INVESTIGATING THE SUITABILITY OF USING PUMICE POWDER AS A PARTIAL REPLACEMENT OF CEMENT IN CONCRETE TO INHIBIT ALKALI-SILICA REACTIONS

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A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

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DEDICATION.

I hereby dedicate this report to my parents, Mr. Ssekandi Richard and Mrs. Ssekandi Annet who have greatly offered me support to have a proper education. I also dedicate it to the members of my entire family for supporting me through the words of encouragement they have always rendered to me and enabled me to have this report written.

DECLARATION

I Rodney Ssebuliba with registration number S20B32/040 hereby declare that this is my original work, and it is not plagiarised and has not been submitted to any other institution for any award.

RODNEY SSEBULIBA

S20B32/040

Signature: ……………………………………. Date: ………………………………

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APPROVAL.

This is to certify that this report was compiled under my supervision and is ready to be handed in to the Faculty of Engineering, Design and Technology as one of the requirements for his degree in Civil and Environmental Engineering at Uganda Christian University.

Eng TIMOTHY MUBBALA.

ACADEMIC SUPERVISOR (Uganda Christian University)

Signature: …………………………………………Date: ……………………………

ABSTRACT

The research was carried out to mainly investigate the suitability of using pumice powder as s a partial replacement of cement in concrete to inhibit alkali silica reactions, that greatly affect the durability of concrete. It was achieved through firstly exploring the properties of pumice powder following a methodology of firstly carrying out both chemical and physical tests on the pumice powder and the cement. Properties of fresh concrete were then determined through carrying out the slump test for concrete, for the different mixes with the varying percentages of pumice powder partial replacement. Tests on hardened concrete were also later carried out, looking at the average percentage length changes in the concrete bars through the accelerated mortar bar test, in order to test for alkali silica reactions. Others tests including compressive strength and water absorption were also done, to determine the effect of partially replacing cement with pumice powder on these vital properties of concrete. From all the tests carried out, results were obtained which informed the conclusions and recommendations as clearly shown in the subsequent chapters of this report.

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LIST OF ACRONYMS AND ABBREVATIONS

ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
AMBT	Accelerated mortar bar test
ASR	Alkali silica reactions
ASTM	American Standard Testing Method
BS EN	European Standards
BS	British Standards
C25	Class 25
CAH	Calcium aluminum hydrate
CML	Central Materials Laboratory
CSH	Calcium silicate hydrate
FI	Flakiness index
ITZ	Interfacial transition zone
LAAV	Los Angeles Abrasion Value
M	Meters
MoWT	Ministry of works and Transport
NDP	National development plan
pH	Hydrogen potential
SDG	Sustainable development goal
SSM	supplementary cementitious material

CHAPTER ONE: INTRODUCTION

1.1 BACK GROUND

Concrete is an extraordinary material that has been at the heart of the construction industry and infrastructure for centuries. Concrete has played a crucial part in accomplishing the architectural and engineering dreams of humanity, from the splendor of ancient Roman building to the soaring skyscrapers of modern cities. Concrete is characterized by a number of qualities which include its strength (Tantawi, 2015), durability appearance, and cost effectiveness. For strength it is a fundamental a crucial property, as it determines the structural integrity and performance of the concrete. Strength in concrete can be described in form of compressive, tensile and flexural strength. For durability, it describes the ability of concrete to stand the test of time by resisting environmental and service conditions over time without significant deterioration. For appearance, concrete must have a uniform, consistent and homogeneous visual quality across its surface, for it to be aesthetically pleasing. For the economic part of it, concrete has to be cost effective right from its production, but without compromising its strength. It is the understated but crucial component of modern society. Although concrete has made significant contributions to the construction industry, it is important to remember that over time, concrete has faced a variety of difficulties and problems that have pushed the limits of its performance, some of which include chemical attacks that can result from exposure. Additionally, Alkali-silica reactions (ASR) have posed a significant threat to concrete.

The history of ASR-related issues, with a concentration on fractures and structural damage, may be traced to around the 1940s (Fanijo, Kolawole and Almakrab, 2021), when incidents of concrete degradation, including cracks and damage, started to appear globally. Early instances of buildings, like dams, bridges, and highways, displaying indicators of difficulty were reported from the United States and Canada. The potential economic and safety ramifications of ASR have drawn attention on a worldwide scale and can have far-reaching impacts. Governments, municipalities, and private stakeholders have all experienced severe financial costs as a result of infrastructure damage and the expensive requirement to repair or replace affected assets. Additionally, these buildings' safety has been compromised, endangering the health and safety of the general population. The historical record of ASR serves as a testament to the importance of ongoing research, preventive measures, and materials engineering innovations aimed at mitigating the impact of this complex and widespread concrete deterioration phenomenon on a global scale. Leaving the global scale, there have been a number of reported cases and concerns related to this concrete deterioration phenomenon on the African continent, having a reach even to Uganda, as is to be discussed in this project.

1.2 PROBLEM STATEMENT

Nalubaale Dam, formerly known as Owen falls dam is the hydroelectric generating facility in Uganda. it is well known and recognized for producing hydroelectric power and facilitating movement and crossing of traffic, as it connects Jinja to Buikwe district, in eastern Uganda, to the central parts of Uganda towards Kampala. Of recent, fresh structural gapping cracks have been evidently observed on the dam, along the machine hall and the turbine blocksn (Otim and Nankanja, 2021). The cracks are attributed to Alkali-silica reactions (Christine, Curtis and Adeghe, 2019). The reactions are a chemical combining of silica from concrete aggregates with alkali hydroxide from the cement paste in the presence of water resulting into an Alkali-silica, which expands on absorbing water exerting internal forces on the concrete thus crack development. It is therefore due to this problem, that a solution is proposed investigating the the suitability of using Pumice powder as a partial replacement of cement in concrete, to produce concrete of reduced alkali-silica reactions.

1.3 OBJECTIVES

1.3.1 Main objective

To investigate the suitability of using Pumice powder as a partial replacement of cement in concrete to inhibit Alkali-silica reactions.

1.3.2 Specific objectives

1. To determine the properties of Pumice powder.
2. To explore the properties of fresh concrete on addition of Pumice powder.
3. To ascertain the percentages of expansions due to ASR and other properties of hardened concrete at varying proportions of Pumice powder.
4. To determine a mix design of concrete with Pumice powder as a partial replacement of cement.

1.4 RESEARCH QUESTIONS

1) What are the properties of Pumice powder?
2) What are the properties of fresh concrete on addition of Pumice powder?
3) What are percentages of expansions due to ASR and other properties of hardened concrete at varying proportions of Pumice powder?

4) What is the mix design of concrete with Pumice powder as a partial replacement of cement?

1.5 SCOPE OF STUDY.

1.5.1 Geographic scope:

The study will be carried out in Nalubaale power station with latitude coordinates 0.443525 and longitude coordinates 33.1847.

The Pumice powder will be sourced from Kisoro district in Southwestern Uganda, (where the Bufumbira ranges are located).

It is 320km^2 (located in the western branch of the rift valley system) and is enclosed between longitude 29^{0}30^{0}E and 29^{0}50^{0}E and latitudes 1^{0}30'S and 1^{0}10'S

NOTE: The tests will be carried out from Central materials laboratory in kireka.

1.5.2 Technical scope:

The project is centered on inhibiting Alkali-silica reactions by partially replacing cement with Pumice powder which has pozzolanic properties capable of achieving this. The target concrete grade of the research is C25.

1.6 JUSTIFICATION.

Nalubaale dam being a 180MW power station, is a major contributor to the nation's energy sector and also plays a great role in aiding the movement and crossing of a considerable number of people in form traffic due to its location, which greatly facilitates the key activities in Uganda like tourism and trade it being in Jinja, thus its Structural safety is important to ensure continuous development of Uganda.

Carrying out this research also helps in the achieving Sustainable development goal (SDG) Number 9, whose focus is on (Infrastructure, Industry, and Innovation). It does so, as it involves innovation and research aims at enhancing the resilience of infrastructure. By having the issue of ASR in the Nalubaale Dam addressed, the research project contributes to ensuring infrastructure resilient, inclusivity promotion, industrialization that is sustainable, and innovation fostering. The maintenance and ensuring structural stability of Nalubaale dam, therefore explicitly helps in contributing to the economic development and general well-being of Ugandans, which supports the broader goals of 2030 Agenda for sustainable development.

The research also contributes to achieving National development plan of Uganda, particularly focus area on "infrastructure development". Addressing the alkali silica reactions (ASR) issue through this research on Nalubaale dam, which is a major dam, directly supports infrastructure development, which is a priority area under NDP 3.

The partial replacement of cement with pumice also not only helps in reduction of the detrimental effects of these reactions on structures like Nalubaale dam, but also reduces the overall cost of concrete by reducing on the cement used which is relatively expensive (Mohammed and Mahdi, 2022).

Basing on past research carried out by scholars, Pumice has been used in different forms, that is as coarse aggregates and also fine aggregates for various purposes. Recommendations were made by researchers to venture into other forms of this rock, in order to utilise its properties in concrete. This research aims at using the crushed form of pumice (powder form) as a gap, to investigate its pozzolanic properties in inhibiting Alkali-silica reactions in concrete.

Pumice powder is pozzolanic in nature (has considerable amounts of oxides like **SiO_2**), thus its reaction in the binder pore solution lowers the solution's alkalinity and significantly raises the concentrations of alumina. This reduces the dissolution of the alumino-silicates from the aggregates hence reducing/minimising the amount Alkali-silica gel formed (thus reducing the expansions in concrete), since the two reactors (silica and alkalis) are now in low concentrations.

Chemical analysis

- Through hydrolysis

$Ca(OH)_2 \longrightarrow Ca^{2+} + 2\bar{O}H$

- $Ca(OH)_2$ being reduced through the reaction with SiO_2 in the Pumice

$Ca^{2+} + 2OH + SiO_2 \longrightarrow CSH$

Since SiO_2 (in the pumice) has reacted with the oxides in the cement paste in the concrete, to form CSH (Calcium Silicate Hydrate), with a low Ca/Si mortar ratio, This CSH gel attracts Na^{2+}, K^{+} immobilizes and produces reduced alkalis (even other minor oxides like NaOH and KOH) for Alkali silica reactions (ASR). At the same time, CSH (from the pozzolanic reaction) converts the large pores of the alkali silica gel into small ones (i.e less than 10nm), this reduces its absorption capacity of water to expand, thus further justifying the use of pumice powder.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION.

The chapter's focus and emphasis is on the literature that is relevant and is in line with the research topic, the study objectives and research questions. It covers a number of study areas as clearly shown below;

2.2 THEORETICAL LITERATURE REVIEW

2.2.1 Pozzolans (which are potential supplementary cementitious materials)

Definition:

It is a siliceous and aluminous material that, by itself, has little to no cementitious value. However, when water is present and the material is finely divided, it can react with oxides, such as $Ca(OH)_2$, or lime, to produce compounds that have cementitious qualities (Dodson, 1990).

Besides Pumice, there is a variety of others pozzolans. It is important to note that, pozzolans are widely divided into two major categories, that is, Natural pozzolans and artificial pozzolans and some of the relevant information about them is described below;

2.2.2 Natural Pozzolans

The types of natural pozzolans are mainly two, that is ones of volcanic origin and those of sedimentary origin (Shukla *et al.*, 2020). The first group includes pumice stone, tuffs, volcanic ash, volcanic slag, obsidian, which are igneous rocks formed through the volcanic ash (gray colored vitreous volcanic igneous rock) Buildup.

Pumice

Pumice is a volcanic rock, made up of a rough high vesicular texture glass. It should be noted that pumice differs from scoria, another vesicular volcanic rock, despite having comparable chemical compositions because pumice contains larger and thicker vesicles (Caiza *et al.*, 2018).

Furthermore, the color of scoria is darker than that of pumice, which is often lighter in color. These vesicles are pore spaces that are produced when dissolved magma gas escapes after it reaches the earth's surface. The magma is shredded and blasted out as a molten foam by a rush of gas coming from the vent. As a result, the foam quickly solidifies while it soars into the air and returns to Earth as pumice fragments.

It is important to note that, Pumice comes in two varieties, that is basic pumice, which is black or brown, and acidic pumice, which is oyster white or white in color. Nonetheless, the most prevalent kind of pumice worldwide is acidic pumice. The US Geological Survey Report states that in 2011 and 2012, the world produced roughly 18 and 17 million tonnes of pumice and pumicicite, respectively.

2.2.3 Artificial Pozzolans

Artificial pozzolans are materials that have undergone industrial processing to produce or modify them (Bumanis *et al.*, 2020). Some of the examples include such as fly ash created by coal combustion, Blast furnace slag, silica fume, metakaolin, ceramic waste, rice husk ash, wood ash, sugarcane bagasse ash and many more.

NB: It is important to note that any material irrespective of its source, can be a pozzolan, depending on its ability in the presence of water to react with lime $Ca(OH)_2$.

2.2.4 **Mechanism of reaction of the pozzolans (pozzolanic activity)**

When they react with lime in the presence of water, the hydroxide ions (OH) are released that increase the pH value to approximately 12.4. It is at this point that pozzolanic reaction occurs (Moropoulou, Bakolas and Aggelakopoulou, 2004).

The silica and aluminum are combined with the available calcium in the cement, producing compounds with cementitious properties like Calcium silicate hydrate (CSH) and Calcium aluminum hydrate(CAH).

Pozzolanic Reactions

$Ca^{2+} + 2OH + SiO_2 \longrightarrow$ CSH (for pozzolans with high silica content)

$Ca^{2+} + 2OH + Al_2O_3 \longrightarrow$ CAH (for pozzolans with high aluminum content)

Pozzolanic materials contain considerable amounts of

- Silicon oxide (SiO_2)
- Iron oxide (Fe_2O_3)
- Aluminum oxide (Al_2O_3)

Any material is considered or designated as a pozzolan, if the sum of these mentioned oxides is 70% as per the weight percentage (Becerra-Duitama and Rojas-Avellaneda, 2022).

NB: It is due to these chemical compounds, that cementitious gel CSH or CAH are produced. The amount of these gels is dependent on the following

- Amount of reactive silicon or aluminum content.
- Specific surface of the pozzolan.
- Characteristics and chemical composition of the pozzolan.

2.2.5 Concrete constituents.

2.2.5.1 Cement

Definition: Cement is can be defined as a binder (finely ground material inorganic in nature) hydraulic in nature, which on mixture with water forms a paste that sets and then hardens through the reactions of hydration and which after hardening, is able to retain its stability and strength even under water (Elsen, Mertens and Snellings, 2011). (According to BS 12)

Types of cement:

Cement comes in a variety of types for various uses in construction; the most popular varieties are:

- Ordinary Portland Cement: - which is free from chemical attack and is used in safe environment
- Sulphate Resisting Portland Cement: - used in construction works with sulphate exposure (such as in chemical industries, sea waters, and many more.).
- Rapid Hardening Portland Cement: - It is used in cases where quick strength attainment is required, especially for large projects with short completion deadlines.

Some of the common tests carried out on cement include: fineness, consistency, setting time, strength, tensile strength, heat of hydration, soundness, chemical composition and specific gravity tests. These tests are divided into physical and chemical tests.

Raw materials for cement production.

As shown in the Table below, the raw materials needed to produce cement are limestone, which produces calcium oxide, clay containing silica, alumina, and iron, which produce silica oxide, aluminum oxide, and ferro oxide, respectively (Aragaw, 2018). In order to lower the setting time, gypsum is additionally added. Additional some other constituents that are allowed in Portland composite cements are natural and artificial pozzolanas such as calcined clays, shale, and volcanic ash glasses, as well as artificial pozzolanas such as silica, fly ash, and blast furnace slag (Waghmare *et al.*, 2021).

Chemical composition of cement

Table 2:1 Chemical Composition of Pumice

Chemical composition	Content (%)
CaO +	60-67
SiO2	17-25
Al2O3	3-8
Fe2O3	0.5-6
MgO	0.5-6
SO3	1-3
Na2O	0-0.5

Source (Anena, 2020)

2.2.5.2 Aggregates

Aggregates are the inert structural fillers in concrete. Natural aggregates can be created by purposeful crushing of a larger parent material or by a combination of weathering and abrasion. Numerous aggregate characteristics are dependent upon the parent rock's characteristics, which are categorized according to their mineral makeup, hardness, strength, specific gravity, chemical stability and physical characteristics. Fresh concrete's performance is significantly impacted by the shape, texture, and grading of the aggregate (Poloju, 2017). Aggregate particles that are smooth, spherical, and well-shaped require less slump than those that are flat, elongated, angular, and rough. Concrete with uniform aggregate gradation will require less water and paste in smaller proportions. Consequently, this lessens issues with durability brought on by heat generation, drying shrinkage, and porosity.

i) Coarse aggregates.

These are retained on a sieve of 4.75 mm in accordance with the IS sieve standards that are used to grade various aggregate sizes. The nominal distribution of coarse aggregates, which includes 20, 14, and 10 mm, is referred to as graded aggregates. Approximately 70% of the volume and 80% of the weight of the concrete are made up of coarse particles. Common examples of coarse aggregates are natural gravel and crushed stone.

ii) Fine particles

These aggregates have a range of particle sizes, from 4.75 mm to 0.075 mm. They form a stable structure for the hardened concrete mix by occupying the space between the coarse particles.

2.2.6 Workability of fresh concrete.

The workability of fresh concrete is essential to its performance during construction. It includes many attributes like flowability, slump, and ease during placement (Hoang and Pham, 2016). A delicate balance between water content, cement paste consistency, and aggregate properties is required in order to achieve a workability that is optimal. While too little water might make the concrete difficult to place and compact, too much water can cause segregation and a weaker finished product. In addition, aggregate size and shape are important; rounded aggregates generally improve workability more than angular ones. Since the workability of concrete influences the ease of placing, compacting, and finishing, It greatly impacts efficiency of the construction and the of the final structure quality. In order to improve workability in accordance with particular project needs and atmospheric conditions, contractors frequently modify mix designs and admixtures (Pacheco, 2024). This ensures that fresh concrete is both workable and capable of reaching necessary strength and durability.

2.2.7 Effect of partial replacement of cement with pumice powder on the micro structure of concrete.

Research study on incorporating pumice powder as a partial replacement of cement in concrete, has an impact on the microstructure and characteristics of the final product. As a pozzolanic material, pumice powder reacts with the calcium hydroxide liberated from the cement hydration to make more calcium silicate hydrate (C-S-H) gel, which improves the microstructure's densification.

Studies such as those conducted on "The effect of pumice powder as a supplementary cementing material on the mechanical properties of concrete" (Rashad, 2021) and one on "The properties of concrete containing pumice as a supplementary cementitious material", indicated that the partial replacement of cement with pumice powder enhances interfacial transition zone (ITZ) properties due to better bond formation between aggregates and paste, this improves the packing density of concrete particles and reduces porosity.

Furthermore, pumice powder's finer particle size helps to increase workability (Zeyad and Almalki, 2021) and lessen bleeding. According to these results, adding pumice powder to concrete mixtures can increase its mechanical qualities, including its flexural and compressive strength (Abraham and Mohan, 2020), as well as its resistance to sulfate attack and chloride ion penetration. Consequently, using pumice powder in partial replacement of cement has the potential to produce concrete with better microstructural properties and better overall performance, making it an effective and sustainable supplementary cementitious material in the concrete production.

2.3 EMPIRICAL LITERATURE REVIEW.

2.3.1 Other recent research that has been done on mitigating alkali silica reactions.

Blast furnace steel slag

Definition: It is a by-product produced during the separation process of iron(steel) ore in blast furnaces in steel manufacturing industries (Gill, Martínez Pavetti and Monteiro, 2020).

How it is produced

In the manufacturing process, scrap metals are burnt in a blast furnace at high temperatures producing molten iron and slag. Molten iron is slowly poured into beds which are cooled under ambient conditions forming hard lamp slag which can subsequently be crushed and screened.

It is a highly cementitious properties due to its composition of silicates, Lime and aluminium, making it a good material for partial replacement of cement in concrete.

Blast furnace steel slag has latent properties that are hydraulic which permit its most common application as a cement additive(Supplementary cementitious material) (Gill, Martínez Pavetti and Monteiro, 2020).It was used for this purpose due to the fact that in it occupies only a large amount of land resources but also leads to soil underground water and the atmosphere pollution, which is environmental pollution.

2.3.2 Factors considered to use Blast furnace steel slag powder as a partial replacement of cement in concrete.(efficiency of Supplementary cementitious material in mitigating Alkali silica reactions)

- Fineness(particle size less than 75µm which is equivalent to the size of cement)
- Low alkali content
- Its chemical composition.
- Mineralogical composition

NB : The fineness is to ensure high rate of pozzolanic reaction, as the greater the fineness of the Blast furnace steel slag powder, the greater the specific surface.

2.3.3 Finely ground glass powder (fine waste glass particles)

It was also used to partially replace cement in concrete to fight or inhibit alkali silica reactions in concrete. Fine waste glass particles less than 75 microns have been found to have pozzolanic properties and even cementitious properties (Tamanna *et al.*, 2013) and once used as a partial replacement of cement can contribute to the inhibition of alkali silica reactions.

It was also used basing on the fact that it contributes to an environment, that is green, as production of one ton of Portland cement, produces approximately one ton of CO_2 resulting into global warming effects (Tamanna and Mohamed, 2013).

2.3.4 Use of Metakaolin powder

Metakaolin being a natural pozzolan, has been used before as an admixture in concrete due to its excellent pozzolanic activity in the inhibition of Alkali silica reactions in concrete(Khatib, Baalbaki and Elkordi, 2018). This was carried out by adding different partial replacement ratios of Metakaolin powder and an Alkali silica reactivity test

(ASTM C 1260). The Alkali silica reactions were reduced greatly as metakaolin partially replaced the Cement in concrete greater than 15% Ramlochan, Thomas and Gruber, 2000).

2.3.5 Knowledge gap

From the empirical literature review, it was clear that research was carried out on the inhibition of Alkali silica reactions in concrete using a number of pozzolans, such as Blast furnace steel slag, crushed glass which are artificial pozzolans, and metakaolin as the natural pozzolan. This research study focuses at the use of a volcanic(rock) pumice, as a natural pozzolan, that is crushing it to a size approximate to that of cement and partially replacing cement with it at varying percentages of 0%, 5%, 10% and 15% to produce concrete of reduced alkali silica reactions.

CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION.

This chapter entails details of the different materials to be used in the execution of this project and the methods in form of the different procedures and tests that were carried out in order to achieve the objectives of this research.

In this study, pumice powder was partially replacing cement in concrete with an aim to inhibit alkali silica reactions. This was achieved through carrying out XRF, setting time, fineness, and specific gravity tests on the pumice powder. The engineering properties of the materials that were used in the concrete were also determined through carrying out tests on aggregates for example particle size distribution, water absorption, aggregate crushing value, aggregate impact value and specific gravity were determined. To evaluate the performance of concrete with pumice powder as a partial replacement of cement, slump test for workability, compressive strength, water absorption test, the accelerated mortar bar test were carried out and lastly, the proportion mix design ratio was also determined. It is important to note that, much as the main objective of this research is focused on inhibiting alkali silica reactions in concrete, tests on compressive strength and water absorption were also carried out to ascertain the effect of the partially replacing cement with pumice powder on these very crucial properties of concrete.

3.2 RESEARCH DESIGN

The research followed an experimental study in obtaining the data, since the purpose of the study was to investigate the suitability of using pumice powder as a partial replacement of cement to inhibit alkali silica reactions in concrete. The experimental study followed to obtain data, is as shown below in the stages involved in the study;

- ✓ Sample collection
- ✓ Sample preparation for all laboratory tests.
- ✓ Chemical and physical Laboratory test on pumice powder and the composite mix of pumice powder and cement.
- ✓ Fine and coarse aggregate Laboratory tests to aid the mix design development process.
- ✓ Concrete cubes and concrete bars casting.
- ✓ Fresh concrete testing (slump test).
- ✓ Concrete sample curing.
- ✓ Concrete sample laboratory tests.

3.3 MATERIALS AND METHODS.

3.3.1 Materials.

i) Pumice Powder.

This was obtained from a volcanic rock known as pumice. It was used as the supplementary cementitious material to partially replace cement in the concrete in order to inhibit alkali-silica reactions. The powder was used since, pozzolanic activity is increased with increase in surface area.

ii) **Cement.**

According to specifications of ASTM C150/C150, Class 42.5 Cement was the type of cement employed in this investigation. Regarding the manufacturer's information, this specimen is not to be subjected to any particular testing. But some of its characteristics, including the grade, were taken into consideration while coming up with the appropriate mix in this research. 2 bags of Portland Pozzolana Tororo cement CEM I 42.5N of 50 kg each were bought and used to carry out the tests.

iii) **Sand**:

Natural sand was used from the Nkokongyeru, which has a size range of 0 to 5 mm. The coarse aggregates with sizes of 6-10 mm, 14-10 mm, and 20-14 mm were sourced from Jesani quarry Mukono. These aggregates were tested for gradation, water absorption, LAAV, specific gravity, 10% fines value, Aggregate Impact Value, and ACV. In order to prevent segregation individually for each sample, riffling is done using a riffle box.

iv) Water

The water used in this investigation was distilled from National Sewage Corporation, whose discharge guidelines state that the water is free of minerals and pathogens and has a pH range of 6.0 to 8.0. The water used for casting and curing needs to be up to BS EN 1008:2002:1980 requirements. This guarantees that the concrete reaches the appropriate workability and strengthens the link between the other concrete constituents.

3.3.2 **Methods**

Pumice powder sample preparation.

Pumice rocks were firstly reduced in size manually, by using a hammer. The reduced pumice rock pieces were then sun oven dried to ensure zero moisture in them. They were then placed in a Los Angeles Abrasion Value Machine which was set to run. After running, the material removed from the LAAV machine was then sieved through a 75µm sieve by use of s sieve shaker to obtain fine pumice powder.

Figure 3-1 Operation of the sieve shaker weighing of pumice powder during sample preparation.

X ray fluorescence test (XRF) Test. (BS EN 196-2:2013)

It is important to determine these properties which are physical and chemical, as they help in knowing the suitability of this material as a partial replacement of cement in concrete.

Besides Pumice being a supplementary Cementitious material, Knowledge of its chemical composition is in important this research study of inhibiting Alkali silica reactions, thus the X ray fluorescent test was carried out to determine the silica content available and find out whether the total composition of Silicon oxide (SiO_2), Iron oxide (Fe_2O_3), Aluminum oxide (Al_2O_3) is greater than 70% which is required for pozzolanic activity. It will be carried out in accordance to BS EN 196-2:2013.

This was carried out at Government analytical lab, were a small sample of the pumice powder, quantities about 25g were placed in the X ray fluorescence machine, and the machine produced results in a print-out showing the composition of the powder by percentage, that is the oxides and the chemical compounds.

Consistency test (BS EN 196:1-6).

Consistency of a concrete binding material is the minimum water requirement to start the chemical reaction between water and the binding material.

Significance of this test.

Helps to identify the minimum water required to make a workable paste.

Apparatus: Vicat apparatus, plunger for standard consistency, graduated scale, vicat mold, movable rod and needles.

NOTE: It is important to note that the consistency test was carried out on the cement and on the composite mix, that is one with pumice powder partially replacing cement, by 5%, 10% and 15%.

Test Procedure as used for the test:

The vicat apparatus was placed on a level base, and the plunger for determining standard consistency was attached to the movable rod.

A weighed quantity of 500g of cement (0% pumice powder) was placed in a bowl and a weighed quantity of water in a beaker which was 130ml (amount of water to give a consistent paste). The sample was mixed thoroughly to form a paste using a mixing machine for 5minutes and a stopwatch was started at the time of adding water to cement.

The Vicat mold was filled with the cement paste while shaking it slightly to expel some voids/air. This was then followed by smoothening of the paste surface, making it have a levelled with the top of the mold.

The mold with the test sample for consistency was placed under the movable rod of the Vicat apparatus bearing a needle. The plunger was lowered gently until it just touched the surface of the paste.

The Plunger was then released causing the needle to penetrate the paste. This was all done while observing the penetration values on the graduated scale of the apparatus.

Other trial samples were prepared varying amounts of water until the penetration range was

33 – 36mm on the scale.

Note: The Standard penetration range on the Vicat apparatus scale is 33 – 36mm to acquire standard consistency of cement.

The Standard consistency of cement was calculated as

$$\frac{\text{Amount of water added for consistency}}{\text{Mass of cement}} \text{ X } 100$$

For example, Consistency $= \frac{130}{500} \text{X } 100 = \mathbf{26}$

NOTE: The procedure above was repeated for the composite mixes for pumice powder and cement, and the results analyzed.

The consistency test is as shown below;

Figure 3-2 Operation of the Vicat Apparatus for setting time test

Setting time (Initial and final setting time) (BS EN 196-3:2016)

Initial setting time: Refers to the time when the concrete binding material paste starts losing its plasticity. or Interval of time from when water is added to concrete binding material to when it starts to become rigid.

Final setting time of cement: Refers to the time when the concrete binding material paste completely loses its plasticity. Or the time interval from when water is added to when it becomes rigid enough to resist light pressure.

Significance of the test.

The initial setting time of concrete binding material is important, to know when the concrete binding material starts losing its plasticity. It is helpful in ascertaining the time recquired for the process of concreting.

Apparatus: Vicat apparatus, weighing machine, stop watch, gauging trowel, measuring cylinder, tray.

Test Procedures undertaken for Initial setting time

- For sample preparation, 500g of cement (0% pumice powder) for making the paste were weighed and the same amount of water used for consistence test i.e. 130ml of water added to the sample to enable thorough mixing to attain a consistent paste. The paste was then placed in the Vicat mold, filled to the top and surface of the paste well smoothened at the same level with the top of the mold.
- The mold was placed under the rod (plunger) bearing the needle. (Needle for the initial setting time determination) and the plunger lowered until it slightly touched the paste surface.
- The paste was then penetrated and the value on the Vicat apparatus scale recorded. Penetrations were made continuously every after 15 minutes while recording values until a penetration value less than 25mm was obtained.
- The period of time that elapsed from addition of water to the cement to this point of a penetration value less than 25mm attained, was recorded as the **Initial setting time** of the cement paste.

Test procedures followed for final setting time.

- To obtain final setting time, the needle was replaced by the (needle for determining the final setting time) needle with an annular attachment.
- The needle on the plunger was lowered until it just slightly touched the surface of the paste. Penetrations were made while recording values on the Vicat apparatus scale and this was done continuously every after a 15 minutes period until no visible penetrations appeared on the surface of the sample.
- The interval of time or the period or time that elapsed from when water was added to the cement to when the needle failed to penetrate the sample was recorded as the **Final setting time** of the cement paste sample.

NOTE: The same procedure was repeated for the composite mix of pumice powder and cement at different proportions and the results obtained, which are shown in Chapter

Fineness test & Specific gravity (BS EN 12390-7)

Fineness test

This was carried out by weighing 25g of pumice powder and sieving it through a standard 90µm sieve until no more pumice powder was going through. The residue on the 90 µm was then weighed and its mass expressed as a percentage, R_1 of the quantity first placed in the sieve to the nearest 0.1%.

The procedure was repeated using a fresh 25g of pumice powder sample to obtain R_2 .

The residue of pumice powder sample, R was then computed as the mean of the R_1 and R_2 , as a percentage also expressed to the nearest 0.1%. Computation and results are presented in Chapter 4

Trial 1

$$R_1 = \frac{1.07}{25} \times 100 = 4.3\%$$

$$R_2 = \frac{1.04}{25} \times 100 = 4.2\%$$

$$R_2 = \frac{R_1 + R_2}{2} = \frac{4.3 + 4.2}{2} = 4.3\%$$

Trial 2

$$R_1 = \frac{1.08}{25} \times 100 = 4.3\%$$

$$R_2 = \frac{1.00}{25} \times 100 = 4.0\%$$

$$R_2 = \frac{R_1 + R_2}{2} = \frac{4.3 + 4.0}{2} = 4.2\%$$

Trial 3

$$R_1 = \frac{0.97}{25} \times 100 = 3.9\%$$

$$R_2 = \frac{0.98}{25} \times 100 = 3.9\%$$

$$R_2 = \frac{R_1 + R_2}{2} = \frac{3.9 + 3.9}{2} = 3.9$$

Specific gravity test procedure for Pumice powder undertaken.

The Le Chatelier Flask method was used following the procedure below;

The weight of the fully dry empty Le Chatelier Flask was obtained from an electronic weighing balance and the weight recorded as W_1 = 95.41g

50g of pumice powder were weighed and poured in the Le Chatelier Flask, and this weight taken with the stopper on the flask as, W_2 = 143.13g

Kerosene, which is the reference liquid was poured into the flask to full capacity, and the composition mixed thoroughly to remove air bubbles. The flask together with the pumice powder sample were weighed as W_3 = 364.52g

The flask was then emptied and filled with kerosene alone up to the top and the weighed measured as, W_4 = 330.35g

Specific gravity was then computed using this equation

$$S_g = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4) \times 0.79}$$

$$S_g = \frac{143.13 - 95.41}{(143.13 - 95.41) - (364.52 - 330.35) \times 0.79}$$

$$S_g = \mathbf{2.30}$$

Preliminary tests carried out on the materials used in the casting of the concrete

Hardened concrete properties are of great significance, as they also inform the suitability of concrete to be used in construction even with the incorporation of the pumice powder. Much as properties of hardened concrete are of great importance, the materials used in making such concrete, need to be tested too against the standards to ascertain whether, they are suitable for use or not. The following are some of these tests carried out on the sand, aggregates that was used in the casting of the concrete;

Silt content test on fine aggregates (sand).

500g mass of sand whose silt content is to be obtained was weighed on the electronic weighing machine. The sample was then washed through a 5mm sieve under flowing water and afterwards washed through a 75µm sieve. This is done until the water coming out becomes clean. An Illustration is shown in Appendix 1

The sample retained on both sieves was then oven dried for 24hours at (100 +/- 5) ^{0}C.

The oven dried sample was weighed as M = 496g

Silt content was obtained as; Silt content = $\frac{500-485}{500}$ X 100 = **3%**

NB: 3% simply implies that the sand sample has less silt, since the maximum value for silt content is 4%

Sieve analysis,(for the fine aggregates).

To determine the fine aggregate's gradation, sieve analysis was performed. The process involved taking suitable samples of the material and weighing a sizable quantity. After that, the material was run through sieves with fine aggregate sizes ranging from 10 mm to 150 mm. Every sieve's retained mass was measured and noted. After that, the percentage was calculated and displayed to display the gradation on a logarithmic scale.

Particle size distribution/ Grading for coarse aggregates.

This test is also referred to as the sieve analysis. The main objective of this test is to identify/reveal the various particles size in a granular material, i.e., aggregates, this is made possible by passing the sample aggregates through a series of sieves of varying sizes ranging from wide apertures to narrow/small ones.

It was carried out firstly by quartering to obtain a representative sample, after which the original weight was obtained as well. The sieves were then arranged in order starting from large to small aperture sizes and the sieving started off.

Mass retained on every sieve was weighed and recorded in the table. The percentage retained was also calculated as. The cumulative percentage retained was also calculated and finally the percentage passing which was obtained by subtracting the cumulative percentage retained from 100, as shown below;

Table 3:1 Percentage passing results from the grading test of aggregates

Total dry mass = 5141g

Sieve size (mm)	Weights (g)	Percentage Retained	Cumulative % Retained	Percentage passing
37.5	0	0	0	100
20	1149	22.35	22.35	87
14	2711	52.73	75.08	25
10	1180	22.95	98.03	2
5.	68	1.32	99.35	1

Flakiness Index (FI).

It is carried out to mainly ascertain the degree of flatness of the coarse aggregates OR It is conducted to determine the shape and angularity of the individual aggregates. Understanding the flakiness index of aggregates, helps, in the proper selection of aggregates that can promote, good bonding and interlocking, thus enhancing the overall performance and longevity of construction works, that are to use such aggregates in the concrete production. This is true, as flaky aggregates have a rough surface, which greatly influences the bonding between the aggregates and the matrix surrounding, that is the cement paste, in concrete.

To obtain FI, the percentage retained column was used considering only values above 5%. Referring to the results tabulated above, 22.35, 52.73 and 22.95 are above 5% hence their respective sieve sizes of 20.0, 14.0 and 10.0 and mass retained values of., 1149, 2711 and 1180 were noted.

The mass retained on sieve size 20.0 that is 1149 was sieved through slots of seizes 28-20 obtaining the weight that passed the slots as 242 and on sieve size, 14.0 that is 2711 was sieved through slots of seizes 20-14 obtaining the weight that passed the slots as 684. The same was done to the mass retained on the 10.0mm sieve, that is, after passing it through slot sizes of 14-10, the weight that passed these slots was 257.

The total of these weights obtained from the slots was calculated as $242 + 684 + 257 = \mathbf{1183}$

The total of the masses retained on the 20, 14 and 10mm sieves were also calculated as

$1149 + 2711 + 1180 = \mathbf{5040}$

The FI was then calculated using the formula, $\mathrm{FI} = \frac{\mathbf{5183}}{\mathbf{5040}} \mathrm{X}\, 100 \approx 23\%$

<u>Specific gravity determination and Water absorption for Coarse aggregates</u>

Specific gravity is defined as the ratio of density of a solid particle to the density of an equal volume of water. In contrast, a low specific gravity also suggests a high density. A high specific gravity indicates a high density. This test yields three parameters:

- Bulk specific gravity: - which is the ratio of the density of a permeable particle to the density of an equivalent volume of water.
- Apparent specific gravity: - The ratio of the impermeable portion of a particle's density to an equivalent volume of water
- Water absorption: - The water amount absorbed by a solid particle that is expressed as a percentage of the dry mass of the particle.

1 Kg of a well graded sample of aggregates was weighed on an electronic weighing machine and was washed through a 5mm sieve to remove the dust that could affect the

absorption. The sample was then soaked in a cylinder filled with water to the brim for 24 hours. After this time the whole combination was weighed as **a** = 2032g and the aggregates poured on a towel to be surface dried and their weight got as **B** = 1002g.The weight of the cylinder filled with water to the brim was taken as **b** = 1414g enabling us to find the weight of aggregates in water as

$\mathbf{C} = 2032 - 1414 = 618\text{g}.$

The surface dried aggregates were further oven dried and their weight got as A= 998g.

Water absorption was determined by

- $Water\ absorption = \frac{B-A}{A}$

$$Water\ absorption = \frac{1002 - 998}{998} \times 100 = 0.4\ \%$$

- $Relative\ density\ of\ the\ aggregates = \frac{B}{B-C}$

$$Relative\ density\ of\ the\ aggregates = \frac{1002}{1002 - 618} = 2.6$$

Aggregate Impact Value (AIV) test.

The test is intended to measure the resistance of aggregates to a suddenly applied load and the toughness of the aggregates. Some of the tool's use include a mold, tamping rod, sieves, AIV hammer etc. The AIV shouldn't exceed 45% by concrete in non-wearing areas, in wearing areas like floors 30% for concrete, runways and pavements and 25% for road pavements.

Total weight = M1

Weight of material retained on 2.36mm sieve = M2

$$AIV\ = \frac{M1 - M2}{M2} \times 100$$

Figure 3-3 Operation of the AIV Machine

Aggregate crushing value (ACV) test.

This main objective of this test is to measure aggregate resistance to a gradually applied load. Some of the apparatus used in this test include large mold, large tamping rod, sieves, plunger, compression machine etc. It is carried out on strong aggregates.

Total weight = M1

Weight of material retained on 2.36mm sieve = M2

$$AIV = \frac{M1 - M2}{M2} \times 100$$

Ten percent fine value test.

This test is also intended to obtain/measure the aggregates resistance against a gradual load. The tools used in this test are similar at those for ACV test as they are almost the same. It can also be used to show the properties of the aggregate when subjected to mechanical degradation.

$$TPFV = \frac{14\ \times}{y+4}$$

$$TPFV = \frac{14\ X\ 220}{9+4} = 237$$

10% fineness value = 237 kN

Los Angeles Abrasion Test (LAAV).

The objective of this test is to measure the resistance of aggregates to wearing or abrasion. It can also be to determine the hardness of the aggregates. This is done by subjecting the aggregates mixed with 11 steel balls to 500 revolutions in a rotary steel drum.

Test procedure.

- The aggregates were passed through sieves i.e., 10- and 14-mm sieves to be sampled. The aggregates that passed through the 14mm sieve and were retained on the 10mm sieve were used to carry out the test.
- 5000g of the sample was weighed and put in the Los Angeles Abrasion machine which was set to rotate 500 revolutions.
- After the revolutions, the sample was passed through a 1.7mm sieve and the aggregates retained were weighed getting a value say, $\mathrm{M2}$.
- The Los Angeles Abrasion value was then calculated as LAAV = [(5000- $\mathrm{M2}$)/5000] x 100.

Table 3:2 Computations for LAAV

Sample	$M1$(g)	$M2$(g)	LAAV= [($M1$- $M2$)/ $M1$] x 100%
1	5000	3653	[(5000-3638)/5000)]x 100% = 27%

Figure 3-4 Operation of the Steel drum to carry out LAAV test

DETERMINING PROPORTION MIX DESIGN FOR C25 CONCRETE

The British method department of Environment was used and the mix design template was followed to determine the proportions for the C25 concrete.

<u>concrete mix design inputs used</u>

- Characteristic strength= 25 N/mm^2
- Target mean strength = 38 N/mm^2
- Maximum Aggregate sizes=20mm

- Free water to cement ratio= 0.58
- Slump= 30- 60(mm)
- Free water content = 210kg/m^3
- Cement content = 362.07kg/m^3
- Relative density of aggregates = 2.61
- Grading of fine aggregates (%passing 600µm) = 44%
- Fine aggregate content = 671.81 kg/m^3
- Coarse aggregate content = 1096.12 kg/m^3

The different mix proportions obtained from the mix design are as shown in the table below.

Table 3:3 The different mix proportions from the mix design.

Pumice powder content(%)	Cement Content (kg/m^3)	Pumice powder Content (kg/m^3)	Fine aggregates Content (kg/m^3)	Coarse aggregates Content (kg/m^3)	Water Content (kg/m^3)
0%	362	-	672	1096	210
5%	344	18	672	1096	205
10%	326	36	672	1096	196
15%	308	54	672	1096	191

METHODOLOGY FOR DESIGNED CONCRETE

1. **Slump test (BS EN 12350-2:2019)**

It looks at Workability of fresh concrete, which is fundamental as it informs the simplicity of movement or plazcement of a concrete mix even on addition of pumice powder.

Material used: The slump test using a truncated cone, tumping rod, Steel base plate, measuring instrument (tape measure or meter rule)

Using the British method, department of engineering, a concrete mix design was formed and designed for a low degree slump, that is between 30- 60 mm with a vebe time lying within 3-6s. For every concrete mix, that is for the neat mix and ones having 5%, 10% and 15% partial replacement of cement with pumice powder, slump was measured by pouring concrete in a truncated cone and tamping it about 15 times till the come was full. Once the come was full, it was placed on a side and a steel rule used to measure the slump as the height difference between the concrete and the cone, measured using a measuring tape. This was done in triplicates from the horizontal meter rule placed on the cone placed aside, and the top surface of the fresh concrete.

Figure 3-5 Carrying out slump test for freshly mixed concrete.

2. **Compressive strength test (BS EN 206-1:2013)**

This was done at 7, 14 and 28 days after casting the concrete cubes. After 7 days of curing in the soaking tank, the first batch of triplicates of concrete cubes were crushed in a compression resistance machine. The three cubes of each percentage replacement results were tabulated to obtain an average value. This same procedure was repeated after 14 and 28 days with the compressive resistance shown by the machine recorded and tabulated with illustrative graphs showing the compressive strength in MPa

Figure 3-6 Inserting of concrete cubes in the compressive strength machine for crushing.

3. **Water absorption (BS EN 12390-8:2019)**

The water absorption of the designed concrete was carried out to determine the impact of partially replacing cement with pumice powder on the water retention capacity of the concrete. It was done by soaking the concrete cubes at each percentage of pumice powder replacement for 28 days. After days, the cubes were placed in an oven for hours to ensure they are totally dry, this dry weight was measured and recorded. The same cubes were then resoaked in soaking tanks for hours, after which their wet weights were measured and recorded. Water absorption was then obtained by subtracting the dry weight of the cubes from the wet weight and dividing this difference by the wet weight, thus obtaining the water absorption as a percentage.

NOTE : Triplicates were carried out for all the tests above, from which both mean and standard deviation were calculated to ensure that the results were reliable.

Schematic flow of evaluating performance.

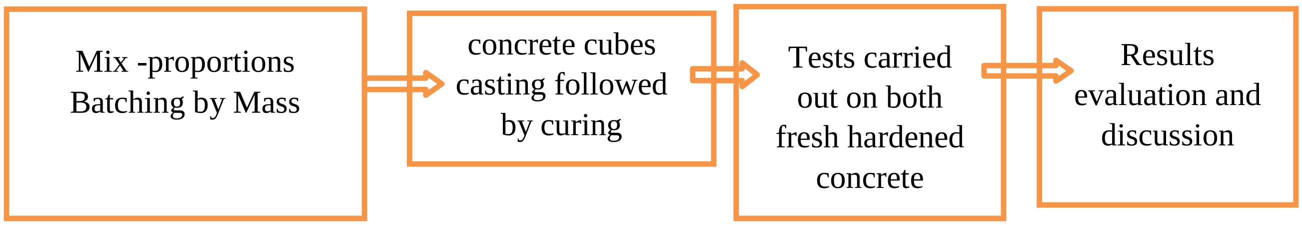

Figure 3-7 Schematic flow for evaluating performance

4. **Accelerated Mortar bar test (AMBT) (ASTM(2014c)**

NOTE: It adheres to the American standard test method (ASTM 1260) for testing Alkali silica reaction (ASR) for cement-Aggregate combination.

Some Instruments used

- Concrete prisms
- Measuring instrument (Dail gauge)
- Alkaline solution (1M NaOH solution)
- Water bath.

Summary of the procedures followed in carrying out the Accelerated Mortar bar test (AMBT).

AMBT is a useful method of testing ASR susceptibility for the cement-aggregate combination(concrete). It is also used as a simulate test for alkali silica reactions in mortar and concrete. The procedures to be carried out are as listed below;

- ✓ Aggregates were be graded and mixed with other components of concrete to form a concrete mix.

- ✓ The concrete beam/bars of 25mm X 25mm X 300mm were then cast in concrete prisms, moist and cured for 24 hours while being stored in a water bath at 80°C.
- ✓ After the 24hours, the concrete beam/bar lengths were then measured.
- ✓ They were then be soaked in IM NaOH solution for a period of 14 days.

Simulated Alkali silica reaction $SiO_2 + 2NaHO + H_2O \longrightarrow Na_2SiO_3.2H_2O$ (Alkali silica gel)

- ✓ The concrete bar measurements were then taken over period of 14 days and the reactivity was determined based on the level of expansion.

Figure 3-8 Operation of the water bath with concrete prisms/bars for the AMBT.

Relationship between the expansions and the reactivity of the concrete

Table 3:4 Expansions corresponding to concrete Alkali Silica reactivity

EXPANSIONS (%)	CONCRETE REACTIVITY
Greater than 0.2	High potential of Alkali silica reactivity.
0.1 - 0.2	Concrete may be affected or safe against ASR
Less than 0.1	Low ASR reactivity potential.

NOTE: A cost benefit analysis (CBA) is be carried out at the end of this research to find out whether its economically favourable.

3.4 DATA ANALYSIS AND INTERPRETATION

It is important to note that, data processing, analysis and Results interpretation was carried out using Microsoft Excel. That is different graphical illustrations (both line and bar graphs) were obtained from excel with the data obtained from the tests, thus making a clear judgement and having a better understanding of the results.

CHAPTER FOUR: RESULTS AND DISCUSSION.

4.1 INTRODUCTION

This chapter outlines the experimental procedures and evaluates the findings from tests conducted on pumice powder, fine and coarse aggregates, also fresh and hardened concrete., for example Particle size determination, specific gravity, water absorption ,bulk density, aggregate crushing value, aggregate impact value, Los Angeles abrasion, and ten percent fine value are among these tests. Slump tests, water absorption, compressive strength and Accelerated mortar bar tests were performed on the cubes and concrete prisms to assess how well they performed when pumice powder partially replaced cement in concrete.

4.2 ENGINEERING PROPERTIES OF PUMICE POWDER.

Table 4:1 XRF test results summary

XRF(Chemical composition test results)			
Chemical composition(%)	**Test results(%)**	**Requirement ASTM C618 (%)**	**Discussion**
SiO_2	63.496	35 minimum	Sufficient for reaction
Al_2O_3	13.552	-	-
Fe_2O_3	8.957	-	-
$SiO_2 + Al_2O_3 + Fe_2O_3$	86.005	70 minimum	It is a natural pozzolana

The table above shows that all of the chemical characteristics of the pumice utilized in this study were within the permissible ranges of ASTM C618. The test result of the chemical analysis of pumice is displayed in table above. This indicates that the total content of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) was 86.005%, which is higher than the ASTM C 618 minimum of 70%, hence pumice is acceptable as a good pozzolan.

Fineness and Specific gravity.

Table 4:2 Physical property test results summary for pumice powder

Physical property test results of Pumice powder			
Physical property	**Test results**	**Requirement**	**Compare result**
Fineness test	4.1%	10 IS:4031(Part 1)-1996	Qualifies as a SCM
Specific gravity	2.3	5 (ASTM C 618-93)	It is a natural pozzolana

From the table above, the physical property of pumice was conducted on the fineness test and it was found to be 4.1%, which is above 10 % in accordance to IS:4031(Part 1)-1996. Therefore, it is acceptable for use as a supplementary cementitious material.

From the same table, Specific gravity as the physical property test for pumice powder was carried out. The result was found to be 2.3 which is less than 5 according to ASTM C 618-93, thus qualifying it to be a natural pozzolana, and hence it is suitable to be used as a partial replacement for cement in concrete to inhibit alkali silica reactions in concrete, which is the purpose of this research.

Setting time results.

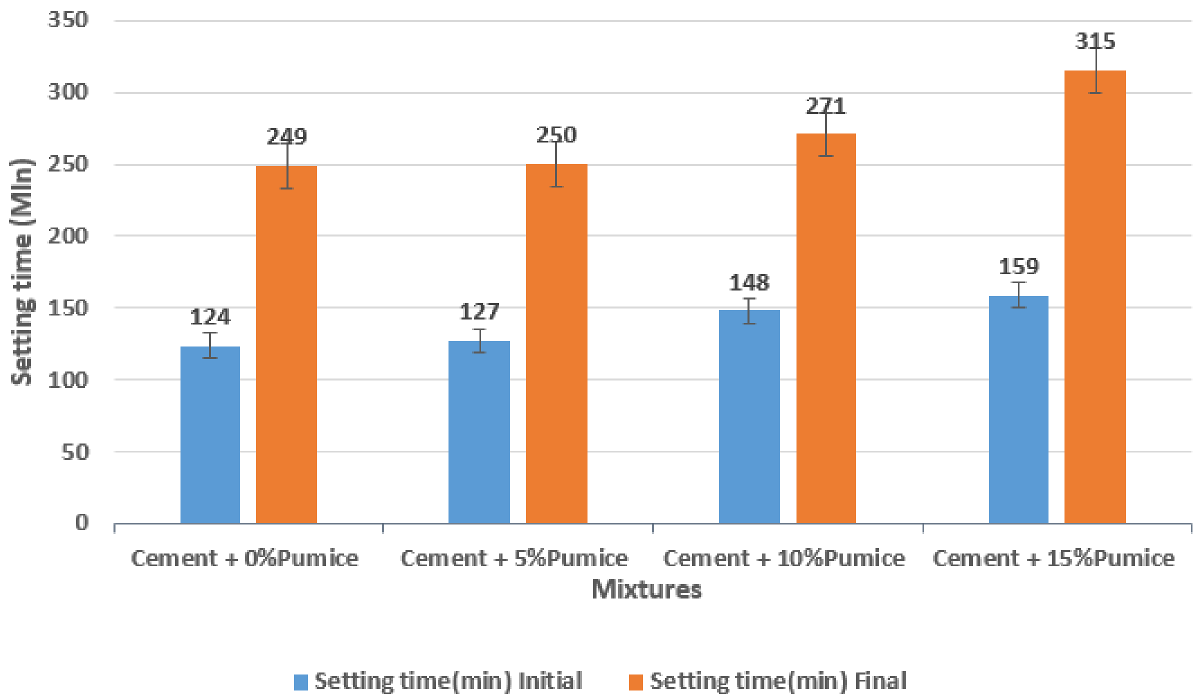

Figure 4-1 Graphical representation of the setting time results

The increasing trend of setting time on the graph, is attributed to the inert filler effect of pumice powder, which reduces the amount of cementitious material present for cement hydration, thus slowing down the overall hydration rate.

Advantages of increased setting time.

- Concrete with an increased setting time, increases the time to enable the complete hydration process of the cement, that potentially improves the strength development of the concrete over a long time period.
- Concrete with a longer setting time, may also have a longer period of initial curing, which could potentially lead to higher early strength development of the concrete.

4.3 THE PROPERTIES OF FRESH CONCRETE ON ADDITION OF PUMICE POWDER.

Material test results.

Table 4:3 Summary results for Sand and Coarse aggregates

SAND	**COMMENT**
Grading	It was found to be a medium sand
Organic Content	Free of injurious amounts of organic impurities
Silt Content	3< 4 (Maximum)
AGGREGATES	**COMMENT**
Grading	Nominal size was found to be 20mm
AIV	10% < 30 (Maximum) BS 882:1992 Concrete works
ACV	18% < 30 (Maximum)BS 882:1992 Concrete works
LAAV	27%< 50 (Maximum)BS 882:1992 Concrete works
10% Fine Value	237 kN >100 (Minimum)BS 882:1992 Concrete works
Water absorption	0.4%< 2(Maximum)BS 882:1992 Concrete works
Specific Gravity	2.61

Sand test results

Table 4:4 Grading results for sand

Sieve Size (mm)	**Percentage Passing the Sieve**	**Specifications: BS 882:1992 (Concrete Works)**	
		Overall Limits	**Additional Limits- M**
10.0	100	100	_
5.0	97	89 - 100	-
2.36	90	60 - 100	65 - 100
1.18	75	30 - 100	45 - 100
0.60	44	15 - 100	25 - 80
0.30	15	5 - 70	5 - 48
0.15	6	0 - 15	-
Silt /Dust Content (%)	3	4 Maximum	
Organic matter by colour comparison (AASHTO T21:00)	Lighter than Standard reference colour	Lighter than Standard reference colour*	

$$\text{Fineness Modulus (FM)} = \frac{\text{(Sum of Cumulative Percentage Retained)}}{100}$$

$$\text{Fineness Modulus (FM)} = \frac{272.9}{100} = 2.7$$

- From the computation above, the fineness modulus was computed as 2.7. which lies within 2.6-2.9. This signifies that the sand is a medium sand as specified in BS 882:1992 for concrete works.
- From the table above, It is also clear that that the sand is well graded since all the values of percentage passing are within the overall limits according to BS 882:1992 for concrete works.

- The silt content of sand was also found to be 3 which is less than 4(maximum) according to BS 882:1992 for concrete works. This shows that the sand is okay since, silt is fine grained, it has a tendency to absorb water, which may have an impact on the ratio of cement to water in concrete mixtures. A high silt content can reduce the workability of the concrete, making it more challenging to compact and place. Acceptable ranges for the workability of the concrete can be maintained by utilizing sand that has a silt concentration lower than the maximum limit
- The Organic matter result was sand lighter than Standard reference colour according to (AASHTO T21:00), implying that Sand for mortar and concrete is free of injurious amounts of organic Impurities whose presence is indicated by **a colour darker than the Standard reference colour.**

Coarse aggregates results discussion

For water absorption: From table of results above, a water absorption of 0.4% was obtained which was less than 2%, according to BS 882:1992 for concrete works. Also, the **specific gravity** for coarse aggregates was found to be 2.61 which is within the range of 2.6 to 2.7 as per BS Standards BS 882:1992. This approves the coarse aggregate as suitable for use in the concrete mixes.

For AIV: From both Tables of results above, the coarse aggregates had a lower AIV of 10% which was less than the standard value of 30% (according to)BS 882:1992 for concrete works), this indicated a higher impact resistance, hence implying more durable and stronger aggregates.

NOTE: The maximum percentage of AIV that concrete should have in non-wearing areas is 45%; in wearing areas, such as floors, runways, and pavements, it should be 30%; and in road pavements, it should be 25%.

For ACV: An ACV of 18% was obtained implying that the coarse aggregates are strong enough and qualify for use in concrete. This is because, the crushing value isn't supposed to exceed 30% for concrete used in construction, as per BS 882:1992.

NOTE: Aggregates with a lower crushing value, are considered stronger aggregates, thus once used in a concrete mix, can produce more stronger and durable concrete.

For TFV: The TFV result obtained as from the table of results above was a load of 237kN, which was greater than 100kN stated in BS 882:1992 for concrete works, meaning, they require a large load to be crushed, hence such coarse aggregates are suitable for use, as have the ability to withstand crushing under different loads once used in a construction project.

For LAAV: From the table of results above, an LAAV of 27% was obtained, implying, that the aggregates are hard enough, to resist wearing and abrasion, hence qualify for use in the concrete mix. For normal concrete works, coarse aggregates should not have an LAA value greater than 50%, Since the result obtained is less than 50%, hence the aggregates are suitable.

Coarse aggregates Grading results.

Table 4:5 Grading Results summary for the Coarse aggregates

Sieve size (mm)	**% Passing the sieve size**	**Specifications:** BS 882:1992 (Concrete works) (%)
37.5	100	100
20.0	87	85 – 100
14.0	25	0 – 70
10.0	2	0 – 25
5.0	1	0 – 5
Flakiness Index (%)	23	35 Maximum

From the table above, the coarse aggregates were classified to have a nominal size of 20mm, since according to the specifications of BS 882:1992 (Concrete works), there is a large percentage passing the 20mm sieve of 87%.

From the table of results above, since the upper limit for FI is 35% according to BS 882:1992 (for Concrete works**),** with 23%, this simply implies that the sample is less flaky hence good for construction, as such aggregates will durable concrete, with a high level of bonding and interlocking.

Slump tests results.

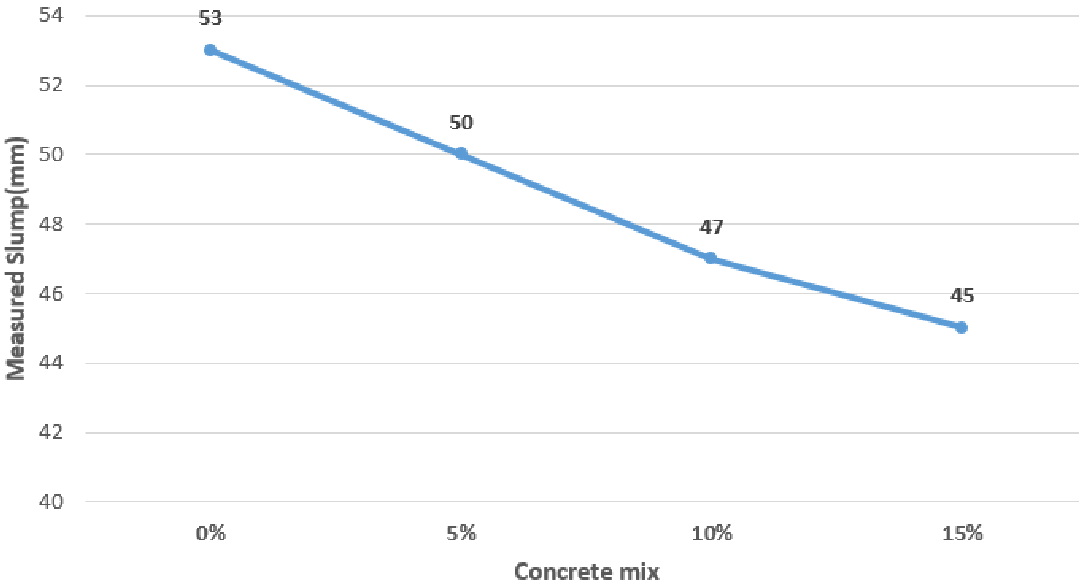

Figure 4-2 Graphical Illustration of the Slump behavior of the fresh concrete.

From the figure above, the replacement of cement with pumice for the neat mix, and the mixes with 5%, 10% and 15% pumice powder, showed an approximately 6% reduction in workability of the concrete mix. This therefore indicates that the results have an overall reduction in workability of the concrete mixes with the percentage increment in the pumice powder. This decreasing trend of slump is due to porous and high specific surface area of Pumice powder which is greater than cement, hence absorbs more water than cement alone, thus effectively reducing the available water in the mixture, resulting in reduction in fluidity/workability of the concrete mixture.

Since the slump range of the concrete mix is 30-60mm, according to the mix design, the slump results of all the four mixes are acceptable as shown in the figure above.

4.4 THE PERCENTAGES OF EXPANSIONS DUE TO ASR AND OTHER PROPERTIES OF HARDENED CONCRETE AT VARYING PROPORTIONS OF PUMICE POWDER.

AMBT test results obtained.

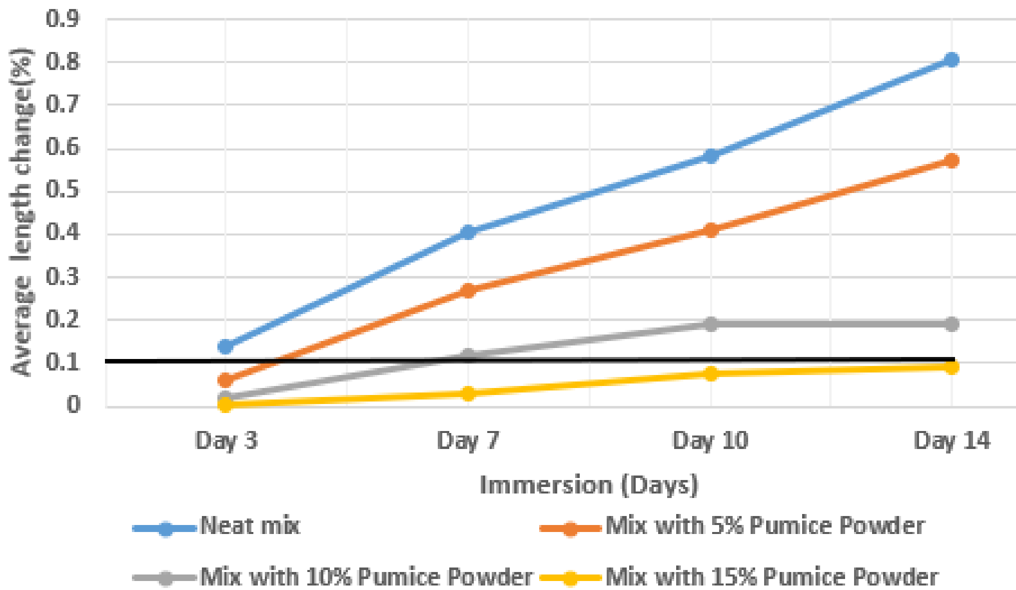

Figure 4-3 Graphical illustration of concrete bar expansions due to ASR

Increment in pumice powder partial replacements in the mixes, indicates a reduction in the percentage length change at Day 14 of immersion, this is due to the pozzolanic activity of pumice powder, which inhibits the reactions, thus accounting for the length change drop at Day 14.

The Neat mix

It showed an high, average percentage length change on monitoring it in a interval of 3 and 4 days totaling up to 14 days as stated in the ASTM specifications, that is on day 14, it had attained a percentage of 0.804% which is way above 0.2%, that is stated in the standards, above which concrete is considered to have considerably high amounts of deterioration reactions (alkali silica reactions).

This clearly justifies what was mentioned in the problem statement, as a problem of the existence of alkali silica reactions in the concrete.

Mix with 5% pumice powder.

The graph clearly shows that on addition of pumice powder, the percentage length change values due to expansions in concrete reduced from 0.804% of the control mix to 0.571%, which evidently shows the contribution of the pozzolanic activity of pumice powder, in reducing the expansions, this is what accounts of the drop in the percentage length change values on addition of pumice powder.

Mix with 10% pumice powder.

The percentage length change value further drops from 0.571% to 0.19%, which can be interpreted as, the concrete having moderate deterioration reactions (Alkali silica reactions). This is still attributed to the pumice powder role in reducing the reactions that cause the expansions.

Mix with 15% pumice powder.

Here, the percentage length change value, drops further to a value of 0.09%, which is below the Acceptable limit of 0.1%, according to ASTM C 1567. This represents the presence of low alkali silica reactions in the concrete.

Compressive strength test results.

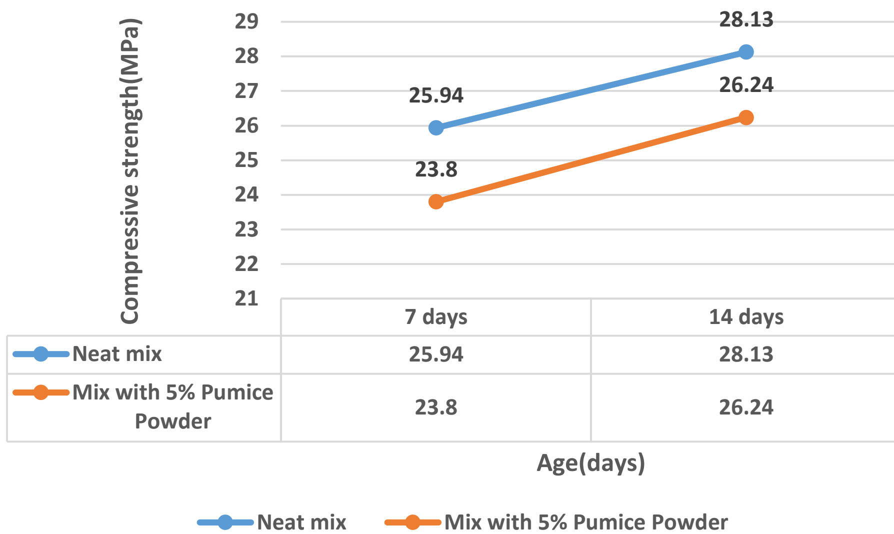

Figure 4-4 Compressive strength results attained for the Neat mix and one with 5% partial replacement of cement with pumice powder

The compressive strength test was in carried out according to BS 1881 PART 116:1983 using a compressive testing machine, with a loading rate that is constant and the variations in the results of compressive strength obtained. Triplicates of concrete cubes of dimensions 150 x 150 x 150 mm were subjected to compression after 7, 14 and 28 days of curing and the compressive strength analysis attained for all the days.

For the preliminary results, compressive strength values for all the four mixes at 7days and also for the neat mix and the mix with 5% pumice powder at 14 days were obtained. Results for 7- and 14-days curing age for both the neat and the mix at 5% pumice powder are as clearly illustrated graphically in the figure above.

From the figure above, there is a slight drop in compressive strength of the neat sample at the 5% partial replacement of cement with pumice powder and this because, At low percentage replacements, the amountof silica is low, thus only a limited quantity of C-S-H is formed, from the reaction between SiO_2 the and the large amounts of $Ca(OH)_2$ liberated from the hydration of the relatively large amounts of cement available. (Since C-S-H has cementitious properties, its limited concentration, accounts for slight drop in Compressive strength at 5% partial replacement for 7 &14 days age.)

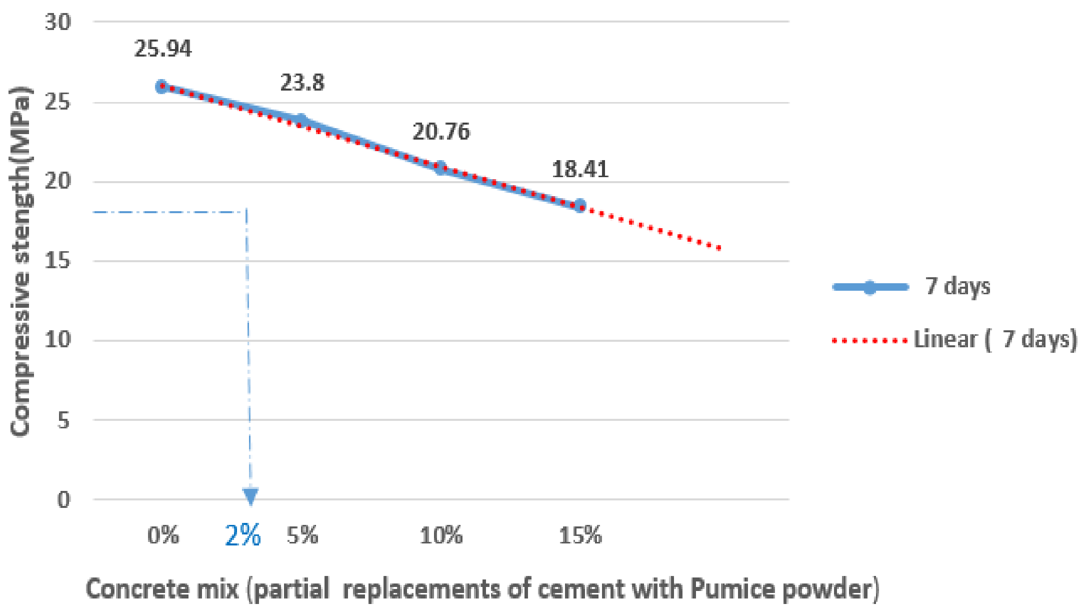

Figure 4-5 Graph identifying the percentage at which 25 Mpa can be attained at 7 days curing age

From the graph above, it is clear that to obtain 25Mpa of concrete strength at 7 days curing age, the partial replacement of cement with pumice powder to have this achieved should be 2%, as clearly shown in the graph.

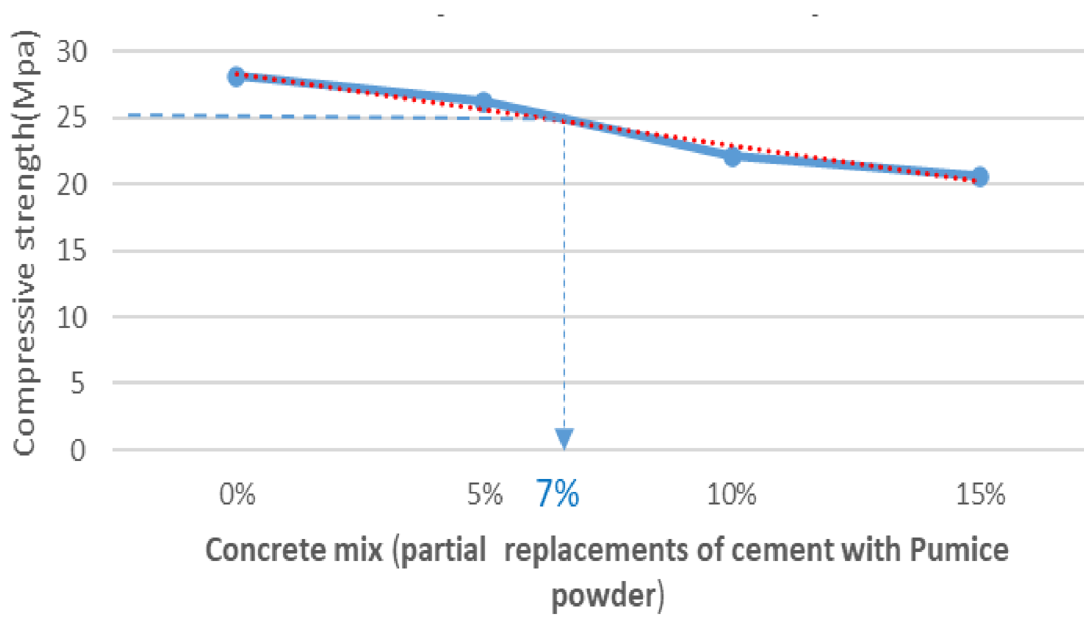

Figure 4-6 Graph identifying the percentage at which 25 Mpa can be attained at 14 days curing age.

From the graph above, it is clear that to obtain 25Mpa of concrete strength at a curing age of 14days, the partial replacement of cement with pumice powder to have this achieved should be 7%, as clearly shown in the graph.

Compressive strength test results for all the concrete mixes at all the curing days.

A detailed representation of the compressive results for the different mixes at the different curing ages is clearly shown in the appendix.

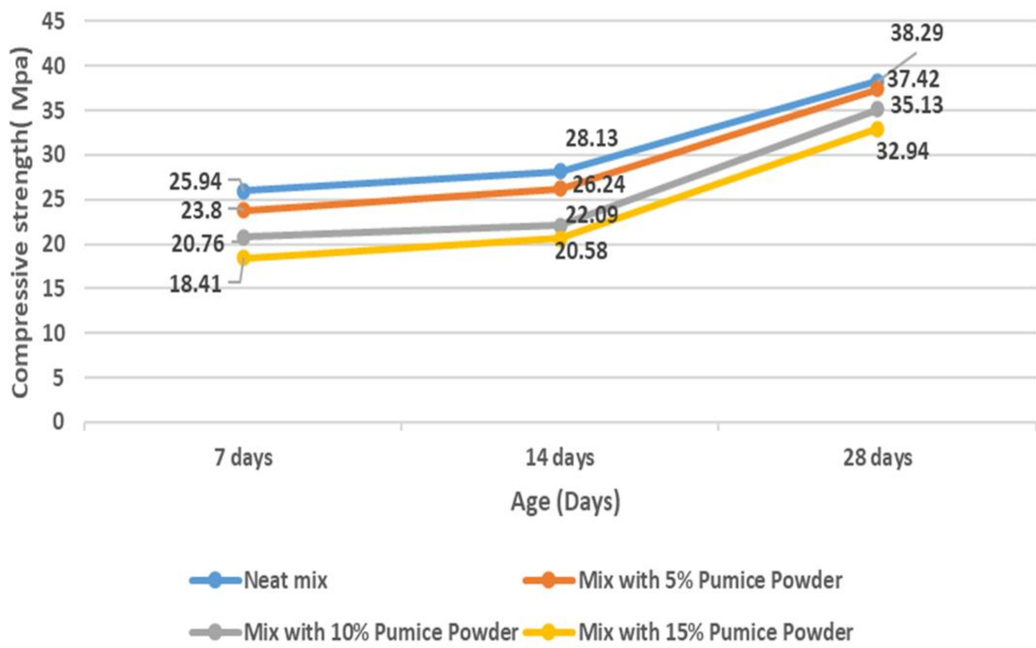

Figure 4-7 Graphical illustration of compressive strength attained by concrete at different curing days.

At low percentage replacements, the silica quantity is low, thus only a limited quantity of C-S-H is formed, from the reaction between SiO_2 the and the large amounts of $Ca(OH)_2$ liberated from the hydration of the relatively large amounts of cement available.

However, at high percentage replacements, the pozzolana quantity increases in the mix, and CSH reduces due to liberation of small quantities of $Ca(OH)_2$ from the hydration of a relatively small quantity of cement available.

Since C-S-H has cementitious properties, its limited concentration, accounts for trend of the graph, that is the general drop in compressive strength of the different mixes at the different curing days.

Water absorption test results obtained

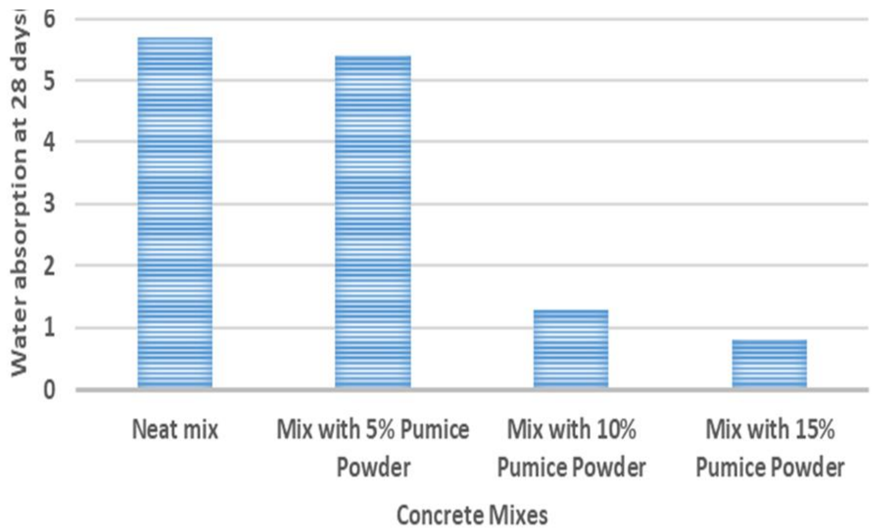

Figure 4-8 Graphical illustration for water absorption results obtained at 28 days.

The water absorption reduction is due to the contribution of Pumice powder which has considerably large amounts of silica, that react with Calcium hydroxide liberated from the hydration of cement, to form Calcium silicate hydrate gel that is cementitious in nature and binds the pores of the concrete specimen, thus reducing the water movement through the free voids in the concrete.

Results relation with Durability of the concrete.

It is important to note that the absorption test is one of the widely used tests in ascertaining the durability of concrete. Durability simply refers to the concrete ability to resist abrasion, weathering actions and chemical attacks while maintaining the engineering properties desired. Test results showed a low water absorption of the concrete at 25days of curing, as the percentage of replacement of cement with pumice powder increased. This implies a low permeability and porosity, which reduces the risk of the ingress of harmful substances like water, ions sulphides and others, which could compromise the quality of the concrete. With such a water absorption result, this clearly shows that the concrete is durable enough to stand the test of time.

Benefits of reducing water absorption of concrete.

It is important to note that concrete with a low water absorption has a low permeability and porosity thus can be able to prevent the ingress of harmful substances like water, ions , sulphates, thus protecting the concrete from chemical attacks like sulphate attack, alkali silica reaction, and other deterioration mechanisms.

A reduced water absorption also is advantageous, as it enhances the compressive strength of the concrete. Concrete with a high-water absorption will have issues of the cement paste separating from the aggregates in the concrete matrix, which in term has great implications on the compressive strength and flexural strength of the concrete. Concrete with a low water absorption will have the cement paste remain intact with the aggregates thus enhancing the strength of the concrete.

The other benefit of a low water absorption is that it protects the embedded steel reinforcement in concrete from rusting thus enhancing the durability of the concrete.

DESIGN

Selection of optimum percentage partial replacement of pumice powder.

Table 4:6 selection of the optimum percentage.

Pumice powder content(%)	Compressive strength at 28 days (Mpa)	Average Length change at Day-14(%)	Water absorption(%)	Workability (mm)
0%	38.29	0.804	5.7	53
5%	37.42	0.571	5.4	50
10%	35.13	0.19	1.3	47
15%	32.94	0.09	0.8	45

Justification for selection of 15% as the optimum.

Basing on the results tabulated above from the tests carried out, an optimum percentage for partial replacement of cement with pumice powder was selected in the design. The points below clearly justify why 15% partial replacement percentage was chosen;

For compressive strength, 32.94Mpa was used in the selection of the percentage, as it is way above the characteristic strength designed for of 25Mpa at 28 days under the C25 class of concrete designed for.

Under average length change percentage at day-14, a value of 0.09% was obtained which is below the Acceptable limit of 0.1% stated in specifications of ASTM C 1567, which implies low alkali silica reactions, in otherwards it implies, that concrete is safe from the deleterious reactions. This qualifies 15% as the optimum percentage.

For water absorption in concrete, the lower it is, the better, as concrete with a low water absorption as explained earlier, has a low porosity and permeability which limits the ingress of harmful substances in the concrete that may compromise its quality, for example water which may not only reduce the bond between the mortar paste and the aggregates thus affecting the flexural and compressive strength of the concrete, but can also result into resting of the embedded steel reinforcement. Low water absorption will also protect the concrete from deleterious mechanisms/reactions like sulphate attack by not allowing ingress of ions, sulphates in the concrete.

From the workability results, the 45mm slump was used to select 15% as the optimum, as this slump value was lying within the design slump under the mix design of 30-60 mm which is (a low degree slump.)

At 15% pumice powder content as the optimum, a **1 : 2 : 4.** mix ratio was adopted and was obtained by dividing the values of both the fine and course aggregates by cement value for this mix.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. The first objective on determining the properties of Pumice powder, was achieved, as from the tests carried out on both the physical and chemical properties of Pumice powder, it qualified as a Supplementary cementitious material and a natural pozzolana in accordance to ASTM-618, thus can be used in concrete to inhibit alkali silica reactions.
2. The second objective on exploring the properties of fresh concrete on addition of Pumice powder, was also achieved, as the properties of fresh concrete were determined and concrete was workable enough as the slump at 0%, 5%,10%, and 15% replacement of cement with pumice were 53mm, 50mm, 47mm, and 45mm respectively which all were lying within the low design slump of 30- 60(mm).
3. The third objective on ascertaining the percentages of expansions due to ASR and other properties of hardened concrete at varying proportions of Pumice powder, was achieved, as 15% partial replacement, gave low expansions in concrete due to Alkali-silica reactions in concrete, since the percentage length change attained at Day 14 was 0.09% < 0. 1%, which is the acceptable limit. Other properties of hardened concrete were also attained including water absorption which was found to reduce with percentage increment of pumice powder. Compressive strength results passed for all the percentage replacements of cement with pumice powder, as they all satisfied the characteristic and target mean strength designed for.

4. The fourth objective on determining a mix design of concrete with Pumice powder as a partial replacement of cement was also achieved, as a mix design was determined and a mix ratio of **1: 2: 4** adopted at 15% partial replacement of cement with pumice powder.

5.2 RECOMMENDATIONS

- The non reinforced concrete designed for of mix ratio 1: 2: 4, with low alkali silica reactivity, low water absorption and allowable compressive strength attained for C25 can be used for making concrete blocks, which can be used in various construction works, such as load bearing walls for building structures like turbine blocks, machine halls, wall fences and residential houses.
- Further studies should be carried at higher percentages above the optimum determined.
- Further research should be carried out on how to lower the setting time of concrete with increment in partial replacement of cement with pumice powder.

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APPENDIX A: XFR TEST RESULTS FOR PUMICE POWDER.

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In any Correspondence on this subject please quote No. GE 041/2024

THE REPUBLIC OF UGANDA
FOR GOD AND MY COUNTRY

MINISTRY OF INTERNAL AFFAIRS
DIRECTORATE OF GOVERNMENT ANALYTICAL LABORATORY
Plot No. 2 Lourdel Road
Wandegeya,
P.O. BOX 105639
Kampala - Uganda

31st January 2024

MR. SSEBULIBA RODNEY AND MR MUGUME MUSA
REG NO. S20B32/040 & S16B32/448
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-782-421994

REPORT OF ANALYSIS

Description of the Samples
One sample in a black polythene bag containing Pozzolana Sample was submitted by Mr. SSebuliba Rodney, on 25th January 2024, and analysed on 31st January 2024. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Cream solid substance sample packed in a black polythene bag.	01	Sample "A" GE 041/2024

Analysis Requested
Elemental analysis

Method of Analysis
Elemental analysis was done using the XRF Method.

Results of Analysis
The above sample has been analyzed with the following results as below

Parameter	Units	Results Pozzolana sample GE 041/2024
Silicon dioxide	% m/m	63.496
Aluminum oxide	% m/m	13.552
Iron (III) Oxide	% m/m	8.957
Magnesium Oxide	% m/m	4.745
Calcium Oxide	% m/m	3.382
Sodium oxide	% m/m	2.497
Manganese (II)Oxide	% m/m	1.573
Titanium di oxide	% m/m	1.119
Europium (III) oxide	% m/m	0.332
Potassium Oxide	% m/m	0.346

Remarks
1. Results relate to sample analyzed and are reported as on received basis.

31/01/2024

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1

APPENDIX B: LAB PHYSICAL TESTS RESULTS FOR PUMICE POWDER AND CEMENT

CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA
PROJECT : FINAL YEAR PROJECT
DATE : 20 JANUARY 2024

TEST RESULTS FOR A SAMPLE OF PUMICE POWDER AND CEMENT (Tested in accordance with the requirements in Uganda Standard, US EAS 18-1:2017 and in accordance with the various test methods in BS EN 196 listed with results)

Source and Type of Cement: Tororo Cement Limited, Portland Cement CEM 1/42.5N

A. Physical Tests

Test	Unit	Test Method	Results	Specifications: Uganda Standard US EAS 18-1:2017 for strength class 42.5N
Initial setting time (Vicat apparatus) for Cement (control)	Minutes	EN196-3:2016	124	≥60
Final setting time (Vicat apparatus) for Cement(control)	Minutes	EN196-3:2016	249	--
Initial setting time (Vicat apparatus) for mixture with 5% pumice powder	Minutes	EN196-3:2016	127	≥60
Final setting time (Vicat apparatus) for mixture with 5% pumice powder	Minutes	EN196-3:2016	250	--
Initial setting time (Vicat apparatus) for mixture with10% pumice powder	Minutes	EN196-3:2016	148	≥60
Final setting time (Vicat apparatus) for mixture with 10% pumice powder	Minutes	EN196-3:2016	271	--
Initial setting time (Vicat apparatus) for mixture with 15% pumice powder	Minutes	EN196-3:2016	159	≥60
Final setting time (Vicat apparatus) for mixture with 15% pumice powder	Minutes	EN196-3:2016	315	--
Fineness(sieving method)	%	EN196-3:2016	4.1	10
Specific Gravity(Le Chatelieur)	-	EN196-3:2016	2.3	--

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CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA
PROJECT : FINAL YEAR PROJECT
DATE : 20 JANUARY 2024

TEST RESULTS FOR A SAMPLE OF PUMICE POWDER AND CEMENT (Tested in accordance with the requirements in Uganda Standard, US EAS 18-1:2017 and in accordance with the various test methods in BS EN 196 listed with results)

Source and Type of Cement: Tororo Cement Limited, Portland Cement CEM 1/42.5N

A. Physical Tests

Consistency (Vicat apparatus) for Cement (control)	%	EN196-3:2016	26	--
Consistency (Vicat apparatus) for mixture with 5% pumice powder	%	EN196-3:2016	26.6	--
Consistency (Vicat apparatus) for mixture with 10% pumice powder	%	EN196-3:2016	27	--
Consistency (Vicat apparatus) for mixture with 15% pumice powder	%	EN196-3:2016	27.4	--

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APPENDIX C: LAB RESULTS FOR TESTS ON SAND.

CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA

PROJECT : FINAL YEAR PROJECT

DATE : 19th December, 2023

TEST RESULTS FOR SAND SAMPLE FROM NKOKONJERU (TESTED IN ACCORDANCE WITH BS 882:1992 AND AASHTO DESIGNATION: T21:00)

Sieve Size (mm)	Percentage Passing the Sieve	Specifications: BS 882:1992 (Concrete Works)	
		Overall Limits	Additional Limits- M
10.0	100	100	–
5.0	97	89 – 100	–
2.36	90	60 – 100	65 – 100
1.18	75	30 – 100	45 – 100
0.60	44	15 – 100	25 – 80
0.30	15	5 – 70	5 – 48
0.15	6	0 – 15	–
Silt /Dust Content (%)	3	4 Maximum	
Organic matter by colour comparison (AASHTO T21:00)	Lighter than Standard reference colour	Lighter than Standard reference colour*	

Legend: *Sand for mortar and concrete shall be free of injurious amounts of organic Impurities whose presence is indicated by a **colour darker than the Standard reference colour.**

M - Medium

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CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA

PROJECT : FINAL YEAR PROJECT

DATE : 19th December, 2023

RESULTS FOR EVALUATION OF FINENESS MODULUS FOR SAND FROM NKOKONJERU (Tested in accordance with ASTM C136)

Sieve Size (mm)	Mass Retained (%)	% Retained (%)	Cumulative % Retained (%)	Fineness Modulus (FM)
10.0	3.00	0.31	0.31	2.73
5.0	26.00	2.67	2.98	
2.36	66.00	6.78	9.76	
1.18	150.00	15.40	25.16	
0.600	299.00	30.70	55.86	
0.300	285.00	29.26	85.12	
0.150	84.00	8.62	93.74	
Total	-	-	272.90	-

$$\text{Fineness Modulus (FM)} = \frac{\text{(Sum of Cumulative Percentage Retained)}}{100}$$

$$\text{FM} = \frac{272.9}{100} = 2.73$$

For Fine Sand - FM - 2.2 - 2.6
Medium Sand- FM - 2.6 - 2.9 ⟵
Coarse Sand - FM - 2.9 - 3.2

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APPENDIX D: LAB RESULTS FOR TESTS ON AGGREGATES

CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA

PROJECT: FINAL YEAR PROJECT

DATE : 20th December, 2023

SUMMARY OF RESULTS FOR AGGREGATES FROM JESANI QUARRY MUKONO TESTED IN ACCORDANCE WITH BS 882:1992 & MoWHC (2005)

A. GRADING AND SHAPE: 20MM NOMINAL SINGLE SIZE AGGREGATES

Sieve size (mm)	% Passing the sieve size	Specifications: BS 882:1992 (Concrete works) (%)
37.5	100	100
20.0	87	85 – 100
14.0	25	0 – 70
10.0	2	0 – 25
5.0	1	0 – 5
Flakiness Index (%)	23	35 Maximum

B. PHYSICAL AND MECHANICAL STRENGTH TESTS

TEST	UNIT	RESULT	Specifications: BS 882:1992 (Concrete works) (%)
Aggregate Impact Value	%	10	30 Max.
Aggregate Crushing Value	%	18	30 Max.
Los Angeles Abrasion Value	%	27	50 Max.
10% Fines Value (Dry)	kN	237	100 Min.
Water Absorption	%	0.4	2 Max.
Specific Gravity	%	2.61	-

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APPENDIX E: CONCRETE MIX DESIGN TEMPLATE

FINAL YEAR PROJECT

BRITISH METHOD DEPARTMENT OF ENVT.

Concrete mix design form

Job title ....

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength	Specified	25 N/mm² at 28 days
				Proportion defective 5 %
	1.2	Standard deviation	Fig 3	1.64 N/mm² or no data 8 N/mm²
	1.3	Margin	C1 or Specified	(k = 1.64) 1.64 × 8 = 13.12 N/mm²
				13 N/mm²
	1.4	Target mean strength	C2	25 + 13 = 38 N/mm²
	1.5	Cement strength class	Specified	✓ 42.5/52.5
	1.6	Aggregate type: coarse		Crushed/uncrushed
		Aggregate type: fine		Crushed/uncrushed ✓
	1.7	Free-water/cement ratio	Table 2, Fig 4	0.58
	1.8	*Maximum free-water/cement ratio*	*Specified*	– } Use the lower value 0.58
2	2.1	Slump or Vebe time	Specified	Slump 30–60 mm or Vebe time 3–6 s
	2.2	Maximum aggregate size	Specified	20 mm
	2.3	Free-water content	Table 3	210 — 210 kg/m³
3	3.1	Cement content	C3	210 ÷ 0.58 = 362.07 kg/m³
	3.2	*Maximum cement content*	*Specified*	.... kg/m³
	3.3	*Minimum cement content*	*Specified*	.... kg/m³
				use 3.1 if ≤ 3.2; use 3.3 if > 3.1 — 362.07 kg/m³
	3.4	Modified free-water/cement ratio		– — –
4	4.1	Relative density of aggregate (SSD)		2.61 known/assumed
	4.2	Concrete density	Fig 5	2340 kg/m³
	4.3	Total aggregate content	C4	2340 − 362.07 − 210 = 1767.93 kg/m³
5	5.1	Grading of fine aggregate	Percentage passing 600 μm sieve	44 %
	5.2	Proportion of fine aggregate	Fig 6	38 %
	5.3	Fine aggregate content	C5	1767.93 × 0.38 = 671.81 kg/m³
	5.4	Coarse aggregate content	C5	1767.93 − 671.81 = 1096.12 kg/m³

Quantities	Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg) 10 mm	20 mm	40 mm
per m³ (to nearest 5 kg)	362.07	210	671.84		1096.12	
per trial mix of .... m³						

Items in italics are optional limiting values that may be specified (see Section 7).
Concrete strength is expressed in the units N/mm². 1 N/mm² = 1 MN/m² = 1 MPa (N = newton; Pa = pascal.)
The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.
SSD = based on the saturated surface-dry condition.

APPENDIX F: CONCRETE MIX DESIGN PROPORTIONS AND SLUMP RESULTS OBTAINED

CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA

PROJECT : FINAL YEAR PROJECT

DATE : 2nd February 2024

CONCRETE DESIGN MIX PROPORTIONS FOR CLASS: C25 USING BRITISH – DOE MIX DESIGN METHOD

Class of Concrete	Type of Cement	Cement Content (Kg/m^3)	Pumice powder content (Kg/m^3)	Sand Content (Kg/m^3)	Coarse Aggregates Content (Kg/m^3)	Water Content (Kg/m^3)	Measured Slump (mm)
C25 (0% PUMICE)	Tororo CEM1/42.5	362	-	672	1096	210	53
C25 (5% PUMICE)	Tororo CEM1/42.5	344	18	672	1096	205	50
C25 (10% PUMICE)	Tororo CEM1/42.5	326	36	672	1096	196	47
C25 (15% PUMICE)	Tororo CEM1/42.5	308	54	672	1096	191	45

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APPENDIX G: LAB TEST RESULTS FOR ALKALI SILICA REACTIONS TESTS

CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA
PROJECT : FINAL YEAR PROJECT
DATE : 1st MARCH 2024

RESULTS FOR ALKALI SILICA REACTIVITY OF CONCRETE SAMPLES/ BARS MADE FROM MIXES WITH DIFFERENT PARTIAL REPLACEMENTS OF CEMENT WITH PUMICE POWDER. (Tested in accordance with the ASTM standards C 1567 – 08 Accelerated Mortar Bar-Method)

Pozzolan	Percentage partial replacement	Number of specimens	Average % length change at different days			
			3	7	10	14
Control	0	3	0.137	0.407	0.584	0.804
Pumice powder	5	3	0.062	0.271	0.408	0.571
	10	3	0.021	0.118	0.19	0.190
	15	3	0.006	0.031	0.077	0.090

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CML CENTRAL MATERIALS LABORATORY	WORKING SHEET ACCELERATED MORTAR BAR TESTS (AMBT)	
Project: FINAL YEAR PROJECT	Date	1/03/2024
Client : SSEBULIBA RODNEY$ MUGUME MUSA		
Responsible Technician: MADAM ENID	Checked by	Mr. Okello Nobert

Pozzolan	Percentage partial replacement		Final lengths and % length changes at different days		
			3		
L_0=300.00			BAR 1	BAR2	BAR3
Control	0	Length final (L_f)	300.411	300.411	300.414
		% length change	**0.137**	**0.137**	**0.138**
Pumice powder	5	Length final (L_f)	300.183	300.186	300.186
		% length change	**0.061**	**0.062**	**0.062**
	10	Length final (L_f)	300.060	300.063	300.066
		% length change	**0.02**	**0.021**	**0.022**
	15	Length final (L_f)	300.018	300.018	300.021
		% length change	**0.006**	**0.006**	**0.007**

Pozzolan	Percentage partial replacement		Final lengths and % length changes at different days		
			7		
L_0=300.00			BAR 1	BAR2	BAR3
Control	0	Length final (L_f)	301.200	301.230	301.233
		% length change	**0.4**	**0.41**	**0.411**
Pumice powder	5	Length final (L_f)	300.813	300.816	300.810
		% length change	**0.271**	**0.272**	**0.27**
	10	Length final (L_f)	300.354	300.351	300.354
		% length change	**0.118**	**0.117**	**0.118**
	15	Length final (L_f)	300.090	300.093	300.096
		% length change	**0.03**	**0.031**	**0.032**

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CML CENTRAL MATERIALS LABORATORY	WORKING SHEET ACCELERATED MORTAR BAR TESTS (AMBT)	
Project: FINAL YEAR PROJECT	Date	1/03/2024
Client : SSEBULIBA RODNEY$ MUGUME MUSA		
Responsible Technician: MADAM ENID	Checked by	Mr. Okello Nobert

Pozzolan	Percentage partial replacement		Final lengths and % length changes at different days		
			10		
L_0=300.00			BAR 1	BAR2	BAR3
Control	0	Length final (L_f)	301.752	301.749	301.755
		% length change	**0.584**	**0.583**	**0.585**
Pumice powder	5	Length final (L_f)	301.227	301.221	301.221
		% length change	**0.409**	**0.407**	**0.407**
	10	Length final (L_f))	300.570	300.540	300.600
		% length change	**0.19**	**0.18**	**0.2**
	15	Length final (L_f)	300.228	300.234	300.228
		% length change	**0.076**	**0.078**	**0.076**

Pozzolan	Percentage partial replacement		Final lengths and % length changes at different days		
			14		
L_0=300.00			BAR 1	BAR2	BAR3
Control	0	Length final (L_f)	302.412	302.415	302.409
		% length change	**0.804**	**0.805**	**0.803**
Pumice powder	5	Length final (L_f)	301.713	301.710	301.716
		% length change	**0.571**	**0.57**	**0.572**
	10	Length final (L_f)	300.570	300.600	300.540
		% length change	**0.19**	**0.2**	**0.18**
	15	Length final (L_f)	300.270	300.240	300.300
		% length change	**0.09**	**0.08**	**0.1**

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APPENDIX H: LAB TEST RESULTS FOR COMPRESSIVE STRENGTH ATTAINED AT 7, 14 AND 28 DAYS.

CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA

PROJECT : FINAL YEAR PROJECT

DATE : 2nd February 2024

TEST RESULTS FOR CONCRETE CUBES MADE FROM MIX DESIGN PROPORTIONS FOR CLASS C25

DATE MADE	DATE TESTED	DIMENSIONS (mm)	WEIGHT (Kg)	DENSITY (Kg/m^3)	CRUSHING LOAD (kN)	ULTIMATE COMPRESSIVE STRENGTH (MPa)
13.01.2024 C25 NEAT MIX	20.01.2024	150 x 150 x 150	8.2	2430	543	24.1
(7days)	"	"	8.2	2430	608	27.0
"	"	"	8.2	2430	600	26.7
15.01.2024 C25 5% PUMICE	22.01.2024	150 x 150 x 150	8.1	2400	550	24.4
(7 days)	"	"	8.2	2430	520	23.1
"	"	"	8.1	2400	537	23.9
20.01.2024 C25 10% PUMICE	27.01.2024	150 x 150 x 150	8.1	2400	470	20.9
(7 days)	"	"	8.2	2430	448	19.9
"	"	"	8.2	2430	484	21.5
21.01.2024 C25 15% PUMICE	28.01.2024	150 x 150 x 150	7.9	2341	409	18.2
(7 days)	"	"	7.9	2341	445	19.8
"	"	"	8.0	2370	388	17.2

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MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA

PROJECT : FINAL YEAR PROJECT

DATE : 2nd February 2024

TEST RESULTS FOR CONCRETE CUBES MADE FROM MIX DESIGN PROPORTIONS FOR CLASS C25

13.01.2024 C25 NEAT MIX (14 days)	27.01.2024	150 x 150 x 150	8.2	2430	651	29.0
"	"	"	8.2	2430	613	27.2
"	"	"	8.2	2430	634	28.2
15.01.2024 C25 (5% PUMICE) (14 days)	29.01.2024	150 x 150 x 150	8.2	2430	618	27.5
"	"	"	8.2	2430	597	26.5
"	"	"	8.2	2430	557	24.8

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20.01.2024(C25 10% PUMICE) (14 days)	2.02.2024	150 x 150 x 150	8.1	2400	496.97	22.09	
"	"	"	8.1	2400	497.46	22.11	
"	"	"	8.1	2400	496.88	22.08	
21.01.2024(C25 15% PUMICE) (14 days)	3.02.2024	150 x 150 x 150	8.0	2370	478.59	21.27	
"	"	"	8.2	2430	466.53	20.74	
"	"	"	8.1	2400	443.86	19.73	

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CENTRAL MATERIALS LABORATORY

CLIENT : M/S SSEBULIBA RODNEY AND MUGUME MUSA

PROJECT : FINAL YEAR PROJECT

DATE : 12th March 2024.

TEST RESULTS FOR CONCRETE CUBES MADE FROM MIX DESIGN PROPORTIONS FOR CLASS C25

DATE MADE	DATE TESTED	DIMENSIONS (mm)	WEIGHT (Kg)	DENSITY (Kg/m^3)	CRUSHING LOAD (kN)	ULTIMATE COMPRESSIVE STRENGTH (MPa)	WATER ABSORPTION MEASURED (%)
13.01.2024(C25 0% PUMICE) (28days)	09.02.2024	150 x 150 x 150	8.1	2400	899.14	39.96	5.7
"	"	"	8.1	2400	766.91	34.09	
"	"	"	8.1	2400	918.66	40.83	
15.01.2024(C25 5% PUMICE) (28 days)	11.02.2024	150 x 150 x 150	8.2	2430	937.43	41.66	5.4
"	"	"	8.2	2430	899.98	40.00	
"	"	"	8.2	2430	688.57	30.60	
20.01.2024(C25 10% PUMICE) (28 days)	16.02.2024	150 x 150 x 150	8.1	2400	787.72	35.01	1.3
"	"	"	8.1	2370	788.98	35.07	
"	"	"	8.1	2370	794.48	35.31	
21.01.2024(C25 15% PUMICE) (28 days)	17.02.2024	150 x 150 x 150	8.2	2430	697.73	31.01	0.8
"	"	"	8.2	2430	787.7	35.01	
"	"	"	8.3	2459	738.13	32.81	

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APPENDIX I: LAB TEST RESULTS FOR WATER ABSORPTION

CML CENTRAL MATERIALS LABORATORY	WORKING SHEET	
	WATER ABSORPTION TESTS	
Project: FINAL YEAR PROJECT	Date	12/03/2024
Client : SSEBULIBA RODNEY$ MUGUME MUSA		
Responsible Technician: MADAM ENID	Checked by	MADAM ENID

TEST RESULTS FOR WATER ABSORPTION OF CONCRETE CUBES MADE FROM MIX DESIGN PROPORTIONS FOR CLASS C25

Percentage partial replacement of cement with pumice powder (%)		Dry mass (kg)	Wet mass (kg)	Percentage Water absorbed (%)	Average Percentage Water absorbed (%)
0	Sample 1	7.650	8.140	6.405	5.670
	Sample 2	7.700	8.080	4.935	
5	Sample 1	7.820	8.240	5.371	5.402
	Sample 2	7.730	8.150	5.433	
10	Sample 1	8.000	8.100	1.250	1.312
	Sample 2	8.000	8.110	1.375	
15	Sample 1	7.940	8.000	0.756	0.815
	Sample 2	8.000	8.070	0.875	

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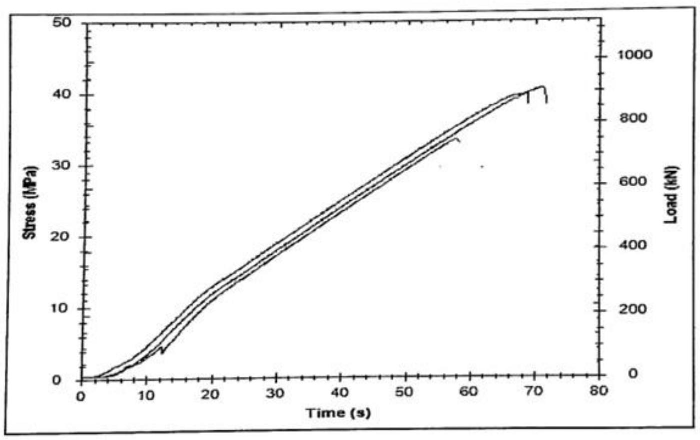
APPENDIX J: COMPRESSION TEST REPORT AT 28 DAYS FOR ALL THE CONCRETE MIXES

Concrete Compression Test Report

Test Date	09/02/2024
Report No	
Sampling Date	13/01/2024
Concrete Plant	
Owner	FINAL YEAR PROJECT-
Contractor	
Layout/Block /Plot	UCU
Concrete Class	C25 0% 28 DAYS
Pace Rate (MPa/s)	0.6
The Place of Use	RESEARCH
Audit Firm	RODNEY AND MUSA



	Sample Dimensions (mm)	Weight (gr)	Density (gr/cm^3)	Age (Days)	Test No	Breaking Load (kN)	Strength (MPa)
1	150 X 150 X 150	8100	2.4	28	175	899.14	39.962
2	150 X 150 X 150	8100	2.4	28	176	766.91	34.085
3	150 X 150 X 150	8100	2.4	28	177	918.66	40.830
4							
5							
6							
					Average	861.57	38.29

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Approved By ENID

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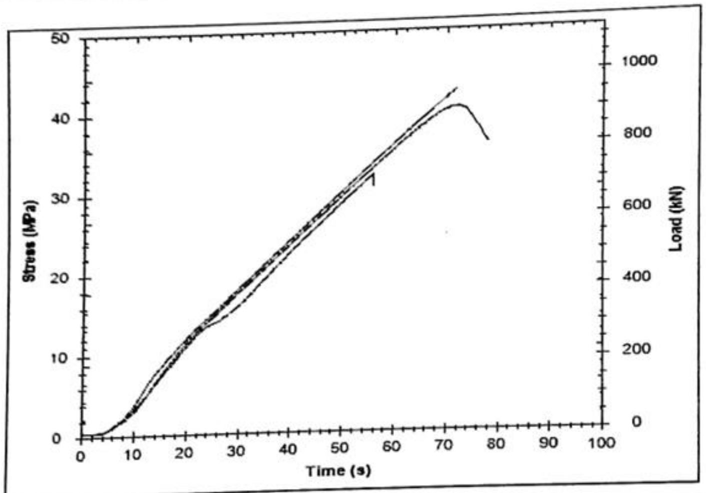
Concrete Compression Test Report

Test Date	11.02.2024
Report No	
Sampling Date	15.01.2024
Concrete Plant	
Owner	FINAL YEAR PROJECT
Contractor	
Layout/Block /Plot	UCU
Concrete Class	C25 5% 28 DAYS
Pace Rate (MPa/s)	0.6
The Place of Use	RESEARCH
Audit Firm	RODNEY AND MUSA



	Sample Dimensions (mm)	Weight (gr)	Density (gr/cm^3)	Age (Days)	Test No	Breaking Load (kN)	Strength (MPa)
1	150X150X150	8200	2.43	28	181	937.43	41.664
2	150X150X150	8200	2.43	28	182	899.98	39.999
3	150X150X150	8200	2.43	28	183	688.57	30.603
4							
5							
6							
					Average	841.99	37.42

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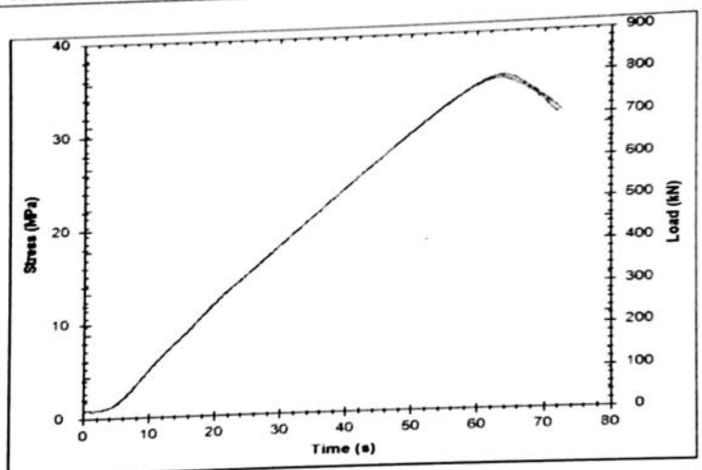
Concrete Compression Test Report

Test Date	16.02.2024
Report No	
Sampling Date	20.01.2024
Concrete Plant	
Owner	FINAL YEAR PROJECT
Contractor	
Layout/Block /Plot	UCU
Concrete Class	C25 10% 28DAYS
Pace Rate (MPa/s)	0.6
The Place of Use	RESEARCH
Audit Firm	RODNEY AND MUSA



	Sample Dimensions (mm)	Weight (gr)	Density (gr/cm^3)	Age (Days)	Test No	Breaking Load (kN)	Strength (MPa)
1	150X150X150	8100	2.4	28	193	787.72	35.01
2	150X150X150	8000	2.37	28	194	788.98	35.066
3	150X150X150	8000	2.37	28	195	794.48	35.31
4							
5							
6							
					Average	790.39	35.13

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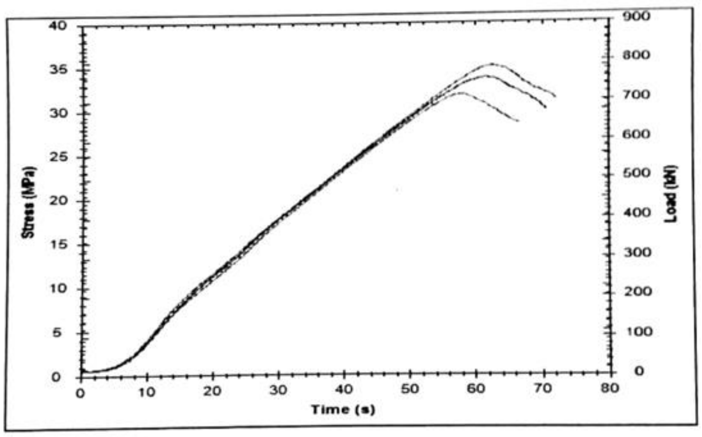
Concrete Compression Test Report

Test Date	17.02.2024
Report No	
Sampling Date	21.01.2024
Concrete Plant	
Owner	FINAL YEAR PROJECT
Contractor	
Layout/Block /Plot	UCU
Concrete Class	C25 15% 28 DAYS
Pace Rate (MPa/s)	0.6
The Place of Use	RESEARCH
Audit Firm	RODNEY AND MUSA



	Sample Dimensions (mm)	Weight (gr)	Density (gr/cm³)	Age (Days)	Test No	Breaking Load (kN)	Strength (MPa)
1	150x150x150	8200	2.43	28	196	697.73	31.01
2	150x150x150	8200	2.43	28	197	787.7	35.01
3	150x150x150	8300	2.459	28	198	738.13	32.806
4							
5							
6							
					Average	741.19	32.94

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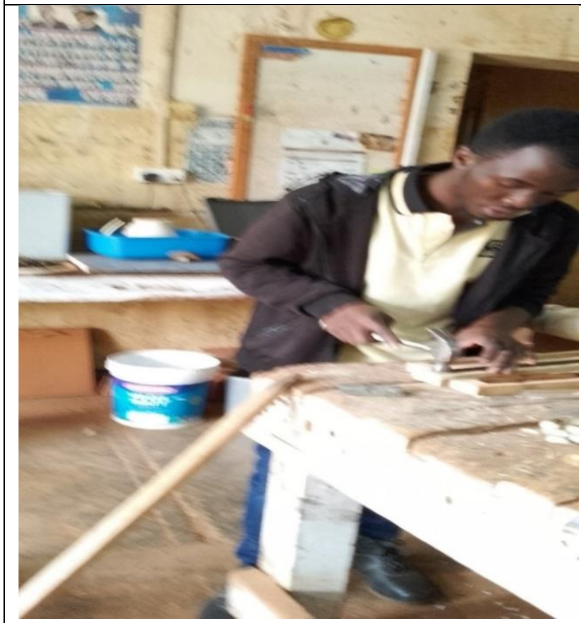
APPENDIX K: IMAGES FOR TESTS CARRIED OUT AT THE LAB.

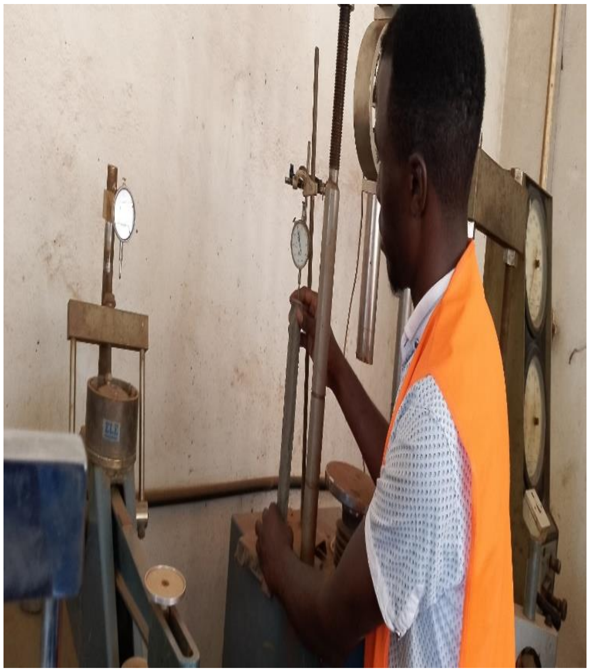
Appendix Figure K-1: Measuring of Pumice powder obtained during sample preparation.

Appendix Figure K-2: Carrying out Consistency $ Setting time test for the combination of pumice powder and cement.



Appendix Figure K-3: Making of wooden prisms for AMBT

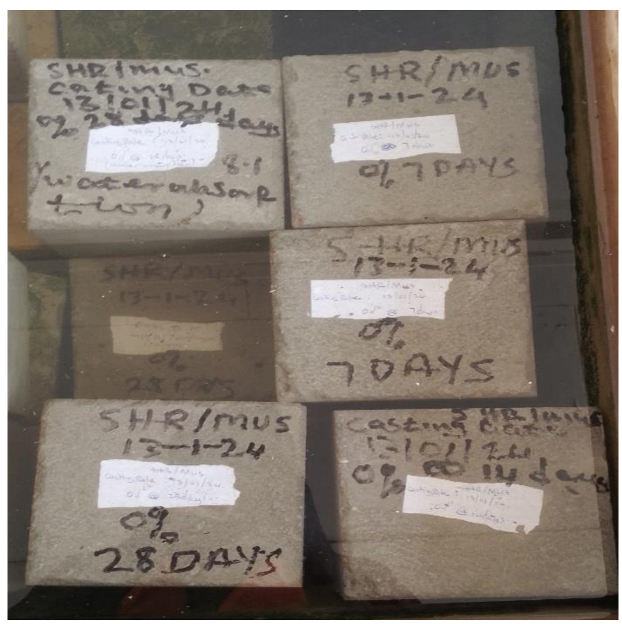
Appendix Figure K-4: Casting of concrete bars for testing of ASR test



Appendix Figure K-5: Measurement of length changes of the concrete bars, using a dial Gauge

Appendix Figure K-6: Mixing of concrete manually

Appendix Figure K-7: Freshly cast concrete left to harden



Appendix Figure K-8: Hardened concrete in soaking tank for curing