range for the concrete target strength as specified by Domone & Illston, (2010).

After 28 days of curing, the control mix (Mix-1) achieved 103.85% of the target strength, indicating higher strength than the target value. Mix-2 had a mean target strength of 35.84 MPa, achieving 106.98% of the target strength that is higher than all replacement mix because At low percentages of replacement, the quantity of silica is low, therefore, only a limited quantity of C-S-H can be formed, though a large quantity of calcium hydroxide is liberated due to the relatively large quantity of Portland cement. However, at high percentage replacement, the quantity of pozzolana in the mix increases, C-S-H reduces due to liberation of a small quantity of calcium hydroxide from the hydration of the relatively small quantity of Portland cement available. Mixes 3, 4, and 5 achieved 100.14%, 92.89%, and 84.65% of the target strength, respectively. Therefore, blended cement concrete containing Mixes 1, 2, and 3 satisfied the target strength of 33.5 N/mm2 after 28 days of curing, while Mixes 4 and 5 attained a characteristic strength of 25 N/mm2.

The reason for compressive strength reduction is due to the high replacement of PP and BLA and cement content reduction per cubic meter of concrete by 10%, 15%, 20% from the normal concrete mix, and also the pozzolanic reaction takes a long time. This confirm with the study conducted individually on PP and BLA. Study by Zeyad & Almalki, (2021), demonstrated that incorporating VPP into concrete led to reduced mechanical strength during the early stages of development. However, the strength was found to be similar to that of conventional concrete at later stages. The research revealed that concrete samples containing 10% PP as a substitute for cement showed a slight improvement in compressive strength compared to control concrete at a later stage. The decrease in compressive strength can be attributed to the substantial replacement of cement and BLA content by 5%, 10%, 15%, 20%, and 25% in each cubic meter of concrete. Additionally, the time-consuming nature of the pozzolanic reaction contributes to the reduction in compressive strength, as noted by Abebaw et al., (2021).

In conformity to the above, previous study on the ternary combination of pozzolans and cement, has been shown that the overall percentage of cement replacement with combined pozzolans is higher compared to individual blending with cement (Umoh & Odesola, 2015).A study on the ternary blend of bamboo leaf ash, periwinkle shell ash (PSA), and ordinary Portland cement in concrete found that a mix of 10% BLA and 10% PSA was suitable for standard structural concrete. This was attributed to the high lime (CaO) content found in PSA, a cementitious material. Furthermore, the study demonstrated that the 28-day curing period exceeded that of the control mix. In another study, Shannag, (2000) examined silica fume and volcanic tuff, determining that both materials could replace cement in a ternary mixture up to 15%, without negatively impacting compressive strength.

Table 4.11: Compressive Strength Increment/ Reduction (%) with Respect to mix-1 (control)

	Increment/ Reduction (%) with reference of control mix by curing day				
Mix code	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5
7 day	0	-4.9	-9.22	-23.39	-38.15
14 day	0	-1.0458	-3.67	-11.39	-23.26
28 day	0	+3.01	-3.56951	-10.54	-18.48

Figure 4.5 illustrates the impact of substituting OPC with BLA and VPP in various proportions on the compressive strength of blended cement concrete for different curing durations in water. Overall, the strength tends to decrese as the amount of replacement rises. Nevertheless, Mix-2, which contains a specific replacement level, exhibits a greater compressive strength compared to other mixes, including the Mix-1 (control), after 28 days of curing. Therefore, it could potentially serve as an optimal replacement option.

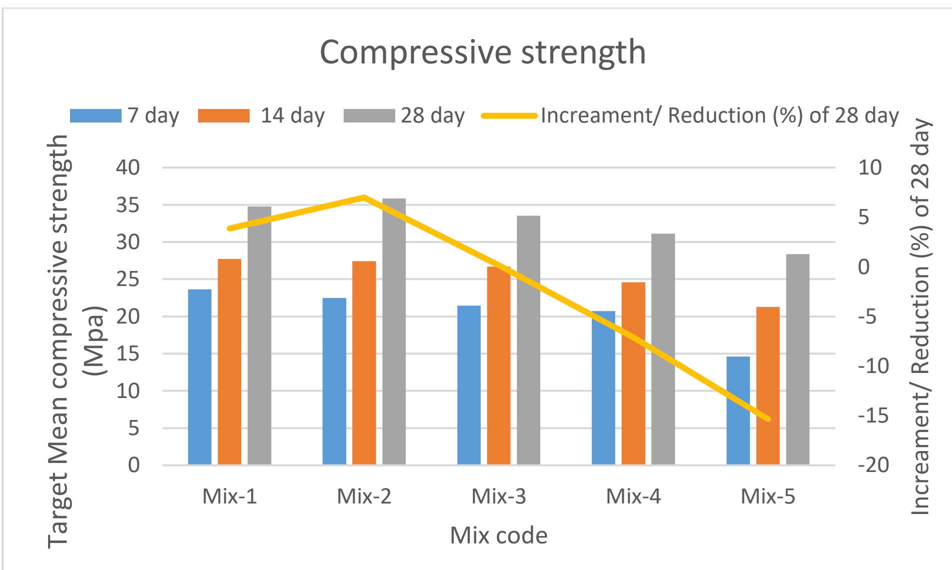

Figure 4.5: Compressive Strength Results

It can be concluded that ordinary Portland cement can be replaced with Mix-2 and Mix-3 to produce blended cement concrete without any significant loss in strength as compared to conventional concrete (ASTMC 618-08, 2008), particularly for normal reinforced concrete. None of the ternary combinations showed favourable results to match the strength of the control after 28 days of curing, except for Mix-2, which could be because VPP and BLA lack sufficient lime content to serve as supplementary cementitious materials for the utilized cement. The reduced compressive strength observed in Mix-5 might be due to its higher concentration of less reactive crystalline silica (SiO_2), than highly reactive amorphous silica.

4.4.1.1 Statistical Analysis of Compressive Strength

This study conducts a statistical analysis using Origin Pro 2022 software to assess the impact of varying curing periods and replacement levels on the compressive strength of concrete. A two-way ANOVA Tukey HSD method is utilized to analyze the experimental data, and the results were discussed.

Upon analyzing the data, a mean difference of 0.06 is observed when comparing the Mix-2 sample to the Mix-1 (control mix) at 28 days of curing. This suggests a potential increase in compressive strength when Mix-2 is used; however, this difference is not statistically significant at the predetermined alpha level of 0.05. Comparing Mix-3 to Mix-1 (control mix), a slight decrease in the mean difference of -1.25 is noted. This difference is statistically significant, as the associated p-value of 0.017 is smaller than the predetermined alpha value, indicating that using Mix-3 can achieve the desired target compressive strength.

The results showed that the control mix (Mix-1) achieved 34.79 MPa, which was the highest among all the mixes. Mix-2, which had 5% BLA and 5% VPP, had a mean target strength of 35.84 MPa, which was slightly higher than the control mix. Mix-3, which had 10% BLA and 5% VPP, had a mean target strength of 33.55 MPa, which was close to the control mix. Moreover, the comparisons between Mix-2 and Mix-1 (control mix) and between Mix-3 and Mix-1 (control mix) reveal statistically significant mean differences of 1.91667 and 1.01667, respectively. These findings imply that Mix-2 and Mix-3 can replace Mix-1 for the production of C25 concrete without adversely affecting other properties of the material.

3.4.1.2 Validity of Compressive Strength Result

A valid test result refers to the average of the test outcomes obtained from three specimens taken from the same concrete batch, made and cured under standard conditions at a specific age (7, 14 and 28 days). This is based on the Indian Standard (IS 2006), requiring that the strength range between the highest and lowest individual result does not exceed 15% of the mean. There is no specific information about this in Ethiopian concrete standards.

Table 4.12 Coefficient of Variation (%) from the Mean Target Compressive Strength

Mix code	**7 day**		**14 day**		**28 day**	
	Standard Deviation	**Coefficient of Variation (%)**	**Standard Deviation**	**Coefficient of Variation (%)**	**Standard Deviation**	**Coefficient of Variation (%)**
Mix-1	0.074	0.312	0.825	2.974	0.023	0.066
Mix-2	0.562	2.500	0.606	2.209	0.603	1.683
Mix-3	0.211	0.982	0.445	1.664	1.089	3.245
Mix-4	0.390	1.882	0.828	3.370	1.077	3.460
Mix-5	0.578	3.951	0.950	4.462	1.045	3.686

An invalid test result, or a series of such results, can signal one or more issues with the testing procedure. From a quality control perspective, an invalid result should be discarded, and the reason for its invalidity must be investigated. Common causes include inadequate sampling and cube creation, cube mislabelling, cube molds not meeting tolerance standards, operator mistakes, and compression machine malfunctions.

Referring to Table 4.12, which contains details of all concrete mixtures incorporating VPP and BLA and their respective curing ages, it can be observed that the coefficient of variation value (%) is less than 15%. This suggests that the concrete mixtures were prepared in accordance with the established mix design procedures and techniques, as confirmed by the validity analysis.

4.4.2 Flexural Strength

The flexural strength of the concrete specimens was evaluated using a flexural strength testing machine. A total of 45 concrete beams were prepared for the flexural strength tests. Three beam specimens of size 100mm x 100mm x 500mm were cast for each replacement levels and subjected to curing. The test was conducted using a two-point load flexural strength testing machine at 7, 14, and 28 days of age in water tank. The specimens were subjected to increasing flexural loads until failure occurred, and the results were reported in units of MPa. To ensure reliable results, the mean value of the tests performed on three specimens from the same batch of concrete, cured under standard conditions at a specific age, was taken as the valid test result for flexural strength.

Table 4.13: Mean Flexural Strength of the Concrete with Different Replacement Percentage at 7, 14, and 28 day's age

Flexural Strength							
	7 day		14 day		28 day		Increment/ Reduction (%) of 28 day
Mix code	Samples	Mean	Samples	Mean	Samples	Mean	
Mix-1	3.178	3.078	3.267	3.163	3.87	3.684	0
	3.219		3.31		3.597		
	2.837		2.912		3.584		
Mix-2	2.702	2.897	3.106	3.229	3.917	3.868	4.99
	2.917		3.452		3.968		
	3.082		3.129		3.723		
Mix-3	2.65	2.696	3.436	3.102	3.504	3.604	-2.17
	2.793		3.382		3.747		
	2.646		3.238		3.581		
	2.48	2.63	2.97		3.248		

Mix-4	2.631		3.17	3.087	3.28	3.249	-11.80
	2.78		3.1		3.34		
Mix-5	2.518	2.562	2.86	2.82	2.761	3.108	-15.65
	2.462		3.1		3.355		
	2.78		2.51		3.208		

*Replacement levels Mix (OPC: VPP: BLA) %

Mix-1(100, 0, 0): Mix-2 (90, 5, 5): Mix-3(85, 10, 5): Mix-4 (85, 5, 10): Mix-5 (80, 10, 10)

The Table 4.13, presents the flexural strength results for different concrete mixes containing bamboo leaf ash and pumice powder as partial replacements for cement at various curing days. At 7 days of curing, the control mix (Mix-1) showed the highest flexural strength at 3.078 MPa, while the mixes with BLA and VPP replacements (Mix-2 to Mix-5) exhibited decreasing flexural strengths ranging from 2.562 MPa to 2.897 MPa. As the curing period increased to 14 days, Mix-1(control) experienced a slight improvement in flexural strength, reaching 3.163 MPa. Interestingly, Mix-2 surpassed Mix-1 with a flexural strength of 3.229 MPa, indicating the positive influence of the BLA and VPP replacements. However, Mix-3, Mix-4, and Mix-5 showed similar or lower flexural strengths compared to control mix and Mix-2 at 14 days of curing.

On 28 days of curing, Mix-1 demonstrated a significant increase in flexural strength to 3.684 MPa, surpassing the required strength of 3.5 MPa for C25 concrete as per IS Standard. Mix-2 continued to show improvement, reaching 3.868 MPa, while Mix-3 and Mix-4 had flexural strengths of 3.604 MPa and 3.249 MPa, respectively. Mix-5 exhibited the lowest flexural strength of 3.108 MPa. Overall, the results indicate that the BLA and VPP replacements influenced the flexural strength of the concrete mixes, with Mix-2 demonstrating the most favourable performance in terms of achieving higher flexural strengths at both 14 and 28 days of curing.

On the other hand, the improvement in flexural strength observed in Mix-2 at 14 and 28 days of curing can be attributed to the pozzolanic reaction between BLA, VPP, and the cementitious components. BLA and VPP contain reactive silica and alumina, which react with calcium hydroxide (CH) liberated during the hydration process, forming additional calcium silicate hydrate (C-S-H) gel. This gel contributes to the formation of a denser and more cohesive microstructure, resulting in improved inter-particle bonding and enhanced flexural strength

Table 4.13 depicts the flexural strength Increment or Reduction in percentage with respect to mix-1 (control) by different curing age. At 7 days of curing, it can be observed that Mix-2, which has a 5% replacement of cement with each of VPP and BLA, showed a reduction of 5.88% in flexural strength compared to Mix-1 (no replacement). Mix-3 exhibited a higher reduction of 12.41%, followed by Mix-4 with 14.55% and Mix-5 with the highest reduction of 16.76%. These reductions indicate that the inclusion of BLA and VPP as partial replacements for cement negatively affected the flexural strength at this early stage of curing. However, it is worth noting that Mix-2 had the least reduction among the blended mixes.

At 14 days of curing, the results indicate that Mix-2, with a 10% replacement of cement with VPP and BLA, exhibited a slight reduction in flexural strength of only 2.08% compared to Mix-1. This suggests that the inclusion of BLA and VPP at this percentage did not significantly compromise the flexural strength development of the concrete. On the other hand, Mix-3 showed a slightly higher reduction of 1.92%, indicating a slightly greater impact on flexural strength. However, these reductions can be considered relatively minor and within an acceptable range.

Moving to 28 days of curing, Mix-2 demonstrated a notable improvement in flexural strength with a positive increment of 4.99% compared to Mix-1. This suggests that the pozzolanic properties of BLA and VPP might have contributed to the long-term strength development of the concrete. In contrast, Mix-3 exhibited a reduction in flexural strength of 2.17% compared to Mix-1. This reduction indicates that at a higher replacement percentage of BLA and VPP, there may be a trade-off between the beneficial pozzolanic effects and the potential decrease in flexural strength.

Table 4.14: Flexural Strength Increment/ Reduction (%) with respect to Mix-1 (Control)

	Flexural Strength Increment/ Reduction (%) with respect to mix-1 (control) by different curing age				
Curing day	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5
7 day	0	-5.88	-12.41	-14.55	-16.76
14 day	0	-2.08	-1.92	-2.4	-10.84
28 day	0	+4.99	-2.17	-11.8	-15.63

As observed from Figure 4.6, the reductions in flexural strength for Mix-4 and Mix-5 at both 14 and 28 days of curing indicate that higher replacement percentages of BLA and VPP negatively impact the flexural strength properties of the concrete. This suggests that there is a threshold beyond which the presence of these pozzolanic materials in higher proportions hinders the development of flexural strength.

The pozzolanic materials may have different particle sizes and shapes compared to cement, which can influence the packing density of the concrete mixture. A study by Gupta et al. (2014) investigated the effect of different pozzolanic materials on the properties of concrete and found that an increase in the replacement of cement with pozzolanic materials resulted in reduced packing density, leading to lower flexural strength.

Furthermore, PP and BLA have different chemical compositions and reactivity compared to cement. This can affect the hydration process and the formation of calcium silicate hydrate (C-S-H) gel, which is responsible for the strength development in concrete. A study by Malhotra & Mehta, (1996), highlighted that the incorporation of pozzolanic materials can delay the hydration process and affect the formation of C-S-H gel, resulting in reduced flexural strength.

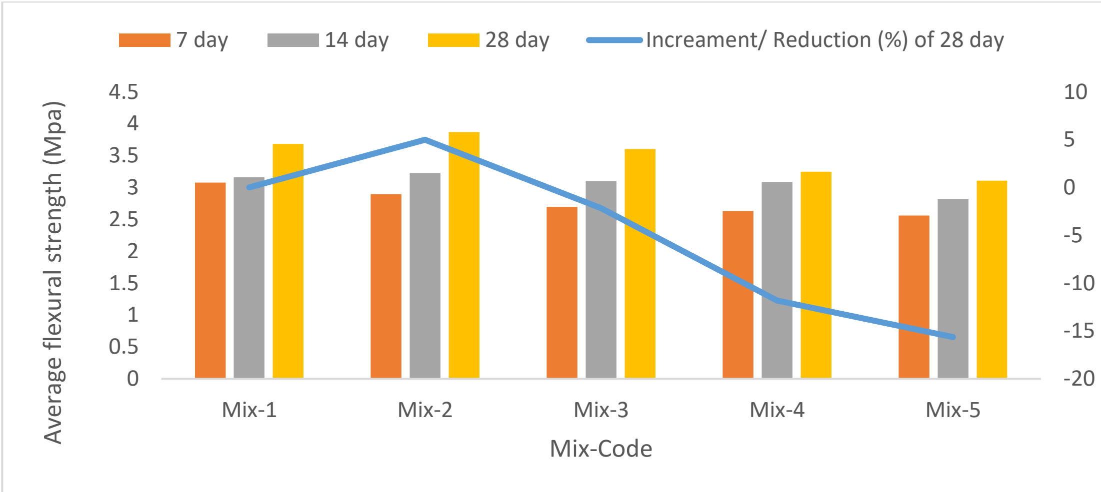

Figure 4.6: Flexural Strength Results

3.4.1.1 Validity of Flexural Result

Table 4.15 Coefficient of Variation (%) from the Mean Flexural Strength

Mix code	7 day		14 day		28 day	
	Standard Deviation	**Coefficient of Variation (%)**	**Standard Deviation**	**Coefficient of Variation (%)**	**Standard Deviation**	**Coefficient of Variation (%)**
Mix-1	0.210	6.813	0.218	6.906	0.162	4.384
Mix-2	0.191	6.570	0.193	5.992	0.129	3.341
Mix-3	0.084	3.106	0.102	3.053	0.124	3.439
Mix-4	0.150	5.703	0.101	3.295	0.047	1.420
Mix-5	0.170	6.563	0.297	10.509	0.309	9.954

A valid test result refers to the average of the test outcomes obtained from three specimens taken from the same concrete batch, made and cured under standard conditions at a specific age (7, 14 and 28 days). This is based on the Indian Standard (IS 2006), requiring that the strength range between the highest and lowest individual result does not exceed 15% of the mean. There is no specific information about this in Ethiopian concrete standards.

Referring to Table 4.15, which contains details of all concrete mixtures incorporating PP and BLA and their respective curing ages, it can be observed that the coefficient of variation value (%) is less than 15%. This suggests that the concrete mixtures were prepared in accordance with the established mix design procedures and techniques, as confirmed by the validity analysis

4.5 The Water Absorption and Acid resistance of PP and BLA Concrete

4.5.1 Water Absorption

Table 4.16: Percentage Water Absorption of VPP and BLA Blended Cement Concrete

Average water absorption @ 28 curing day			
Mix code	weight of oven dry(Kg)	Weight submerged in water(Kg)	Water absorption %
Mix-1	7.85	8.165	4.01
Mix-2	7.675	7.97	3.84
Mix-3	7.675	8.145	6.12
Mix-4	7.715	8.295	7.51
Mix-5	7.61	8.38	10.11

*Replacement levels Mix (OPC: VPP: BLA) %

Mix-1(100, 0, 0): Mix-2 (90, 5, 5): Mix-3(85, 10, 5): Mix-4 (85, 5, 10): Mix-5 (80, 10, 10)

Water absorption is a crucial parameter used to assess the durability and moisture susceptibility of concrete. It quantifies the amount of water absorbed by the concrete under ASTM C1585 .The Table4.16, depicts the water absorption percentages after 28 days of curing for five different concrete mixes, identified as Mix-1(control mix) to Mix-5 at different percentage of replacement. These percentages provide valuable insights into the water absorption characteristics of each mix.

Starting with Mix-1, it shows a water absorption percentage of 4.01%. This suggests that the concrete in control Mix-1 has the ability to absorb approximately 4.01% of its weight in water after 28 days of curing.

Moving on to Mix-2, it exhibits a slightly lower water absorption percentage of 3.84%, indicating a relatively lower tendency for water absorption compared to other mixes. The decrease in water absorption might be due to the preliminary filling of gaps by PP and BLA concretes, which subsequently function as a water-resistant barrier. This study conforms to the previous research (Umoh & Odesola, 2015).

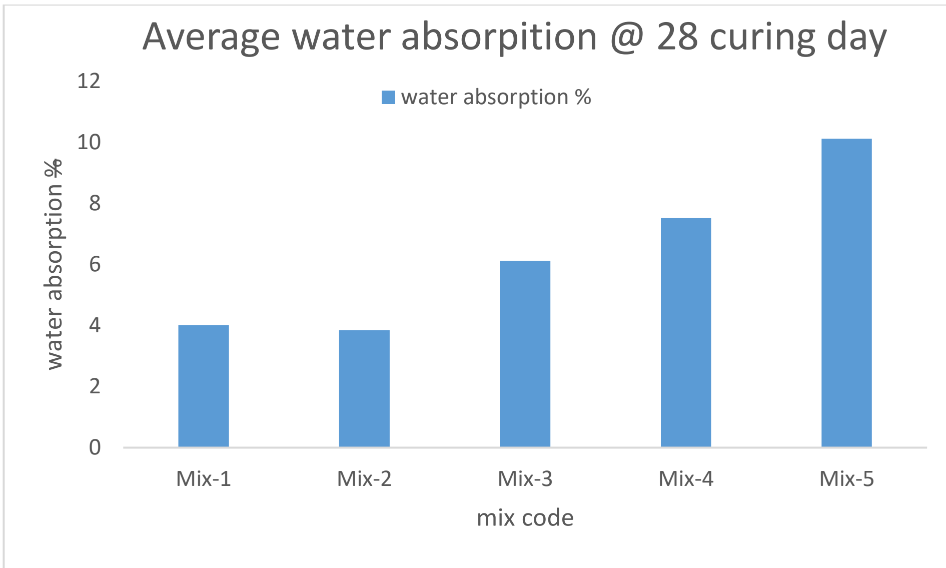

Figure 4.7: Water Absorption at 28 Curing Day of Different Replacement Level

However, Mix-5 stands out among the listed mixes with the highest water absorption percentage as seen from figure 4.7 of 10.11%. This suggests that the concrete in Mix-5 has a relatively higher tendency to absorb water compared to the other mixes. This increase in water absorption of PP and BLA mixtures refers to the increase in the porous volume of mortar mixtures and at higher levels of substitution, there was an insufficient quantity of calcium hydroxide to react with the excess PP and BLA, Thus creating pores in the mixture and thereby increasing the water absorption, these findings are in agreement with what was reported in previous works on Table 2.10, use of fine pozzolanic substances and effect on water absorption.

4.5.2 Acid resistance

In this study, the concrete samples were exposed to 5% sulfuric acid for a duration of 30 days, following a 7-day curing process in water. The decrease in compressive strength was evaluated using the strength deterioration factor (Hewayde et al., 2007) by comparing it to a control exposure containing 0% H_2SO_4.

Table 4.17 Compressive Strength for Concrete Exposed to 0% and 5% of H_2SO_4

	Cured for 37 day in water with 0% H_2SO_4		Cured for 30 day in 5% H_2SO_4	
Mix-Code	Compressive Strength (N/mm)	Strength deterioration Factor (%)	Compressive strength(N/mm)	Strength deterioration Factor (%)
Mix-1	36.64	0	23.89	33.34
Mix-2	34.99	0	25.55	26.55
Mix-3	32.75	0	30.33	9.59
Mix-4	31.82	0	27.66	11.12
Mix-5	29.36	0	24.6	13.2

*Replacement levels Mix (OPC: VPP: BLA) %

Mix-1(100, 0, 0): Mix-2 (90, 5, 5): Mix-3(85, 10, 5): Mix-4 (85, 5, 10): Mix-5 (80, 10, 10)

Tables 4.17, show the compressive strength of PP and BLA mixed cement concrete when subjected to a 5% concentration of sulfuric acid (H_2SO_4). Sulphuric acid has a strong and damaging effect on concrete, exhibiting two different forms of behaviour. Firstly, as an acid it corrodes the calcium hydroxide and calcium silicate hydrate products present in concrete (Shetty, 2006). Secondly, it acts as a sulphate which attacks the calcium aluminate hydrate component (Neville & Brooks, 2010; Shetty, 2006).

5% sulphuric acid concentration had the maximal effect on the blended cement concrete (Table 4.15). At 30 days of exposure, the control replacement suffered the greatest strength reduction of 33.34% while replacement Mix-3 had the least strength reduction of 9.59%. Replacement Mix 2, 4 and 5 had percentage strength reduction of 26.55%, 11.12% and 13.2% respectively

Figures 4.8 show the resistance of each replacement level to sulphuric acid attack for 5% acid concentration increases with percentage replacement of PP and BLA increases. Replacement mix-3 performed best and replacement mix 2, 4 and 5 provided better resistance than the control. Hence, it is suggested that when concrete is subjected to extreme acid or sulfate conditions, using Mix-3 (85% cement, 10% PP, 5% BLA) as a replacement for OPC in concrete can lead to improved durability and similar strength. The compressive strength of the concrete cubes was increasing. With the increase in compressive strength of the concrete cubes, the deleterious ettringite generated by the sulfuric acid reaction continued to occupy the available pores within the cubes (Chen et al., 2013)

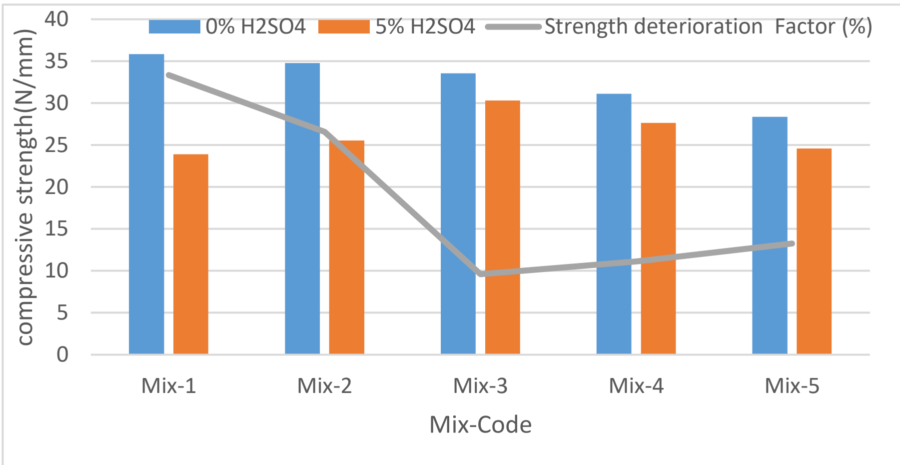

Figure 4.8: Variation of Compressive Strength with Exposure Period of Concrete Exposed to 0% and 5% H_2SO_4

4.5.3 Microstructure of concrete

4.5.3.1 Scanning Electron Microscopy (SEM)

Microstructural observation of mixes without blending of PP and BLA and with 5% PP and 5% BLA through SEM analysis can be seen in the Figure 4.9. Control mix and Mix-2 were investigated using SEM due to the maximum compressive strength, flexural strength and better workability observed at Mix-2 (90%, 5%, 5%) replacement versus other replacement percentages. SEM images are taken after a prolonged curing period of 28 days. Each mix was explored under (x1500) magnification to investigate the microstructure of the concrete. Calcium hydroxide is identified by its relative brightness and hexagonal habits in the concrete (Maroliya, 2012). In the control mix, a narrow and bright structure with crystalline formation was observed that could be CH, as shown in the Figure 4.9(a).

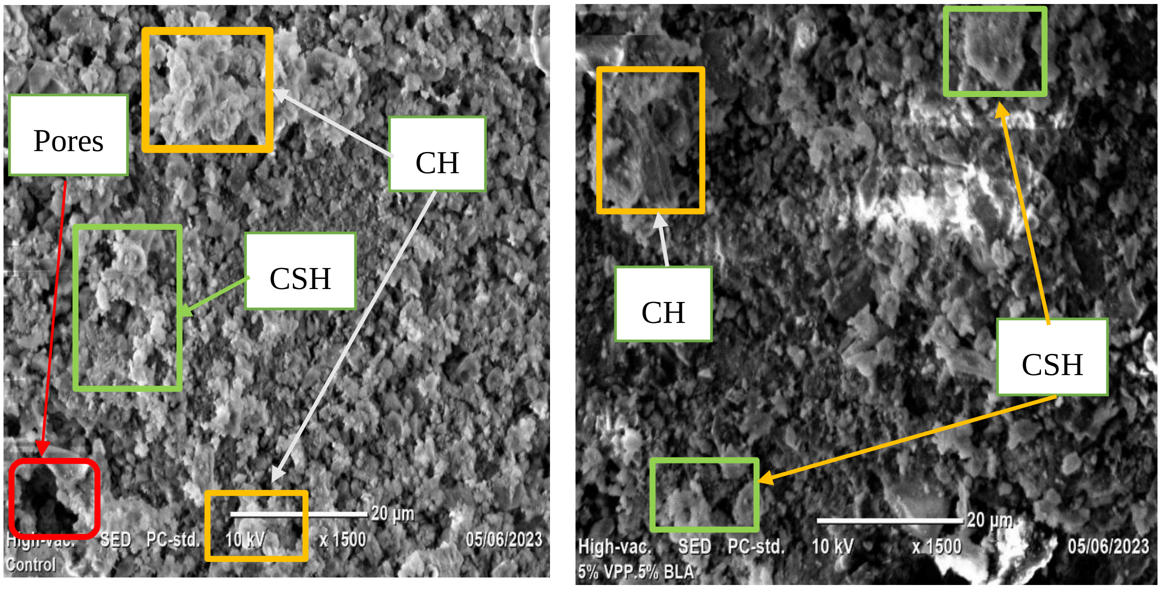

Figure 4.9: SEM Images of at 1500 Magnification: a) Control mix and b) Mix-2 (90, 5, 5)

While PP and BLAs pore structure is becoming more refined, it is still dense at Mix-2 (90, 5, 5) replacement, as shown in Figure 4.9(b). The mix-2 replacement could be seen, as voids on the surface due to improved hydration and a high occurrence of calcium silica hydrate (C-S-H) gels on the surface, as short noted by the networked fiber structure and the filler effect of BLA in the concrete(Türkmen et al., 2003). This could account for the maximum compressive strength achieved at this mixed level. The formation of amorphous C-S-H gel is primarily due to secondary hydration caused by addition of PP and BLA's pozzolanic properties (Lemonis et al., 2015). The reduction in CH content caused by the pozzolanic reaction of ash particles is the most significant difference between control concrete with 5% of PP and BLA concrete.

4.5.3.2. X-ray diffraction (XRD)

X-ray diffraction (XRD) is a powerful technique for identifying the crystalline phases in a material. The XRD pattern of concrete is a superposition of the patterns of its constituents. By irradiating the concrete samples with X-rays and measuring the angles and intensities of the diffracted rays at 2θ. The main peak that appear in the XRD pattern of concrete is CH, which is a by-product of cement hydration. CH has a hexagonal structure and produces a strong peak at 18.1° 2θ. Another important peak compound appear in the XRD pattern of concrete is usually C–S–H, which is the main binding phase in cement paste. C–S–H has a nanocrystalline structure that produces a broad hump in the low-angle region of the XRD pattern, typically between 10° and 35° 2θ

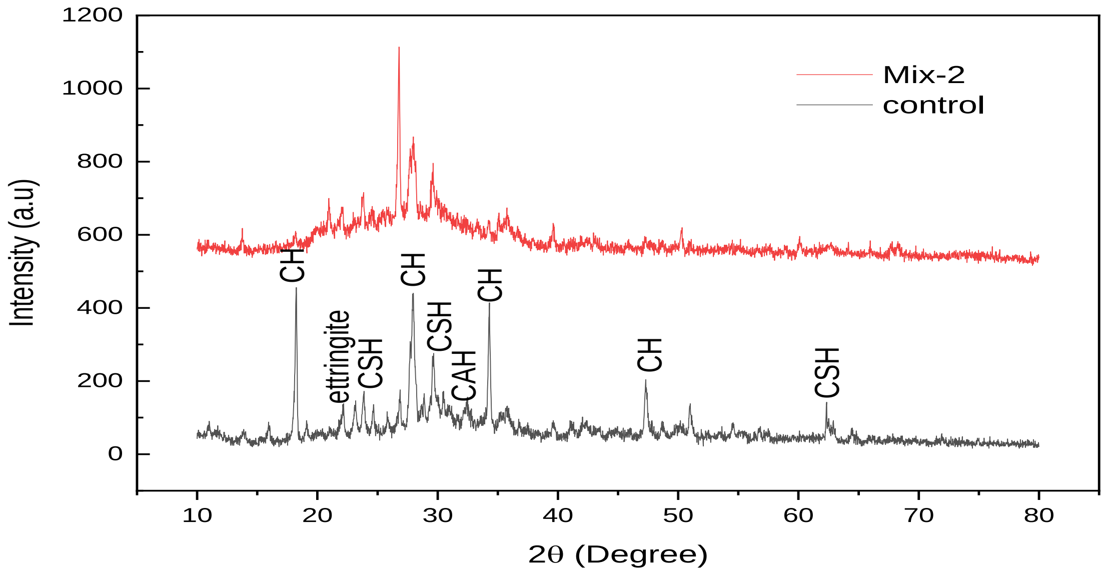

Figure 4.10: XRD Pattern: (a) Conventional Concrete; (b) Mix-2(90%cement, 5%VPP, 5%BLA)

The XRD patterns of the concrete samples are shown in Figure 4.10. The peaks indicate the presence of different compounds and their positions correspond to the 2θ angles. The control concrete shows peaks at 2θ = 18.24°, 27.98°, 34.3°, 47.3°, 51°, and 62.32°, which are attributed to calcium hydrate (C-H), the main binding phase in hydrated cement (Moneghan, 2020; Tavares et al., 2020; Yaseen et al., 2023). The concrete with (BLA) and (VPP) as partial replacement of cement shows similar peaks but with lower intensities, indicating a lower amount of C-S-H formation due to the dilution effect of the SCMs (Yaseen et al., 2023). However, some new peaks are also observed at 2θ = 26.6°, 28.1°, 31.8°, and 46.7°, These peaks correspond to calcium aluminate hydrate (C-A-H), calcium carbonate (CaCO3), ettringite, and calcium hydroxide (Ca(OH)2), respectively (Tavares et al., 2020). These peaks indicate that the SCMs have reacted with the cement and water to form additional hydration products that can improve the strength and durability of the concrete.

4.6 Cost Comparison between Convectional and PP and BLA blended concrete

Majority of the cement plants in Ethiopia use a vertical shaft kiln (VSK) for their clinker production The use of such kind of obsolete technologies not only consumes a high amount of energies but also have an environmental impact (Mulatu et al., 2018). All input data for evaluation of economic implication of concrete made by blending of VPP and BLA for this study is based on Mugher cement in puts data(Beressa & Saradhi, 2021), since they use similar kiln technology for production of Cement with national cement. Manufacture has three fundamental stages: preparation of feedstocks, production of clinker, and preparation of cement (Gursel et al., 2014).

Table 4.18: Input Raw Material and Energy for Production of OPC, BLA, and VPP per ton

Input item	for OPC production	For BLA production	For VPP production	Remarks
Input raw material (kg/ ton-clinker)				
Lime stone	1440	Only bamboo leaf is required that is waste in our environment	Natural available volcanic pumice	Remarkable save of Input raw material
Clay	120			
Sand stone	50			
gypsum	70			
Input Energy intensity (MJ/ ton-clinker)				
electricity	345.51	0.41*345.51=142.96	From the total thermal and Electricity use in cement production clinker consumes 90% and reaming 10% is raw meal preparation and finish grinding (Gursel et al., 2014), since VP need only grinding it use 10% of total energy.	
Desil fuel	167.13	OPC (1450C) **BLA (600C)** **Ratio of BLA to OPC is 0.41**		
Heavy fuel oil	26.66			
Imported coal	2287.83			
Local coal	842.33			

Total energy	3669.46MJ/ton	142.96MJ/ton	0.1*3669.46= 366.94MJ/ton

The Mugher cement factory's energy usage intensity was found to be 3.67 GJ/ton, with greenhouse gas emissions at 0.84 tons of CO2-equivalent/ton of Ordinary Portland cement (OPC) (Beressa & Saradhi, 2021). The study examined Ethiopian cement production by performing impact analyses on raw material extraction, transportation, and manufacturing stages. The production of OPC followed the CEMI-42.5 standards, consisting of 95% clinker and 5% gypsum, and included energy consumption data for activities such as raw meal preparation, pyro-processing, finish grinding, and cement packing. In the Mugher cement factory, four energy sources were utilized: electricity, imported coal, local coal, and heavy fuel oil (Beressa & Saradhi, 2021). Input raw material and Energy for production of OPC, BLA, and VPP per ton show in Table 4.18.

As Table 4.18 shows that the production of VPP and BLA has Remarkable save of Input raw materials compared to input raw material required to produce OPC and the production of OPC require total energy input of 3669.46MJ/ton while the VPP and BLA needs 36.69MJ/ton and 142.9MJ/ton that is much lower than the OPC per ton production. The OPC manufacture produces 841.68 Kg CO_2 eq / ton-product of global warming potential whereas VPP and BLA produces 84.6 and 172.5 Kg CO_2 eq / ton-product. Generally, this show there is much more improvements in terms of saving input raw materials and input energy and reduction of global warming while replacing the VPP and BLA as partial replacement of cement in concrete production.

The process of calcination contributes to 50% of the overall CO_2 emissions in cement production, while the combustion of fossil fuels is responsible for 40%. The final 10% of emissions stems from energy consumption during the preparation of raw materials and the finishing of grinding processes (Global, 2020).

Table 4.19: CO_2 Emissions of OPC, BLA, and, VPP kg CO_2 eq / ton-product

Impact Category	Impact indicators	Unit	OPC	BLA	VPP
Global warming potential	CO_2 CH_4 N_2O	Kg CO_2 eq / ton-product	841.68	calcination accounts for 50% of total cement CO_2 emissions **841.68*0.41=345.08/2 172.5**	10% of CO_2 emissions raw meal preparation and finish grinding **0.1*841.68= 84.16**

A) The cost for 1 m^3 of conventional concrete was estimated based on the current Market price on April 30, 2023

Producing 1 cubic meter (m) of conventional concrete comprises several components, for which the associated costs must also be taken into account as shown in Table 4.20. For this research, 7.52 bags of cement and 6216.87 ETB are needed; 0.88086 m^3 of fine aggregate requires 1256.98579 ETB; 1.00815 m^3 of coarse aggregate comes out to 1260.1875 ETB; and a quantity of water that is equal to 0.229 m^3 requires 4.58 ETB in total cost of materials amounts to 8738.62 ETB this is based on the C-25 normal concrete with mix Ratio of 1:2.337: 2.675.

Table 4.20: Cost Analysis of Conventional Concrete

Cost for 1 m3 of conventional concrete				
Types of material	Unit	Quantity	Rate	Cost (ETB/m3)
Cement	2*50Kg bag	7.52	1650	6216.87
Fine aggregate	M^3	0.88086	1427	1256.98
Course aggregate	M^3	1.00815	1250	1260.18
Water	M^3	0.229	20	4.58
Total				**8738.62 ETB**

B) Total cost of one cubic meter of concrete with 5% pumice powder and 5% bamboo leaf ash

PP and BLA cost was exclusively calculated in terms of labor costs during material collection and burning of bamboo leaf ash and grinding of volcanic pumice powder and also the cost of electric energy required by ball miller and furnace chamber were also considered.

One collector was employed for two days with each day requiring 1 hour for collecting Pumice and BL. The rate of the collector's labor was 30 ETB per hour resulting in a total labor cost of 60 ETB. Additionally, one lab assistant worked 3 hours every day for two days to facilitate the production of PP and BLA. At an hourly rate of 40 ETB, this resulted in a total labor cost of 240 ETB. The total cost to produce 100 kg of VPP and BLA was 300 ETB.

Table 4.21: Illustrates Costs Incurred During Collection and Production of PP and BLA.

Collection and production cost per 100 Kg					
Item	Quantity	Working day	Working hour	Rate per hour	Amount(ETB)
During collection both PP and BLA	1	2	1	30	60
During production both PP and BLA	1	2	3	40	240
Total					**300.00 ETB**

Analyzing 1 kg of bamboo leaf via calcination in the Standard Chamber Furnaces CWF, with a capacity of up to 1300°C at 600 C requires 3 kW for two hours. Additionally, producing pumice in powdered form through a ball miller requires the powering of 0.25 kW. In Ethiopia in April 2023, businesses are charged 1.22 birr per kilowatt hour (kWh), which also includes components such as distribution costs and taxes portioned towards the electricity bill. The Table 4.23 presents the total cost of 1 Kg of VPP and BLA including collection, production and energy are 3.03birr and 3.366 birr per Kg.

Table 4.22: Estimated Total Energy per 1Kg of PP and BLA

Item	Quantity	Power(KW)	Rate(ETB)	Amount (ETB)
PP	Ball miller	0.25	1.22	0.305
BLA	Standard Chamber Furnaces	3	1.22	3.66

Table 4.23: Estimated Total Cost of Materials for Concrete with 5% of PP and 5% of BLA

Types of material	Unit	Quantity	Rate	Cost (ETB/m3)
5%PP	Kg	18.83	3.030	57.064
5%BLA	Kg	18.83	3.366	63.381
Cement	2*50Kg bag	7.14	1650	5890.5
Fine aggregate	M^3	0.88	1427	1256.98
Course aggregate	M^3	1.008	1250	1260.18
Water	M^3	0.229	20	4.58
Total				**8532.68 ETB**

The estimated total cost of one cubic meter of concrete with 5% volcanic pumice powder (PP) and 5% bamboo leaf ash (BLA) decreases by 205.93 ETB compared to concrete without these blend materials, this confirm with (Aderibigbe & Ojobo, 1982; Mohamed et al., 2022). It's important to consider that these cost implications are based on research-scale production. If PP and BLA were produced on a larger scale, similar to cement mass production, their costs could potentially be reduced. Furthermore, the benefits of conserving non-renewable materials, saving energy, and reducing CO2 emissions outweigh the cost implications of utilizing bamboo leaf and volcanic pumice as replacements for cement in concrete production, even considering the research-scale production costs (Ince et al., 2020; Mohamed et al., 2022). Therefore, as the production scales up and becomes more efficient, the cost-effectiveness and environmental advantages of incorporating PP and BLA into concrete would become more prominent.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research study concludes based on the major findings of the study. The following conclusions are made.

- ✓ PP and BLA are suitable materials as pozzolan based on their meeting the minimum requirements stipulated as per ASTM C 618 and the chemical characterization test classify BLA fall under class F pozzolans while PP is a class N pozzolan.
- ✓ The addition of PP and BLA in blended cement concrete reduced its workability, hence, more water is required to make a concrete workable which leads to strength reduction. BLA required more water than PP.
- ✓ On the 28th day, the compressive strength of concrete made with blend of cement by PP and BLA at Mix-2 and mix-3 attains the target mean strength (33.5Mpa) and mix-2 having greater compressive strength than all other mix including control mix, Any further increase beyond Mix-3 replacement would lead to strength reduction.
- ✓ The flexural strength of concrete made with partial replacement of cement by PP and BLA at 28 curing day has higher flexural strength than all other mix including control mix that satisfied the required strengths 3.5Mpa for C25 as per IS 5860 - 2000
- ✓ The water absorption of the PP and BLA blended concrete was lower than the control (4.01%) at mix-2 (3.84%), However, at higher levels replacements mix 3 (6.12%), mix 4 (7.51%) and mix 5 (10.11%) water absorption where observed higher than the control due to pores structure of PP and finer particles of BLA.
- ✓ Incorporation of VPP and BLA in concrete improved its resistance to sulphuric acid attack and Mix-3 (85% cement, 10% PP, 5% BLA) had the least strength reduction of 9.59%. Because PP has high Al_2O_3 (18.13%).While control mix has 33.34% strength reduction.
- ✓ The cost-effectiveness and environmental advantages of incorporating PP and BLA into concrete more prominent when compared to conventional concrete.

5.2 Recommendations

From the conclusions made above, the following recommendations are made.

- ✓ PP and BLA can be used and commercialized as pozzolans since they exist as waste in our environment. This approach can decrease the dependence on ordinary Portland cement, resulting in cost savings.
- ✓ Chemical resistant concrete can be achieved with the use of BLA and PP. Concrete exposed to severe acid/sulphate environment, OPC in concrete can be replaced by Mix-3 (85% cement, 10% PP, 5% BLA) for better durability with comparable strength.
- ✓ Since PP has a high alkali content, the petrographic analysis should be performed before use to examine the aggregate's alkali-silica characteristic.
- ✓ Other durability parameters and strength properties such as tensile and shear can be studied for the ternary combination of BLA, PP and OPC in concrete.

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Adama, Ethiopia

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APPENDEX

APPENDEX A: Test producer for concrete composing material

APPENDEX A1: Oxide composition of volcanic pumice powder (VPP)

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name:- Haris Hassen Adem
Sample type :- VPP (Powder)
Sample Preparation: -200 Mesh
Date Submitted:- 22/03/2023

Issue Date:-03/04/2023
Request No:- GLD/RQ/1040/23
Report No:- GLD/RN/1641/23
Number of Sample:- One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.
Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
HH-2	61.06	18.13	5.40	2.12	0.34	3.90	4.04	0.16	0.32	0.10	0.63	4.68	500 gm

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

Analysts
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Geochemical Laboratory Desk — Page 2

APPENDEX A2: Oxide composition of Bamboo leaf ash (BLA)

	GEOLOGICAL INSTITUTE OF ETHIOPIA	**Doc. Number: GLD/F5.10.2**	**Version No: 1**
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	**Complete Silicate Analysis Report**	**Effective date:**	**Nov. 2022**

Customer Name:- Haris Hassen Adem
Sample type :- BLA (Powder)
Sample Preparation: -200 Mesh
Date Submitted:- 27/03/2023
Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.
Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Issue Date:-03/04/2023
Request No:- GLD/RQ/1040/23
Report No:- GLD/RN/1640/23
Number of Sample:- One (01)

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
HH-1	68.12	4.92	1.36	6.02	1.52	0.66	0.16	0.12	1.46	0.01	2.39	14.25	220gm

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

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Geochemical Laboratory Desk Page 2

APPENDEX A3: Test producer for Normal Consistency Test for Cement, VPP, BLA

1. 400 grams of cement were measured.

2. Water amounting to a percentage of cement (22-30%) was added to cement and mixed.

3. Within 3-5 minutes, properly combine the paste. Gauging time is the time it takes to get cement paste after adding water.

4. Filled the paste in the Vicat mold appropriately, and removed any surplus paste with a trowel.

5. Then, set the Vicat mold on the glass plate, making sure the plunger lightly touches the surface of the Vicat mold.

6. Allow the plunger to sink into the test mold after it has been released.

7. Take note of the plunger's penetration from the bottom of the mold as indicated on the scale.

8. Repeat the experiment with varied percentages of water until the Vicat apparatus scale reading is between 5-7 mm.

9. The water added is right and the penetration is between 5 mm and 7 mm.

APPENDEX A4: Test producer for Specific gravity test

Procedure:

1. Dry the flask carefully and fill with kerosene or naphtha to a point on the stem between zero and 1 ml.
2. Record the level of the liquid in the flask as initial reading.
3. Put a weighted quantity of cement (about 60 g) into the flask so that level of kerosene rise to about 22 ml mark, care being taken to avoid splashing and to see that cement does not adhere to the sides of the above the liquid.
4. After putting all the cement to the flask, roll the flask gently in an inclined position to expel air until no further air bubble rise3s to the surface of the liquid.
5. Note down the new liquid level as final reading

APPENDEX A5: Test producer for Silt Content

1) The researcher took a graduated cylinder having a capacity of 1000 ml.
2) 300 ml of sand was poured into the cylinder.
3) Approximately 3/4 of the jar was filled with water.
4) The jar was shaken vigorously for about a minute.
5) The jar was left for an hour to allow the silt to settle on the layer of sand.
6) The amount of fine forming a separate layer on the top was measured.
7) The silt content was calculated based on Equation 3.1.

Silt content = (A)/ (B) x 100% ………. Equation 3.1

Where

A = Silt deposited above the sand

B = Amount of clean sand

APPENDEX A6: Test producer for Grading Fine Aggregate

1. The researcher weighted a sample of 2 kg of fine aggregates.

2. The sample was quartered.

3. From the quartered sample, weighing 500 g,

4. The empty sieves were weighted, and the data was recorded properly.

5. The pan was placed on the bottom and the other sieves were put on the pan with increasing opening sizes of the sieves.

6. Placed the 500 g of sample on the top of the sieves (having a larger opening size).

7. Smashed the sample for about 10 minutes in a sieve shaker.

8. Each sieve, together with the aggregate retained on it, was measured and the weight retained on each sieve was calculated.

9. The gradation chart was filled in and the fineness modulus was computed.

Fineness modulus = Cumulative retained by mass / 100 …..Equation 3.2

APPENDEX A7: Test producer for Unit Weight of Fine Aggregate (UWFA)

1. Fill the measure one-third full and level the surface with your fingers. Rod the layer of aggregate with 25 strokes with the tamping rod evenly distributed over the surface. Then fill the measure to two-thirds capacity, level and rod as before. Finally, fill the measuring cup to overflowing and rod as above.

2. Level the surface of the aggregate with your fingers in such a way that any slight projections of the large pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

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

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

X: Fine aggregate plus cylinder weight = 6,674 g.

Y: Weight of empty cylinder = 4,734 g

V: Cylinder volume = 0.001375 m3

UWFA = X –Y/ V ……………………………………………………..Equation 3.3

APPENDEX A8: Test producer for Specific Gravity and Water Absorption of Fine **Aggregate**

Procedure:

1. The S.S.D sample was weighted at 500 g.

2. Partially fill the Pycnometer with water and put 500 g of saturated surface dry aggregates into the Pycnometer.

3. Then they filled the pycnometer with additional water to fill it to 90% of its capacity.

4. The pycnometer was rolled and inverted to eliminate all air bubbles.

5. Place the Pycnometer in a water bath at 23 °C for an hour.

6. Brought the water level in the pycnometer to its calibrated capacity.

7. Then, the total weight of the pycnometer, specimen, and water was measured.

8. The researcher removed the fine aggregate from the pycnometer, dried it to a constant weight at 105 °C, cooled it in room temperature air for one hour, and measured it.

9. The weight of the pycnometer filled to capacity with water was determined at 23°C, and the following data were recorded:

APPENDEX B: Mix design for C-25 normal concrete

Step 1: Calculating the required mean compressive strength based on characteristic strength of 25 Mpa which gives; fck = f'ck + 8.5 = 25 + 8.5 = 33.5 Mpa

Table 3.1 Average Compressive strength Conversion

Characteristics strength (f'ck, Mpa)	Mean strength (fck, Mpa)
<21	F'ck + 7
21-35	F'ck +8.5
>35	1.1 x F'ck + 5

Step 2: Determining the minimum cement content

From a durability point of view, the minimum cement content was taken as 300 Kg/m^3.

Step 3: Choose a slump Value

For C-25, a concrete slump of 2-10 cm is recommended

Step 4: Choose the maximum aggregate size.

For higher compressive strength, a reduced maximum size aggregate was selected, In this case, the maximum size aggregate was 20, and the nominal size aggregate was 19 mm.

Step 5: Mixing water and air content determination

The amount of water per unit volume of concrete required for required slump value is dependent on aggregate grading, amount of entrained air, and maximum size aggregate.

Table 3.2 Mixing water for different slump and Maximum size aggregate

Slump (cm)	Water (**Kg/m^3**) of concrete for indicated maximum size aggregate in mm							
	10	12.5	20	25	40	50	70	150
				Non-air entrained concrete				
2-10	205	200	185	180	160	155	145	125
8-10	225	215	200	195	175	170	160	140
15-18	240	230	210	205	205	185	180	170
Amount of entrapped Air (%)	3	25	2	15	1	0.5	0.3	0.2

In table 3.2 above, with a slump of 2-10 cm and a maximum size aggregate of 20 mm, the water content becomes 185 Kg/$\boldsymbol{m^3}$ and 2%, or 20 liters and entrapped air.

Step 6: Determine the water cement ratio

In a concrete mix, the water-cement ratio is the ratio of the weight of water to the weight of cement.

Table 3.3 Average Compressive Strength with water Cement Ratio

Compressive strength at 28 days (Mpa)	Water cement ratio (by mass)
45	0.38
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

The ACI table above can't provide the exact value of the water-cement ratio for a 33.5 MPa mean strength. This can be calculated via interpolating the above and below values as follows: 33.5 MPa.

35 0.47 by interpolation, $\frac{33.5-35}{30-35} = \frac{x-0.47}{0.54-0.47}$

33.5 x by solving the above equation, x=0.491

30 0.54 Hence, the minimum water cement ratio is 0.491

Step 7: Determination of mix cement content

$$\text{cement content} = \frac{\text{water content}}{\text{water cement ratio}}$$

$$= \frac{185}{0.491}$$

= 376.78 Kg/$\boldsymbol{m^3}$

Snice the mix cement content is higher than the minimum cement it’s OK

Step 8: Estimating the Bulk volume per unit volume of concrete

This depends on the fineness modulus, which is 2.89, and the maximum size aggregate of 20 mm.

Table 3.4 Volume of coarse aggregate per unit volume of concrete

Maximum size of aggregate	Volume of coarse aggregate per volume of concrete for different fitness modules		
	2.6	2.8	3.0
10	0.50	0.46	0.44
12.5	0.59	0.55	0.53
20	0.66	0.62	0.60
25	0.71	0.67	0.65
40	0.76	0.72	0.70
50	0.78	0.74	0.72
70	0.81	0.77	0.75
150	0.87	0.83	0.81

The bulk volume of dry rodded aggregate was not found in the above table directly. It can be calculated by interpolation snice the fitness modulus of 2.78 is found between 2.6 and 2.8 for a 20 mm maximum size aggregate.

2.8 0.62 by interpolation, $\frac{2.8-2.89}{0.62-x} = \frac{2.89-3.0}{x-0.60}$

2.89 x by solving the above equation, x=0.602

3 0.60 Hence, the dry volume of aggregate per volume of

Concrete is 0.611

Step 9: Calculate the weight of coarse aggregate (WCA) per $\boldsymbol{m^3}$ of concrete.

WCA= bulk volume x bulk density of coarse aggregate

WCA= 0.611*1650

= 1008.15

Step 10 : Determine the solid volume of coarse aggregate

Solid volume of coarse aggregate = WCA/Specific gravity

= 1008.15/2.83

= 356.236 Kg/m^3

Step 11: Calculating the solid volume of cement, water, and air

Volume of cement (VC) = Weight of cement / Specific gravity of cement

= 376.78/3.15

= 119.612 Kg/m^3

Volume of Water (VW) = 185 Kg/m^3

Volume of Air (VA) = 20 Kg/m^3

Step 12: Calculating Volume of sand

Solid volume of Sand = 1000 **-** (VCA + VC + VW + VA)

= 1000 – (356.236 +119.612 + 185 + 20)

= 1000 – 680.848

=319.152 Kg/m^3

Solid Weight of sand = dry volume * specific gravity

= 319.152 * 2.76

= 880.859 Kg/m^3

Step 13: Adjustment for moisture in the aggregate

Actual moisture content of fine aggregate (Am) = 0.02

Fine aggregate water absorption (WA) = 2.08

Correction factor = $\frac{100+Am}{100+WA} = \frac{100+0.02}{100+2.08}$ = 0.97942

Actual moisture content of coarse aggregate (Am) = 0.01

Coarse aggregate water absorption (WA) = 1.6

Correction factor = $\frac{100+Am}{100+WA} = \frac{100+0.01}{100+2.7}$ = 0.9738

Amount of fine aggregate = 880.859*0.97942

= 862.713 kg/ m^3

Amount of fine aggregate water absorbed = 862.713-880.859

= -18.1454kg/ m

Amount coarse aggregate = 1008.15 * 0.9738

= 981.736 kg/ m^3

Amount of water absorbed by coarse aggregate = 981.736- 1008.15

= -26.413kg/ m^3

Amount of water needed to be add is = 18.145+ 26.413

= 44.558 kg/ m^3

Fine aggregate = 880.859 Kg/m^3

Coarse aggregate= 1008.15 kg/ m^3

Amount of water added = 185 + 44.558

= 229 kg/ m^3

Water	229 Kg/$\boldsymbol{m^3}$
Cement	376.78 Kg/$\boldsymbol{m^3}$
Fine aggregate	880.859 Kg/$\boldsymbol{m^3}$
Coarse aggregate	1008.15 Kg/$\boldsymbol{m^3}$

The above result in the mix design ratio can be expressed in Tbale 3.6 below.

Table 3.6 Mix Ratio for C-25 Concrete Grade

Ingredients	Cement	Fine aggregate	coarse aggregate
Amount/$\boldsymbol{m^3}$	376.78/376.78	880.859/376.78	1008.15/376.78
Ratio	1	2.337	2.675

Based on the mix proportion given above, the quantity of each concrete ingredient can be calculated for one cube standard mold.

Wet volume for 1 mold = length x width x height

=0.15 x 0.15 x 0.15= 0.00375 m^3

Dry volume = wet volume x 1.55

= 0.00375 m^3 x 1.55

= 0.0058125 m^3

Sum of ratio = 1 +2.337 + 2.675 = 6.012

Weight of the cement = $\frac{1}{sum\ of\ ratio}$ x dry volume x unit weight of the cement

= $\frac{1}{6.012}$ x 0.0058125 x 1440

= 1.3922 kg

Weight of FA = $\frac{2.337}{sum\ of\ ratio}$ x dry volume x unit weight of FA

= $\frac{2.337}{6.012}$ x 0.0058125 x 1515.5

= 3.424 kg

Weight of GA = $\frac{2.678}{sum\ of\ ratio}$ x dry volume x unit weight of GA

= $\frac{2.678}{6.012}$ x 0.0058125 x 1650

= 4.272 kg

Based on the mix proportion given on table 3.6, the quantity of each concrete ingredient can be calculated for one beam standard mold.

Wet volume for 1 mold = length x width x height

=0.5 x 0.1 x 0.1= 0.005 m^3

Dry volume = wet volume x 1.55

= 0.005 m^3 x 1.55

= 0.00775 m^3

Sum of ratio = 1 +2.337 + 2.678 = 6.012

Weight of the cement = $\frac{1}{sum\ of\ ratio}$ x dry volume x unit weight of the cement

= $\frac{1}{6.012}$ x 0.00775 x 1440

= 1.856 kg

Weight of FA = $\frac{2.337}{sum\ of\ ratio}$ x dry volume x unit weight of FA

= $\frac{2.337}{6.012}$ x 0.00775 x 1515.5

= 4.565 kg

Weight of GA = $\frac{2.678}{sum\ of\ ratio}$ x dry volume x unit weight of GA

= $\frac{2.678}{6.012}$ x 0.00775 x 1650

= 5.696 kg

Interaction between replacement levels from origin pro 2022

curing day	% Replacn	curing day	% Replacn	MeanDiff	SEM	F Value	Prob	Alpha	Sig	LCL	UCL
28	Mix-2	14	Mix-5	14.35333	0.57681	44.22951	3.89E-16	0.05	1	11.273	17.434
28	Mix-2	28	Mix-1	1.61667	0.57681	0.56111	0.87347	0.05	0	-1.464	4.697
28	Mix-3	7	Mix-1	10.00333	0.57681	21.48306	7.37E-12	0.05	1	6.923	13.084
28	Mix-3	7	Mix-2	11.13667	0.57681	26.62668	4.24E-13	0.05	1	8.056	14.217
28	Mix-3	7	Mix-3	12.19333	0.57681	31.91916	3.61E-14	0.05	1	9.113	15.274
28	Mix-3	7	Mix-4	12.94	0.57681	35.94803	7.01E-15	0.05	1	9.859	16.021
28	Mix-3	7	Mix-5	19.04333	0.57681	77.85608	1.22E-19	0.05	1	15.963	22.124
28	Mix-3	14	Mix-1	5.92	0.57681	7.52402	2.06E-06	0.05	1	2.839	9.001
28	Mix-3	14	Mix-2	6.21	0.57681	8.27923	7.48E-07	0.05	1	3.129	9.291
28	Mix-3	14	Mix-3	6.92667	0.57681	10.30043	6.57E-08	0.05	1	3.846	10.007
28	Mix-3	14	Mix-4	9.10333	0.57681	17.79129	8.49E-11	0.05	1	6.023	12.184
28	Mix-3	14	Mix-5	12.16333	0.57681	31.76229	3.86E-14	0.05	1	9.083	15.244
28	Mix-3	28	Mix-1	-0.57333	0.57681	0.07057	1	0.05	0	-3.654	2.507
28	Mix-3	28	Mix-2	-2.19	0.57681	1.02966	0.45261	0.05	0	-5.271	0.891
28	Mix-4	7	Mix-1	7.47333	0.57681	11.99044	1.11E-08	0.05	1	4.393	10.554
28	Mix-4	7	Mix-2	8.60667	0.57681	15.90291	3.52E-10	0.05	1	5.526	11.687

Interaction	MeanDiff	SEM	F Value	Prob	Alpha	Sig	LCL	UCL
Mix-2 Mix-1	0.06444	0.33302	0.00936	0.99982	0.05	0	-1.02787	1.15676
Mix-3 Mix-1	-1.25667	0.33302	3.55989	0.01719	0.05	1	-2.34898	-0.16435
Mix-3 Mix-2	-1.32111	0.33302	3.93436	0.01103	0.05	1	-2.41343	-0.2288
Mix-4 Mix-1	-3.07444	0.33302	21.30734	2.07E-08	0.05	1	-4.16676	-1.98213
Mix-4 Mix-2	-3.13889	0.33302	22.20996	1.32E-08	0.05	1	-4.2312	-2.04657
Mix-4 Mix-3	-1.81778	0.33302	7.44865	2.72E-04	0.05	1	-2.91009	-0.72546
Mix-5 Mix-1	-7.04556	0.33302	111.899	1.41E-17	0.05	1	-8.13787	-5.95324
Mix-5 Mix-2	-7.11	0.33302	113.9555	1.09E-17	0.05	1	-8.20232	-6.01768
Mix-5 Mix-3	-5.78889	0.33302	75.54162	3.18E-15	0.05	1	-6.8812	-4.69657
Mix-5 Mix-4	-3.97111	0.33302	35.54839	5.54E-11	0.05	1	-5.06343	-2.8788