# INVESTIGATING THE PERFORMANCE OF PAPYRUS ASH IN REINFORCED CONCRETE TO REDUCE DEFECTS DUE TO CARBONATION

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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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## Abstract

The study investigated the use of papyrus ash collected from Buziranjovu wetland in Mukono as a partial replacement for fine aggregates in concrete. Various physical and mechanical properties of concrete ingredients and papyrus ash were evaluated. Concrete cubes were casted with different percentages of papyrus ash replacements and tested at different curing ages. Results showed that increasing papyrus ash replacement led to higher compressive strength and reduced porosity and permeability. The optimum replacement was determined as 4%, meeting acceptable ranges for all properties, with a compressive strength of 28 MPa meeting design requirements. Further research should be conducted on how to improve the workability, strength properties of this concrete and higher concrete class such that these materials could be used broadly.

# Declaration

I Bamwesigye Joel, hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any academic award.

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

BAMWESIGYE JOEL

S20B32/004

# Approval

This final year research project report has been submitted by BAMWESIGYE JOEL to the department of Engineering and Environment at Uganda Christian University for examination with my approval as the university supervisor.

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

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# CHAPTER ONE: BACKGROUND AND INTRODUCTION

## 1.1 Introduction.

Globally, reaction of carbon dioxide in the air with calcium hydroxide in cement paste is known as carbonation worldwide. The formation of calcium carbonate (CaCO3) when carbon dioxide from the air reacts with Ca(OH)2 in concrete has proven to be a challenge in the construction industry and has been identified as one of the causes of reinforcement corrosion. This reaction lowers the pH of the concrete from 12.5 to 13.5 to approximately 9, making it more acidic (Shafigh, 2020). The higher the acidity, the more prone the reinforcing steel is to rust since at this point the protective oxide layer surrounding it dissolves and corrosion becomes feasible (Meena, 2017).

Conversely, carbonation results in a variety of chemomechanical alterations in the cement paste, including modifications to its chemistry, strength, porosity, and pore size distribution. It also causes the cementitious matrix to shrink and shatter (Branko Šavija, 2016). Furthermore, because CO2 is present in the earth's atmosphere, practically all cement-based products must experience some degree of carbonation reaction during their service life (Construction and Building Material, 2016). The porosity of the concrete, the kind of cement used (such as regular Portland cement), and the length of time the concrete is exposed to carbon dioxide all affect how much the concrete's qualities are reduced as a result of carbonation (Gruyaert, 2013).

According to research carried out in Finland (Jukka Lahdensivu, 2019), carbonation was found to be the major cause of deterioration of concrete buildings, it induced corrosion of reinforcement together with freeze-thaw damage in concrete facades and balconies hence causing repair need in Finland. According to the study, the concrete's carbonation depth reached 30 mm, which is substantially more than the 20 mm cover thickness that is advised for reinforcing steel. Concrete cracked and spall because of the reinforcing steel corroding due to the carbonation (Siddique, 2017).

Ten concrete buildings in Finland that were constructed in the 1960s and 1970s served as the study's sample. It investigated the 20-year carbonation of concrete in Finland and concluded that the main factor causing concrete buildings to deteriorate was carbonation. The study also discovered that a number of factors, including the usage of inferior concrete mixes, the exposure of concrete to harsh conditions, and the aging of the concrete stock, were contributing to an acceleration of the pace of carbonation.

Put another way, it came to the conclusion that concrete buildings in Finland face a significant issue with carbonation and that action must be taken to lower the carbonation of these buildings. According to the study, engineers and construction experts should employ concrete admixtures that can increase the durability of concrete, dense concrete mixes with a low water-to-cement ratio, and low-permeability concrete. In order to lessen $CO_2$ infiltration, the study also suggested that engineers and construction experts put a sealant to the surface of concrete structures (Construction and Building Material, 2016).

A by-product of ferrosilicon, silica fume effectively lowers both the porosity and permeability of paste-form cement and concrete. It has been utilized to reduce carbonation in concrete and is a crucial component in the production of high-strength and high-performance concrete (Pratama, 2020). The silica fume concrete will have excellent resistance to abrasion and bond strength. The use of silica fume will also increase the compressive strength (Sharbatdar, 2023). By densifying the concrete matrix and obstructing the entry of carbon dioxide ($CO_2$), silica fume can be used to lessen the carbonation of concrete. Raising the pH of the concrete reduces its susceptibility to carbonation and forms calcium silicate hydrate, which is resistant to carbonation, when it reacts with calcium hydroxide (Holland, 2012). The studied parameters of silica fume that are important for reducing carbonation in concrete include its surface area, particle size distribution, and purity.

Ferrosilicon plants, which are not commonly seen in Ugandan markets, can yield silica fume. Because papyrus plants are abundant in Uganda's wet regions, papyrus ash can be utilized locally to lessen this problem.

Native to Africa, papyrus (Cyperus papyrus) is a tall, robust aquatic plant whose growth period is approximately six months. The type of wetland, the climate, and the water quality all affect the rate at which papyrus grows. For instance, papyrus typically grows more quickly in wetlands with warmer temperatures and deeper water (Opio, 2014). It can be found in a range of wetland environments, such as wetlands, rivers, and lakes.

Papyrus can be found in a variety of wetlands in Uganda, such as the Nile River, Lake Victoria, Lake Kyoga, and the Nakivubo marsh. It may be utilized to create a wide range of goods, including mats, baskets, rope, and paper, and has numerous commercial and ecological applications. In addition, it provides building materials and gasoline.

There are two types of silica: crystalline and amorphous. Crystalline silica is found in rocks and sand grains, but amorphous silica is found in plants and poses no risks

(Industries, 2007), suggesting that the silica included in papyrus ash is amorphous silica. Since it can react with the calcium hydroxide in concrete to form calcium silicate hydrate, which is the primary binding agent and gives concrete its strength and durability, amorphous silica is a highly reactive non-crystalline form of silica that is perfect for use in concrete. Additionally sustainable is papyrus ash, which is a byproduct of the papyrus processing business (Abdulhussein, 2021).

Papyrus is crucial for wildlife habitat, flood management, and water filtration in the ecosystem. The primary ecological function of papyrus wetlands is that of a carbon sink (Kansiime, 2013), in wastewater treatment, in flood control and as a biodiversity reserve (Jones, 2018). Papyrus is a major resource used by indigenous populations in Uganda. To guarantee that papyrus wetlands continue to offer ecological and economic benefits, sustainable management is crucial. Papyrus, though, can have unfavourable effects. (Njenga Mburu, 2015).

First, papyrus is an extremely flammable plant, with dry papyrus being especially prone to fire. A papyrus fire in hot weather can start with a single spark and spread quickly, making it difficult to put out (Ryken, 2015). Large tracts of wetland habitat can be destroyed by papyrus fires, which can also cause property and infrastructure damage nearby and discharge dangerous pollutants into the atmosphere.

Thus, to lower the risk of fires and save papyrus wetlands, dry papyrus must be chopped down. It is harder for fires to start and spread when the fuel load is reduced. Moreover, clearing dry papyrus helps increase visibility, which facilitates the detection and fighting of potential fires. Removing dead and dying plants from papyrus wetlands can enhance their health and vitality; also, it can create new homes for species and improve water quality by lowering the quantity of organic debris that enters the water. The National Building Review Board began looking into the development of cracks on the sixth-floor columns of the Lotis Towers in Kampala on August 18, 2022. The study revealed that the cracks were caused by carbonation in the concrete, which makes using papyrus ash a feasible solution to this problem.

## 1.2 PROBLEM STATEMENT

Based on earlier studies, silica fume has been utilized to lessen the effects of carbonation in concrete that has hardened (Rafat, 2011). The addition of silica fume to freshly mixed concrete improves its compressive strength, bond strength, and abrasion resistance, which helps prevent corrosion of the reinforcing steel (Khan, 2011). Even if this was a realistic goal, carbonation is still a problem. The National Building Review Board noted and investigated it on the concrete columns of the Lotis Towers in Kampala on August 18, 2022. Concrete buildings can be adversely affected by the rate of carbonation in the material, as it can cause the pH value to drop from 12.6 to less than 9, increasing its acidity and eroding the passive coating surrounding the steel (Jack et al., 2002).

There is an urgent need to investigate substitute materials that not only solve the environmental issues related to conventional concrete components but also provide improved structural performance considering the increased emphasis on sustainable construction methods. To address the growing environmental and financial demands of the industry, this study aims to determine how well papyrus ash can be added to concrete mixtures to reduce carbonation faults. It is a sustainable and economical method. Through an investigation of the characteristics of papyrus ash and how it affects the durability of concrete, this study attempts to close the information gap about the use of this substitute material. It is anticipated that the results of this research will offer significant perspectives for researchers, policymakers, and industry practitioners, ultimately aiding in the creation of sustainable and financially feasible remedies for carbonation-related flaws in concrete constructions.

## 1.3 OBJECTIVES OF THIS STUDY

### 1.3.1 MAIN OBJECTIVE

To investigate the performance of papyrus ash in reducing carbon dioxide infiltration in reinforced concrete.

### 1.3.2 SPECIFIC OBJECTIVES

1. To determine the chemical properties and composition of papyrus ash.
2. To determine the setting time & workability of the freshly mixed concrete with papyrus ash.
3. To determine the compressive strength, water absorption and porosity of hardened concrete mixed with papyrus ash.
4. To determine the optimal dosage of papyrus ash in concrete for reducing carbon dioxide infiltration.

### 1.3.3 RESEARCH QUESTIONS

1. How considerably does the carbonation resistance of the final structures change when papyrus ash is added to concrete mixtures?
2. In contrast to conventional concrete mixtures, how do the mechanical qualities of concrete—such as its compressive strength and durability—change when papyrus ash is added?

3. What is the economic feasibility of using papyrus ash in concrete mixtures as compared to traditional concrete components, considering factors such as material costs, production processes, and long-term maintenance expenses?
4. How do the environmental advantages of adding papyrus ash to concrete, taking into account the full life cycle of the materials, compare to the environmental effects of using conventional concrete components?

## 1.4 JUSTIFICATION OF THE STUDY

In the building sector, carbonation-induced concrete deterioration is a well-researched problem (Fuhaid et al., 2022) because carbonation lowers the alkalinity of the concrete, embedded steel reinforcement corrodes and the structure deteriorates as a result. Investigating substitute materials becomes essential as the need for sustainable building methods grows. The purpose of this study is to determine whether adding papyrus ash to concrete mixtures can eliminate carbonation-related problems in a sustainable manner.

Concrete, a cornerstone of modern construction, is susceptible to deterioration over time, primarily due to carbonation which is a widespread and costly issue in the construction industry (Bhalla et al, 2016). It is estimated that carbonation-induced defects in concrete structures lead to annual repair costs exceeding $1.8 trillion globally (Niaz, 2022). Traditional methods for mitigating carbonation, such as using low water-to-cement ratios and specialized cement, are often expensive and have limitations, for example lower w/c ratios lead to stiffer concrete mixes, making them harder to work with and requiring more effort to place and finish (Morandeau *et al.*, 2011). Therefore, there is an urgent need for sustainable, cost-effective, and environmentally friendly alternatives to address this prevalent problem.

The major binding phase of concrete, calcium silicate hydrate gel, is created when pozzolans, which are introduced by the addition of powdered silica ash to the concrete mix, react with calcium hydroxide, a result of cement hydration. This gel is what gives concrete its strength and durability (Wei, 2022). Low silica content in the concrete mix can have a number of negative effects, such as decreased durability, increased permeability, weakened adhesion, and lower strength (Neville A., 2016). The use of papyrus silica ash introduces silicon dioxide, a covalent compound that reacts with calcium hydroxide to form calcium silicate hydrate gel and water.

Papyrus ash, a byproduct of papyrus processing, offers an environmentally friendly alternative to traditional concrete constituents and has emerged as a potential solution to mitigate carbonation in concrete (Mendis et al., 2016) because of its pozzolanic characteristics, the silica found in papyrus ash can react with calcium hydroxide to create more calcium silicate hydrate (CSH) gel (Kamau et al., 2019). This additional CSH gel densifies the concrete matrix, reducing its permeability to $CO_2$ and slowing down the carbonation process.

It is crucial to investigate the financial viability of including papyrus ash into concrete mixtures in addition to the structural and environmental advantages. In comparison to conventional concrete components, this material is more affordable in some areas because to the amount of agricultural waste (Jing He, 2020). For such a method to be adopted in a variety of construction projects, it is imperative that its economic viability be examined. Through the use of this resource, the research advances a circular economy and helps reduce waste. This addresses both the environmental impact of building activities and the requirement for responsible

resource management, which is in line with the principles of sustainable development (Principles of Sustainable
Development, 2014).

### 1.4.1 SIGNIFICANCE

According to previous research, silica fume is one of the most widely used pozzolanas. When added to concrete mixtures, it reduces porosity, permeability, and bleeding because its oxides ($SiO_2$) react with and eat calcium hydroxides, which are created when regular Portland cement hydrates (Mazloom, 2004), thus lowers the quantity of silicon or silicon-containing alloys used in electric arc furnaces to produce this silica fume (Srivastava, 2016). This research investigates the sustainable substitution of papyrus ash, a result of agricultural waste, in concrete compositions. If effective, this might reduce reliance on conventional materials with larger ecological footprints and open the door for more ecologically friendly building techniques.

In areas like Namanve wetland, situated in the Nama sub-county of Mukono district, papyrus fiber is in plentiful supply. Covering an expansive 894 hectares, with 21 percent of its land being wetland, utilizing papyrus fiber byproducts in construction could have significant economic benefits. This approach has the potential to invigorate local economies and offer new avenues for sustainable resource management by transforming agricultural waste into valuable resources.

### 1.4.2 SCOPE

The scope of this research project extends to the unique ecological context of Buziranjovu Wetland in Mukono, aiming to investigate the applicability and impact of incorporating papyrus ash in concrete mixtures within this specific geographic region. Buziranjovu Wetland, known for its diverse flora and fauna, presents an opportunity to explore sustainable construction practices that align with the local environment. By focusing on this specific wetland, the study considers the regional variations in material availability, construction practices, and environmental concerns. The research will delve into the feasibility of utilizing papyrus ash sourced from Buziranjovu Wetland in concrete, addressing the localized challenges and opportunities presented by the wetland's distinct characteristics. The findings will not only contribute to the broader understanding of sustainable construction but will also offer insights tailored to the specific needs and conditions of Buziranjovu Wetland, providing a foundation for environmentally conscious construction practices in this unique Ugandan setting.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

Concrete, a fundamental building material, is susceptible to carbonation-induced defects, threatening the longevity and structural integrity of constructions. When atmospheric carbon dioxide combines with the alkaline elements of concrete, a process known as carbonation takes place. This lowers the pH of the mixture and causes embedded steel reinforcement to corrode (Niaz et al., 2022). Addressing this issue is pivotal for sustainable and resilient construction practices. This literature review explores the evolution of research in mitigating carbonation defects, focusing on the utilization of papyrus ash in concrete mixtures.

### 2.1.1 Carbonation Transport through concrete.

As previously mentioned, carbon dioxide diffuses through the concrete, and the carbonation front's rate of movement roughly follows Fick's law of diffusion (Šavija & Luković, 2016). This states that the rate of movement and the distance from the surface are proportionate. This is simply an estimate, though, because the carbonation process changes the pore structure of the concrete as it goes on. Deviation from the ideal diffusion equation can also be caused by cracks, variations in the composition of the concrete, and changes in moisture levels with depth (Tongaria, Mandal and Mohan, 2019).

The movement of the carbonation front can be roughly predicted using the square root law that is produced by solving the equation. Empirically, a number of equations have been developed to relate concrete quality, environment, and carbonation rates. There is typically a t1/2 dependence. As was previously mentioned, additional considerations include exposure, the ratio of cement to water, strength, and the concentration of CaO (which is an alkali content and a function of cement) (Liang, Huang and Fang, 2013).

$$d = At^n$$

d = carbonation

depth. t = time in

years A = diffusion

coefficient

n = exponent (approximately ½)

### 2.1.2 Carbonation Mechanisms in Concrete.

One well-known spontaneous phenomenon that frequently happens to hydrated cement paste is carbonation. It has to do with the aging, hardening, and durability mechanisms of materials made of cement. In the cement matrix, ambient carbon dioxide reacts with calcium hydroxide ($Ca(OH)_2$) to generate calcium carbonate ($CaCO_3$) and water. This is the major chemical process (Zhang, 2020).

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

This reaction lowers the alkalinity and starts the corrosion process, which compromises the concrete's structural integrity.

### 2.1.3 Introduction of Alternative Supplementary Materials.

Researchers have looked into alternative materials to improve the durability of concrete as sustainability has become a major concern in the building industry. By introducing the idea of employing agricultural waste as supplemental resources, these materials—often pozzolanic—have (Javed et al., 2018). Pozzolan is the mineral additive that is most frequently utilized in the concrete industry. A pozzolan is characterized as an aluminous or siliceous material that has little to no cementing characteristics. However, when it is finely divided and reacts chemically with calcium hydroxide in the presence of moisture, it forms compounds having cementitious qualities (Naji et al., 2015; Marchetti, 2020).

Fly ash, burnt clay, pumice, and volcanic ash are a few types of pozzolanic materials. In order for silica in a pozzolana to be reactive, it must be amorphous, or glassy. This produces low-permeability concrete, which is stronger and more resistant to the entry of harmful chemicals, and points to papyrus ash, which has pozzolanic properties.

Based on earlier studies that looked into the engineering qualities of concrete when cement is partially replaced by sugarcane bagasse ash (SCBA). The study examined a range of SCBA concrete properties at different water-cement ratios (0.3, 0.4, 0.5) and curing times (7, 28, 56, and 91 days). These properties included microscopic characteristics as well as fresh-mixed properties like slump, flow, unit weight, and setting time, as well as engineering traits like compressive and splitting strength, pozzolanic index, ultrasonic pulse velocity (UPV), resistivity, sulfate attack, and water absorption (Wang et al., 2024). According to the study, adding 5% SCBA to cement improves its hydration reaction, which in turn results in better long-term durability, UPV, strength, and reduced weight loss in sulfate tolerance tests. The study emphasizes SCBA's potential as an agricultural waste resource for sustainable and ecologically friendly concrete production.

### 2.1.4 Papyrus ash as a Sustainable Alternative.

Recent studies have investigated papyrus ash as a sustainable alternative in concrete mixtures (Frayah et al., 2021). Sustainable construction demonstrated that papyrus ash, rich in silica and pozzolanic properties, will react with calcium hydroxide to form calcium silicate hydrate (C-S-H), a key cementitious phase responsible for concrete strength (Ahmed, 2019).

$$SiO_2 + Ca(OH)_2 \rightarrow CaSiO_3 + H_2O$$

An inventive solution that tackles both environmental and financial issues is the use of papyrus ash as a sustainable substitute for traditional concrete. One renewable plant resource that grows abundantly in some areas is papyrus, particularly in the Mukono district and other parts of Uganda (WETLANDS ATLAS, 2016).

Papyrus has traditionally been used for crafts such as papermaking, but its potential as a building material has drawn interest. When making concrete, papyrus ash—which is made by burning the leftovers of papyrus plants—can be used as an additional cementitious material (SCM). As an SCM, it can take the place of cement, which is a significant source of carbon dioxide emissions in the building sector. The use of papyrus ash lowers the total carbon footprint of concrete manufacturing by lowering the cement content. Moreover, it has been demonstrated that adding papyrus ash to concrete increases its longevity and compressive strength, offering a potential remedy for carbonation-induced flaws (Wei, 2022).

### 2.1.5 Cement

Portland cement is the most widely used kind of cement, which is combined with other ingredients to create various forms of concrete. Burning a combination of calcium carbonate (limestone or chalk) and an alumino silicate (clay or shale) yields Portland cement, which is subsequently mixed with around 5% gypsum. Hydraulic binder, or cement, is an inorganic material that has been finely powdered. When combined with water, it forms a paste that uses hydration reactions and processes to set and harden.

Once hardened, the paste maintains its strength and stability even under water (BSI Standards Publication, 2011). Cement that is widely accessible in Europe is divided into five primary categories according to the European Standard EN 197 standard.

### 2.1.6 Cement type I, CEM I: Portland cement.

Contains 5% additional secondary sand elements. Cement is typically an inorganic fine powder that, when combined with water, experiences a hydration process to create a paste, which serves as the binder in concrete, holding the particles together. Alumina, silica, iron oxide, and lime are the raw components used to make cement. Ground clinker and up to 5% of small additional ingredients make up Portland cement (Verbeck 1958; Taylor, 1997). The most popular kind of cement used in building is Portland cement (CEM I), which can undergo a process known as carbonation. Some authors contend that the production of calcium carbonate is the result of the chemical process known as carbonation.

($CaCO_3$), which is thought to be the most susceptible to carbonation, is produced when atmospheric carbon dioxide ($CO_2$) combines with the calcium phases ($Ca^{2+}$) and water ($H_2O$) found in Portland cement. According to Tuutii (1982), Saetta et al. (1993), Castro et al. (2000), Sanjuán et al. (2003), Thiery et al. (2007), Andrade (2008), Muntean (2009), Guiglia (2013), and Zhang (2016), carbonation is formed in two steps: the transport and reaction of $CO_2$. Since diffusion is the primary mechanism for allowing carbon dioxide to enter concrete, carbonation is dependent on this coefficient; nevertheless, diffusion does not proceed deeper until all reactive species have been consumed.

In the concrete pore solution, carbon dioxide ($CO_2$) dissolves and interacts with the calcium phases of Portland cement (Verbeck 1958; Taylor, 1997). Initially, the calcium hydroxide in the pore solution reacts with carbon dioxide. Then, more carbon dioxide might react with calcium aluminates (Fernández-Carrasco et al., 2012), ettringite (Zhou et al., 2000), and C-S-H gel. According to Sanjuán et al. (2018), the carbonation of C-S-H gel results in the removal of calcium ions from the gel as well as the creation of calcium carbonate and silica gel. Around the world, carbonation in materials based on Portland cement modifies the microstructure of concrete and affects its mechanical and durability-related qualities.

*Table 1: Composition of Portland*

| Ingredient | Percentage |
|---|---|
| Lime ($CaO$) | 62 |
| Silica ($SiO_2$) | 22 |
| Alumina ($Al_2O_3$) | 5 |
| Calcium Sulfate ($CaSO_4$) | 4 |
| Iron Oxide (Fe2O3) | 3 |
| Magnesia ($MgO$) | 2 |
| Sulphur (S) | 1 |
| Alkalis | |
| Total | 100 |

According to Table 1, these are the concentrations of the different components of Portland cement and they each play a crucial

- Limestone (Calcium Carbonate): Limestone is the primary source of calcium in Portland cement. It's typically extracted from quarries and mines. Calcium carbonate ($CaCO_3$) is the main component of limestone, and it undergoes a chemical transformation during the cement manufacturing process.
- Silica (Silicon Dioxide): Silica is another essential ingredient, usually sourced from clay, sand shale, or other materials containing silicon dioxide ($SiO_2$). Silica provides the necessary silicon component to the cement, contributing to its strength and durability.
- **Alumina (Aluminum Oxide)**: Alumina is obtained from clay, bauxite, or recycled materials containing aluminum oxide ($Al_2O_3$). It helps in enhancing the cement's setting time and also improves its strength and durability.
- **Iron Oxide ($Fe_2O_3$)**: Iron oxide is often found in clay or iron ore and provides the cement with its characteristic gray color. In addition to coloration, iron oxide also influences the cement's properties, including setting time and strength development.
- **Gypsum (Calcium Sulfate Dihydrate)**: Gypsum is added to control the setting time of Portland cement. Without gypsum, the cement would set too quickly, making it impractical for use. Gypsum slows down the hydration process, allowing more time for workability and ensuring that the cement doesn't harden prematurely.
- **Other Minor Ingredients**: In addition to the main components mentioned above, Portland cement may contain trace amounts of other minerals and

additives to modify specific properties. These can include materials like fly ash, blast furnace slag, silica fume, and other supplementary cementitious materials (SCMs) that improve various aspects of the cement, such as strength, durability, and sustainability.

# CHAPTER 3: METHODOLOGY

## 3.1 INTRODUCTION

The methodology chapter of this project outlines the systematic approach employed to investigate the feasibility and effectiveness of incorporating papyrus ash as a reinforcement in cementitious materials.

## 3.2 MATERIALS TO BE USED IN THE RESEARCH

### 3.1.1 PAPYRUS FIBER

The papyrus was collected from Buziranjovu in Mukono District, Central Region, Uganda & this was done by cutting mature papyrus reeds at the base, leaving the younger shoots to grow. It is usually pretreated for extracting the required ash as follows:

- 87 dry papyrus reeds were collected as observed in Figure 2 below from Buziranjovu (0.2833° N, 32.7167° E) in Mukono District, Central Region, Uganda & this was done by cutting dry mature papyrus reeds at the base, leaving the younger shoots to grow. The mature leaves are characterised by brown shoots and culms as observed in Figure 1 below. It is usually pretreated for extracting the required fiber ash as follows:

- The outer green rind is carefully peeled away, revealing the white pithy core.

This pith is the source of the papyrus fibers, it’s then dried for five days.

- Burning it in the air to reduce its size.

- Heating the filler which passed through sieve number 200 in a special oven at a temperature from 350 to 450°C (Tameem et al., 2022) to activate the silica the silica within the ash.

*Figure 1: Papyrus plantation.*

*Figure 2: Dry papyrus reeds collected.*

### 3.1.2 CONCRETE

**Aggregates**

Natural aggregates and fine aggregates (sand) were collected from Zirobwe quarry and

Lukaya respectively. We conducted quite a number of tests on these materials such as sieve analysis test, ACV and AIV test, specific gravity, abrasion value test, flakiness index among others.

**Cement**

In this study, cement of grade C25 was used. Cement as a material acts as binding agent and when it is mixed with water a chemical reaction takes place as cement paste hardens/binds aggregates together. Portland Tororo cement was used since it conforms to the KS EAS 18-1 cement standards as adopted from the EN-197 specification that is equivalent to the Uganda specification US EAS 18-1.

**Water**

The Water used while carrying out tests was gotten from national water and sewage cooperation. Water as material governs the workability and strength of concrete depending on the amount of it used while mixing fresh concrete.

## 3.3 PROPERTIES OF THE MATERIALS USED

### 3.2.1 PHYSICAL PROPERTIES OF PAPYRUS ASH

Understanding the physical characteristics of papyrus ash, such as surface area and porosity, requires knowing the distribution of its particle sizes. This will be accomplished by carrying out an extensive investigation utilizing the BS EN 933-1:1997 standard to regulate the fine aggregate's size using a sieve analysis. A 5mm sieve was used to filter the fine papyrus ash, which was then collected on a 75µm sieve (No. 200).

**a) Chemical composition of papyrus ash**

The x-ray fluorescence method is to be used to determine the chemical composition of papyrus ash that has undergone activation from Figure 3, to Figure 4 then to activation in Figure 5.

One non-destructive analytical method for figuring out a material's elemental composition—including that of papyrus ash—is X-ray fluorescence (XRF). The basis of XRF is the idea that materials that are exposed to X-ray radiation produce secondary, or fluorescence, X-rays that are indicative of the elements that are present in the sample. The elemental makeup of the sample can be ascertained by measuring the energy and intensity of these X-rays that are released (Jenkins 2000).

**b) Particle size distribution of papyrus ash.**

The process of ascertaining the materials' particle size distribution is called sieve analysis. The purpose of this test is to identify the physical characteristics of the papyrus as in Figure 5. This test will assist us in comprehending the size-distribution of these aggregate particles in order to meet the design standards, control specifications, and verification criteria.

*Figure 3: Papyrus ash*

*Figure 4: Crushed papyrus ash*

*Figure 5: Activated papyrus ash*

**c) Specific gravity of papyrus ash**

A substance's specific gravity (SG) is determined by dividing its density by that of a reference material. When measuring solids, it is usually done in relation to water. It gives information on the density of materials such as papyrus fiber ash in relation to water (Barrass and Derrett, 2006)

**Procedure**

- **Preparation of Sample**: Obtain a representative sample of the papyrus fiber ash. Ensure it is finely ground and free from any extraneous material.
- **Weighing of Sample**: Weigh the prepared sample of papyrus fiber ash using a balance that is accurate to at least 0.1% of the mass of the sample.
- **Drying**: If the sample is not already dry, place it in an oven set at a suitable temperature (typically around 105°C) until it reaches a constant mass. This ensures that all moisture is removed from the sample.
- **Weighing After Drying**: Once the sample has reached a constant mass, weigh it again to determine the dry mass.

- **Preparation of Pycnometer**: Clean and dry a pycnometer (a specific type of glass jar used for measuring the density of solids) and record its empty mass.
- **Filling the Pycnometer**: Fill the pycnometer with distilled water at a known temperature (usually around 20°C) up to a mark. Record the mass of the waterfilled pycnometer and its contents.
- **Adding Sample to Pycnometer**: Carefully introduce the dried papyrus fiber ash sample into the water in the pycnometer until it is completely immersed. Avoid trapping air bubbles. Record the mass of the pycnometer, water, and sample.
- **Calculation**: Calculate the specific gravity of the papyrus fiber ash using the formula.

- **Repeat**: Perform the above steps at least three times to ensure accuracy and repeatability. Take the average of the results as the specific gravity of the papyrus fiber ash.
- **Report**: Report the specific gravity of the papyrus fiber ash in the appropriate units as specified in the standard.

It's essential to follow the specific procedures outlined in BS 812 Part 2 (1995) for accurate results and compliance with the standard. Always ensure safety precautions are followed, especially when working with ovens and glassware.

*Table 3: Relative density and water absorption for papyrus ash.*

| Specimen reference | | | 1 | 2 | Average |
|---|---|---|---|---|---|
| **Mass of saturated surface dry aggregate in air** | A | g | 9.0 | 9.2 | 9.1 |
| **Mass of Pycnometer + sample + water** | B | g | 331.0 | 331.1 | 331.05 |
| **Mass of Pycnometer filled with water only** | C | g | 326.1 | 326.1 | 326.1 |
| **Mass of oven-dry aggregate in air** | D | g | 8.7 | 8.8 | 8.75 |
| **Particle density on an oven-dry basis** | $P_d = \frac{D}{A-(B-C)}$ | $Mg/m^3$ | 2.096 | 2.120 | 2.108 |
| **Particle density on a saturated and surface-dry basis** | $P_s = \frac{A}{A-(B-C)}$ | $Mg/m^3$ | 2.195 | 2.191 | 2.193 |
| **Apparent Particle density** $Mg/m^3$ | $P_a = \frac{D}{D-(B-C)}$ | | 2.195 | 2.191 | **2.193** |
| **Water Absorption** | $W_{abs} = 100x\left(\frac{A-D}{D}\right)$ | % | 0.0 | 0.0 | 0.0 |

### 3.2.2 PROPERTIES OF THE CONCRETE INGREDIENTS

#### 3.2.2.1 FINE AND COARSE AGGREGATES

**d) Particle Size Distribution (Sieve Analysis)**

The process of ascertaining the materials' particle size distribution is called sieve analysis. The purpose of this test is to identify the physical characteristics of coarse and fine (sand) aggregates. This test will assist us in comprehending the size-distribution of these aggregate particles to meet the design standards, control specifications, and verification criteria.

**Procedures to determine particle size distribution of aggregates:**

1. The test samples are weighed after being dried to a constant weight at 110 +/- 5oC.
2. Next, in compliance with BS EN 12620 or IS Sieves, the samples are sieved through sieves of varying diameters. Each sieve's material is then weighed.
3. The total weight of the sample is divided by the cumulative weight that passes through each filter arranged as observed in Figure 6.
4. The cumulative percentage of aggregates retained on each sieve is added, and the total is divided by 100 to determine the fineness modulus.
5. The aggregates are categorized using a unified classification system, and a graph of the cumulative % passing against sieve sizes is shown on a semi-log graph with particle size as the abscissa (log scale).

*Figure 6: Experimental setup for the particle size distribution test*

**e) Flakiness index (FI) - BS 812: Section 105.1: 1989**

One test used to categorize stones and aggregates is the Flakiness Index. When an aggregate's thickness is less than 60% of its mean sieve size, it is categorized as flaky.

The flaky particle separation process is used to conduct this test, and the mass of aggregates retained on FI sieves is reported as a percentage. Consequently, the percentage of aggregate mass whose least dimension is smaller than 0.6 times its mean dimension is known as the flakiness index. Only materials that pass a 63 mm sieve and are held on a 6.30 mm BS test sieve are suitable for the test.

**f) Water absorption and Specific Gravity.**

In accordance with BS: 812:1975, the water absorption test was performed to ascertain the maximum amount of water that the coarse aggregates could absorb. This test provides insight into the internal structure and strength of coarse aggregates. It is simpler to determine whether your aggregates are naturally more porous or less porous based on the study of the data. To determine the strength or quality of coarse aggregates to be utilized in construction, the specific gravity test is carried out.

At the conclusion of the test, it is noted that, in comparison to aggregates having a greater specific gravity, those with a lower specific gravity are recognized to be weaker materials. A sample weighing at least 2000 grams is used for these tests, and the following equipment is used: a shallow tray with a minimum area of 650 square centimetres; an oven; a plastic coated with wire hangers for suspending the sample from the balance; a dry, soft, absorbent cloth; a watertight container for suspending the basket; and an airtight container with a capacity comparable to the basket.

The material's strength is determined by these two tests. The weight of a specific volume of aggregate divided by the weight of an equivalent volume of water is known as specific gravity. It is a measurement of the material's strength or quality. In general, aggregates with lower specific gravities are weaker than those with greater specific gravities. According to standards BS: 812:197, the apparent specific gravity of the most widely used rocks ranges from 2.6 to 2.7.

**g) Aggregate Impact Value (AIV)**

The purpose of this test is to evaluate coarse aggregates' mechanical deterioration. This test measures the resistance of aggregates by subjecting them to a known load (Barrass and Derrett, 2006) As to BS 812: Part 112:1990, this test is carried out on coarse aggregates to ascertain how robust they are to impact-induced disintegration. The AIV of these aggregates was ascertained using a 28-cylindrical measure and plunger, a compression testing machine, and test sieves with sizes of 14 mm, 10 mm, and 2.36 mm.

**h) Aggregate crushing value (ACV) test**

A relative assessment of an aggregate's resistance to crushing under a gradually applied compressive stress is provided by the aggregate crushing value test on coarse aggregates. The integrity of the structure is probably going to suffer if the aggregates are weak. The Aggregate Crushing test can be used to determine the strength of coarse aggregates. The material that passes through a certain sieve after being crushed under a 400 kN load is measured to determine the aggregate crushing value, or ACV. A standard fraction aggregate that passes through a 14 mm filter and is kept on a 10 mm sieve can be subjected to the test. When evaluating soft aggregates with an ACV more than 30, the approach is not appropriate. Referring to CML Test No. 2.7, the Ten Percent Fines Value (TFV) technique is applicable in these situations.

### 3.2.2.2 CONCRETE

**a Fresh concrete slump test**

In compliance with BS 1881: Part 102:1983, this test was conducted to assess the flow characteristics of freshly mixed concrete that contained stone dust and the other standard concrete ingredients. In order to perform this test, concrete was added to an inverted cone in three stages, and each stage was completed by tamping down the concrete with a metal rod. Grasping the handles on either side of the cone allowed it to be raised off the work surface. It was measured and noted how far the slump cone's initial height was from the slumped height of newly mixed concrete. For fresh concrete, the ideal slumps should be between 4 and 5 inches in order to achieve the right equilibrium between workability and consistency.

**b Preparation of testing cubes from the fresh concrete.**

This explains how to make concrete cubes for permeability, porosity, and compressive strength tests. Three concrete cubes will be cast for each trial mix in this experiment, and they will be allowed to cure for seven, fourteen, and twenty-eight days.

**Procedure**

A tiny layer of oil is applied to the inside faces of cube mold plates after the slump test of freshly mixed concrete has been completed, and then a sample of the freshly mixed concrete is placed into the mold. The sample is placed in a mold in three layers, with each layer being compacted with a tapping rod to eliminate air pockets.

**c Compressive strength test**

The ability of a material or structure to support loads on its surface without cracking or deflecting is known as its compressive strength. This test will be conducted on cubes of hardened concrete that have been cured for seven, fourteen, and twenty-eight days. It will be conducted in compliance with B.S. 1881 part 116:1983.

**Procedure for performing compressive strength test on concrete cubes.**

Three layers of fresh concrete are poured into a 15 x 15 x 15 cm mold, and each layer is properly compacted using a tamping rod to remove voids. However, this must be done carefully so as not to destroy the pervious concrete's structure, as it is precisely the presence of voids that gives it its unique properties. The cubes are then placed in water and allowed to cure for 7, 14, and 28 days after being left to cure for 24 hours. Following this, the molds are removed, and the cubes are checked using a compression testing equipment arranged as seen in Figure 7. Until the specimens fail, a load of 140 kg/cm2 per minute should be applied progressively. The applied load will be divided by the cross-sectional area of the cube to determine the compressive strength.

*Figure 7: Experimental setup for compressive strength test*

**d Porosity test**

This is the test that is done to know the ability of the concrete to hold water or the ease with which water can infiltrate through it. It was carried out using the cubes that we were using for testing for compressive strength of our cubes.

# CHAPTER 4: RESULTS AND DISCUSSIONS

## 4.1 Introduction

This chapter of this project delves into the comprehensive evaluation of incorporating papyrus ash as a reinforcement in cement while making concrete. This study aims to investigate the potential benefits and impacts of utilizing papyrus ash.

## 4.2 Properties of papyrus ash

### 4.2.1 CHEMICAL COMPOSITION OF PAPYRUS ASH

The chemical composition of PA (papyrus ash) was studied using X-ray Fluorescence (XRF) that was conducted at the Directorate of Government Analytical Laboratory (DGAL) in Wandegeya.

**Identification of other constituents:** we analyze the papyrus ash for other key constituents, including calcium oxide, alumina, and iron oxide, to understand its chemical composition. The different chemical attributes of are listed as per the results obtained in Table 2 and explained below.

*Table 2: Chemical analysis of papyrus ash*

| Parameter | Units | Papyrus ash sample GE 033/2023 |
|---|---|---|
| Calcium Oxide | %m/m | 19.494 |
| Silicon dioxide | %m/m | 66.968 |
| Manganese (II) Oxide | % m/m | 11.591 |
| Potassium Oxide | %m/m | 1.129 |
| Phosphorous pent oxide | %m/m | 0.196 |
| Iron (III) Oxide | %m/m | 0.504 |

Calcium oxide, also known as quicklime, plays a crucial role in the setting and strength development of concrete, particularly Ordinary Portland Cement and hence undergoes a highly exothermic reaction called hydration. This reaction transforms CaO into calcium hydroxide, releasing significant heat and contributing to the initial setting of the cement.

$$\mathbf{CaO + H_2O \rightarrow Ca(OH)_2 + Heat}$$

The chemical reactions involving calcium oxide contribute to the strength and durability of concrete. Calcium carbonate, formed through carbonation, helps fill in pores and voids within the concrete matrix, thereby increasing its strength and reducing permeability.

$Ca(OH)_2$ further reacts with other components in the cement, primarily silica ($SiO_2$) and alumina ($Al_2O_3$), through a process called pozzolanic reaction. These reactions form Calcium silicate hydrate (CSH) which is the main binding phase responsible for concrete's mechanical strength and long-term durability.

$$SiO_2 + Ca(OH)_2 \rightarrow CaSiO_3 + H_2O$$

Silicon dioxide: Both OPC and the papyrus fiber ash sample contain silicon dioxide in significantly different proportions. In OPC, it usually ranges from 17-25%, while in PA (PAPYRUS ASH), it was much higher at 66.968%. Implying the that the excess silica in papyrus ash will react with calcium hydroxide from OPC to form additional cementitious materials.

**Manganese (II) Oxide (MnO)**: When added to concrete in small amounts, manganese oxide can act as a pigment, giving the concrete a gray or brown color. It can also improve the workability of the concrete and slightly increase its strength. However, if too much manganese oxide is added, it can have the opposite effect, weakening the concrete and making it more susceptible to cracking (Juenger et al., 2002).

**Potassium Oxide ($K_2O$)**: Potassium oxide is not commonly used in concrete, but it can have some beneficial effects when added in small amounts. It can improve the workability of the concrete and make it more resistant to frost damage. However, if too much potassium oxide is added, it can react with the calcium hydroxide in the concrete to form a white powder that can weaken the concrete and make it more susceptible to cracking (Hewlett, 2012).

**Phosphorous Pentoxide ($P_2O_5$)**: Phosphorous pentoxide is not commonly used in concrete, but it can have some negative effects when added. It can react with the calcium hydroxide in the concrete to form a white powder that can weaken the concrete and make it more susceptible to cracking. It can also accelerate the corrosion of steel reinforcement in the concrete (Mehta et al., 2014).

**Iron (III) Oxide ($Fe_2O_3$)**: Iron oxide is the main component of rust, so it is not surprising that it can have negative effects on concrete. When iron oxide comes into contact with moisture, it can expand and crack the concrete. It can also react with the calcium hydroxide in the concrete to form a white powder that can weaken the concrete and make it more susceptible to cracking (Neville, 2018).

### 4.2.2 SIEVE ANALYSIS OF PAPYRUS FIBRE ASH

Using the BS EN 933-1:1997 standard method for sieve analysis of fine aggregates to ensuring consistency and accuracy in the measurements. The specific sieves 5mm and 75µm are appropriate for capturing the relevant size range for fine PFA. The 5mm sieve retains any larger particles, while the 75µm sieve captures the finer fraction.

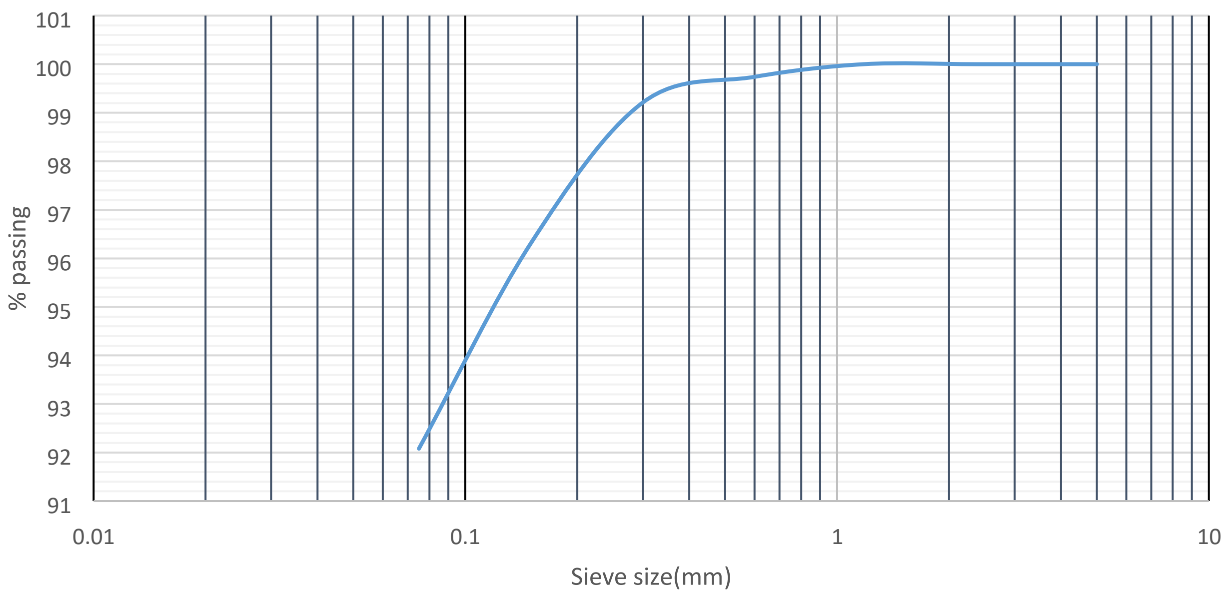



*Figure 8: Sieve analysis for papyrus ash.*

### 4.2.3 SPECIFIC GRAVITY AND WATER ABSORPTION OF PAPYRUS ASH

Specific gravity & water absorption of the PA ash using BS 812: Part 2:1995 method procedures.

The water absorption of papyrus ash was found to be zero which implies that papyrus ash has a very dense and compact structure with minimal voids and pores inhibiting penetration of water. It also implies that it is highly resistant to water ingress that makes it suitable for its use as a supplement for cement in concrete. Water ingress, in theory, can cause deterioration of materials overtime, leading to structural weakness, cracks, spalling and ultimately structural failure. (Gardner *et al.*, 2018)

## 4.3 Properties of concrete ingredients

### 4.3.1 Sieve analysis for coarse aggregate (5-20mm)

Based on the sieve analysis data and BS 882:1992 being the governing specification, here are some of the observations:

**Overall Grading:** The sample appears to be well-graded across the entire size range of 5-20mm, with no sieve exceeding the specified limits. This means the aggregate should have good packing density and workability in concrete mixes.

**Fineness Modulus:** The fineness modulus (FM) is a single numerical value that represents the overall particle size distribution of an aggregate. It is calculated by adding the cumulative percentages retained on each sieve and dividing by 100. For this sample, the FM is approximately 7.2, which falls within the typical range for wellgraded coarse aggregates (6-7).

**Specific Sieve Sizes:** The percentage retained on the 20mm sieve (0.4%) is very low, indicating there are few particles larger than the nominal maximum size. This is good for concrete quality and consistency.

The percentage retained on the 5mm sieve (97.3%) is very high, indicating a significant amount of material close to the nominal minimum size. This could be acceptable depending on the specific application, but it might also affect workability and the amount of finer aggregate (sand) needed in the concrete mix.

The percentage retained between the 14.0mm and 5.0mm sieves falls within the specified limits, indicating a good distribution of intermediate-sized particles.

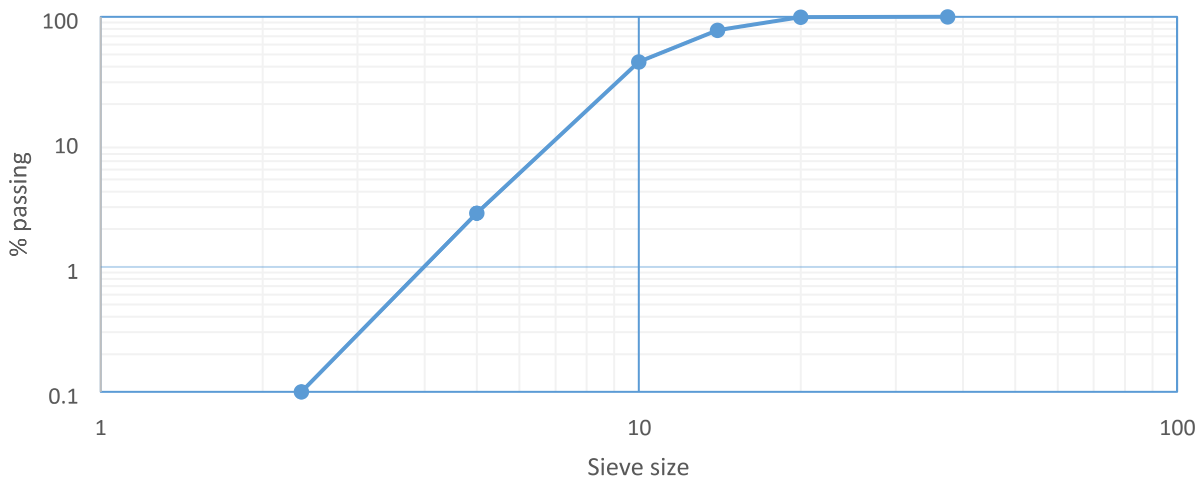



*Figure 9: Sieve analysis for coarse aggregate (5-20mm)*

### 4.3.2 Flakiness index for coarse aggregates

Based on the data and BS 882:1992 the governing standard.

Flakiness Index:

The flakiness index (FI) for the sample is 15.0 %, which falls within the acceptable limit of **25%** specified in BS 882 for coarse aggregates used in concrete. This indicates that 15% of the aggregate particles by weight have a thickness less than 0.6 times their nominal size. While some elongated particles are present, they are not excessive and shouldn't significantly impact the concrete's workability or strength.

Observations:

The FI value is relatively low, suggesting a good overall shape of the aggregate particles, here's a gradual increase in the percentage of flaky particles with decreasing sieve size, which is typical for crushed aggregates. The highest FI value (22.1%) is for the 10mm sieve fraction, but it still falls below the specified limit.

### 4.3.3 Water absorption, bulk density and apparent particle density for coarse aggregates.

Based on the assumption that BS 812: Part 2: 1995 is the governing standard:

**Material source:** Zirobwe quarry
**Sample description:** (5-20mm) Coarse aggregates.

*Table 1: Results for water absorption, AIV, bulk density and apparent particle density.*

| | Average |
|---|---|
| **Water Absorption (%)** | 0.36 |
| **Aggregate Impact Value (AIV)** | 16.8 |
| **Apparent Particle Density (mg/m³)** | 2.668 |
| **Bulk density(mg/m³)** | 1433.5 |

The water absorption values for both specimens are very low, well below the typical limit of 5% for coarse aggregates used in concrete according to BS 882. This indicates that the aggregates have a low porosity and will absorb minimal water when mixed with cement and water. The particle density values are also within the expected range for common coarse aggregate materials like crushed rock. There is a minor difference in water absorption between the two specimens, but this is likely due to normal variation within the material.

**Bulk density of coarse aggregates.**

The loose density, also known as bulk density, refers to the mass of the aggregate per unit volume in a loose, unpacked state.

The values in the image indicate that the loose density of the coarse aggregates is relatively high, ranging from 1433.0 to 1434.0 $Mg/m^3$. This is generally considered **good** for coarse aggregates used in concrete applications.

Higher loose density is often associated with better packing and workability in concrete mixes, potentially leading to improved strength and durability.

### 4.3.4 Aggregate Impact Value (AIV) results for the coarse aggregates.

Aggregate Impact Value (AIV) results for the coarse aggregates using the test method followed by BS 812: Part 112: 1990.

The AIV test measures the resistance of aggregates to fragmentation by impact. Lower AIV values generally indicate higher impact resistance and better-quality aggregates.

The AIV values in the image are relatively low, which is **positive**. They fall within the typical range for good quality coarse aggregates according to BS 882, although the specific limits may vary depending on the application.

A lower AIV value suggests that the aggregates are less likely to break under impact during transportation, placement, and compaction of concrete, potentially leading to better durability and performance.

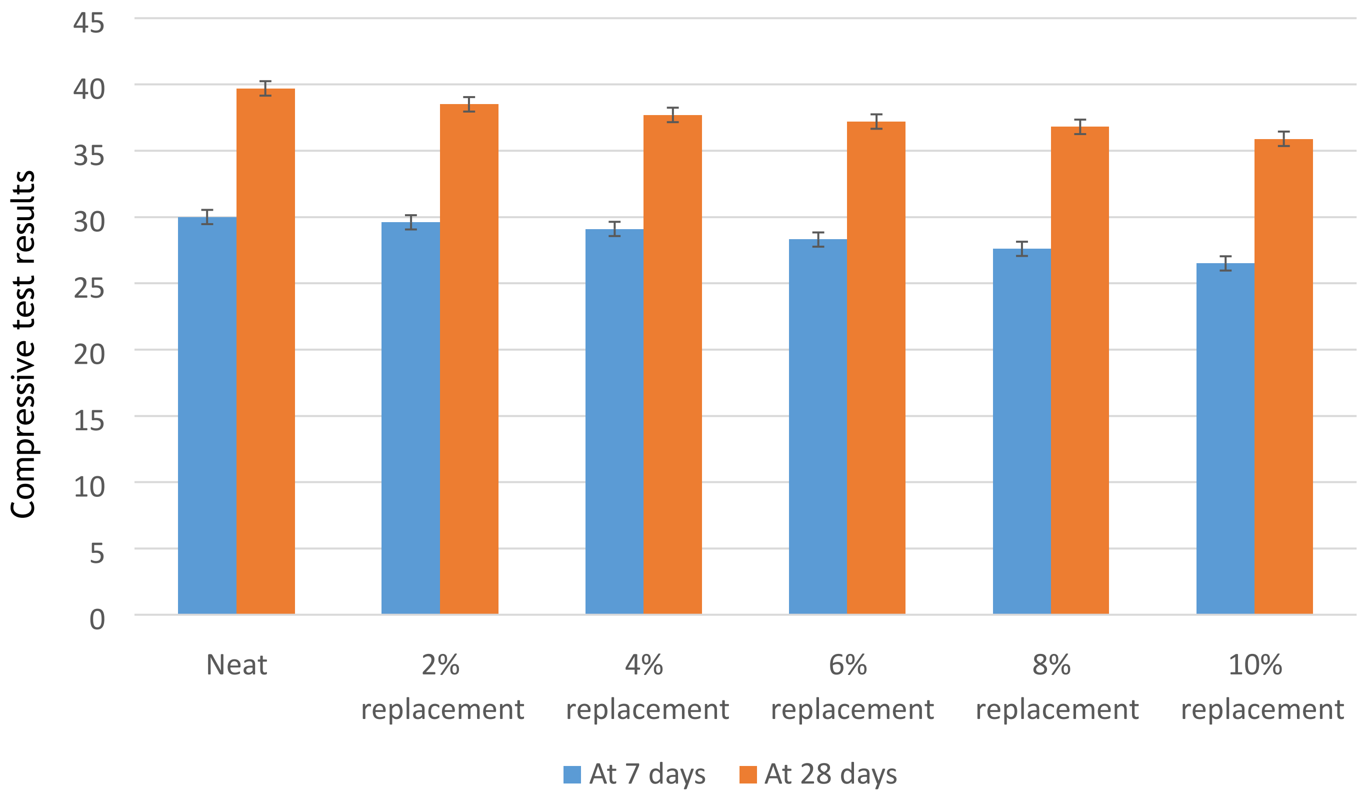
#### 4.3.5 Aggregate Crushing Value (ACV) Test on Coarse Aggregates.

The percentage by weight of the crushed material that results from subjecting test aggregates to a certain load under uniform conditions is known as the aggregate crushing value, or ACV. A relative assessment of an aggregate's resistance to crushing under a gradually applied compressive stress is provided by the aggregate crushing value test on coarse aggregates. ACV provides the relative measure of crushing under an, as per BS 812-part 110. raising the compressive load. Aggregates that clear a 14.0 mm test sieve and are held on a 10.0 mm test sieve can be used with this procedure. The ACV value was discovered to be 13.3, although the guidelines call for a maximum value of 25. In hindsight, this suggests that the material meets the requirements for usage in concrete even if it has a relatively poor resistance to crushing.

## 4.4 Properties of Concrete

#### 4.4.1 Compressive strength Test

This is a comprehensive interpretation of the graph showing the relationship between comprehensive strength and papyrus ash at different percentage replacements with cement in concrete.




The graph shows a gradual decrease in the compressive strength with increase in percentage replacements. The decrease however doesn't significantly affect the ability of concrete to perform to the required expectations. The values of compressive strength are seen to be still within range of the recommended values for concrete compressive strength as per the British standards. This could be attributed to a number of reasons that include;

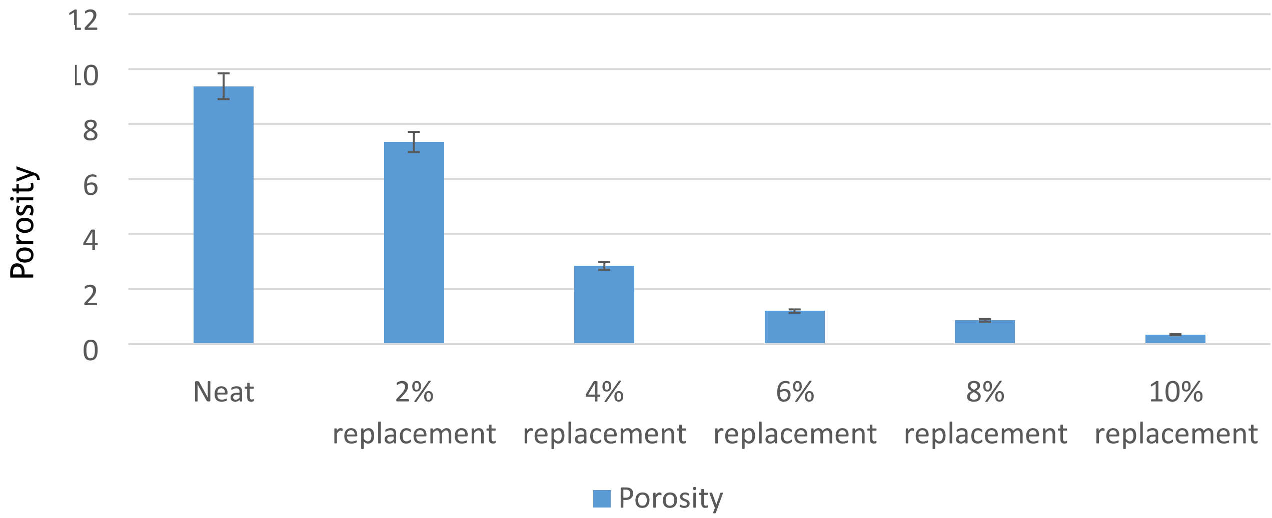
- Papyrus may increase the water demand of the concrete mix due to its high surface area and porosity, leading to a higher water-to-cement ratio. This excess water can weaken the concrete matrix. (Panda and Sarkar, 2020)

- While papyrus ash contains silica, it requires specific processing or activation methods to maximize their reactivity and effectiveness in concrete. (Schwing, 2010)

- The particle size and shape of papyrus ash may not be optimal for enhancing the packing density and mechanical properties of concrete. (Kadhim, 2021)

#### 4.4.2 Porosity Test

This parameter was our main focus of study and is what was used to relate the addition of papyrus ash with decrease in atmospheric infiltration which in turn significantly reduces carbon-induced corrosion of the steel reinforcement.




At our optimum replacement percentage, we observe that porosity values have dropped far lower than the average recommended 5% implying that the material has fulfilled its design expectations, and the concrete mix will not support atmospheric infiltration from water and gases such as carbon dioxide which is seen to be the primary raw material in the carbon induced corrosion of steel reinforcements within concrete.

#### 4.4.3 Concrete Mix Design

To generate a concrete mix design, we followed a series of procedures to analyze the data we received from the experiments carried out and the different optimization procedures we carried out to generate the best appropriate mix. This mix design was based on different properties such as, workability, strength, durability, but the parameter we focused on in this experiment was the concrete's porosity since we discovered that porosity in reinforced concrete can be detrimental since it was seen to be one of the leading causes of carbon induced corrosion in steel reinforcements. Another factor that has amplified this defect is also the increased concentrations of carbon dioxide in the atmosphere due to human activities such as burning of fossil fuels.

Here is an overview of the steps we used to come up with the mix design;

- Define the requirements. We defined each of the materials we required to generate the concrete based on their intended use. We based this on strength, workability, durability and other characteristics including water absorption needed for the environment the concrete will be used.
- Choose Materials: Select materials that will make up the concrete. Common components including cement, papyrus ash, aggregates, water.

- Establish Proportions: We determined the ratio of cement, water and aggregates. We then looked into the different percentage replacements of cement with papyrus we could use to achieve the desired results based on previous research.
- Trial mixes: We mixed and tested the different variations in small batches to determine the best mix required to achieved maximum results. The tests are outlined in the previous chapters.

- Adjust and finalize: Based on the results we achieved, we adjusted the mix design to fit the results we obtained, and the most appropriate mix design was selected.

FINAL MIX DESIGN

| | % addition & replacement of silica PFA | w/c | PFA (kg) | Coarse aggregate (kg) | Fine aggregates (kg) | Cement (kg) | Water (kg) |
|---|---|---|---|---|---|---|---|
| **Reference mix** | 0 | 0.50 | 0 | 19.68 | 14.79 | 8.30 | 4.15 |
| **Mix-1** | 2 | 0.50 | 0.42 | 19.68 | 14.79 | 7.89 | 4.15 |
| **Mix-2** | 4 | 0.50 | 0.83 | 19.68 | 14.79 | 7.47 | 4.15 |
| **Mix-3** | 6 | 0.50 | 1.25 | 19.68 | 14.79 | 7.06 | 4.15 |
| **Mix-4** | 8 | 0.50 | 1.66 | 19.68 | 14.79 | 6.64 | 4.15 |
| **Mix-5** | 10 | 0.50 | 2.08 | 19.68 | 14.79 | 6.23 | 4.15 |

The text outlined in red indicates the mix design we selected as the most appropriate mix design.

# CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSION

The purpose of the study on the partial substitution of papyrus ash for cement in reinforced concrete was to assess the viability of employing papyrus ash as an additional cementitious material to lessen corrosion caused by carbon. The study concentrated on the durability, corrosion resistance, and mechanical qualities of the concrete mix that had been altered by adding different amounts of papyrus ash.

The materials obtained and the trial mixes for the concrete at different percentage replacements with papyrus ash all conformed to the British standards but the researched aimed at obtaining the most optimum mix yielding expected results. At 8% replacement, our compressive strength remained within the recommended values and our porosity drastically reduced to below 5% which is the appropriate porosity for reinforced concrete which implies that infiltration is greatly minimized and chances of carbonation minimized as well.

It was observed that the incorporation of papyrus ash led to a denser microstructure within the concrete, attributed to the pozzolanic reactions between the ash and the calcium hydroxide in the cement paste. This densification aids in reducing the concrete's permeability, thereby enhancing its durability and reducing the likelihood of corrosion in the embedded steel reinforcement.

## 5.2 RECOMMENDATIONS

Basing on the objectives of this research and the gap that was addressed was covered and obtained. However, in order to increase the usage of papyrus ash in this reinforced concrete and also improve its applicability on a large-scale area and purpose, there is need to:

Further examine the aspect of viability for papyrus ash. This would be examining the harvesting methods of the senescent papyrus which would most appropriately be best for environmental conservation for example sectioning of different areas in order to leave room for regrowth.

Further studies need to carried out to examine the relationship between carbonation and porosity in regards to carbon induced reinforcement. This involves looking at the infiltration rates of ther different atmospheric components in the environment and their impact on the concrete and steel reinforcements.

Studies also need to be carried out to look into the slight decrease of compressive strength with initial addition of different supplementary cementitious materials such as papyrus ash, pumice powder and others. This would also include looking into the long term implication of this decrease and analyse any further changes in strength and other properties over time.

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# Appendix

## Lab tests and results

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In any Correspondence on
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FOR GOD AND MY COUNTRY
THE REPUBLIC OF UGANDA

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DIRECTORATE OF GOVERNMENT
ANALYTICAL LABORATORY
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Wandegeya,
P.O. BOX 105639
Kampala - Uganda

**GE 033/2024**
**31st January 2024**

MR. AJUTU PHILLIP AND MR BAMWESIGYE JOEL
S18B32/003 / S20B32/004
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-761-122146

**REPORT OF ANALYSIS**

**Description of the Samples**
One sample in a green polythene bag containing papyrus fiber ash was submitted by Mr. Ajutu Phillip, on 19th January 2024, and analysed on 29th January 2023. A summary of the sample received is shown in table below

| S/N | Description | Quantity | Assigned Lab ID |
|---|---|---|---|
| 1 | Grey powdered ash sample packed in a black polythene bag. | 01 | Sample "A" GE 033/2024 |

**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 Papyrus Fiber Ash sample GE 033/2024 |
|---|---|---|
| Silicon dioxide | % m/m | 69.494 |
| Calcium Oxide | % m/m | 11.768 |
| Aluminum Oxide | % m/m | 9.321 |
| Manganese (II) Oxide | % m/m | 7.591 |
| Potassium Oxide | % m/m | 1.129 |
| Iron (III) Oxide | % m/m | 0.502 |
| Phosphorous pent oxide | % m/m | 0.193 |

**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"*

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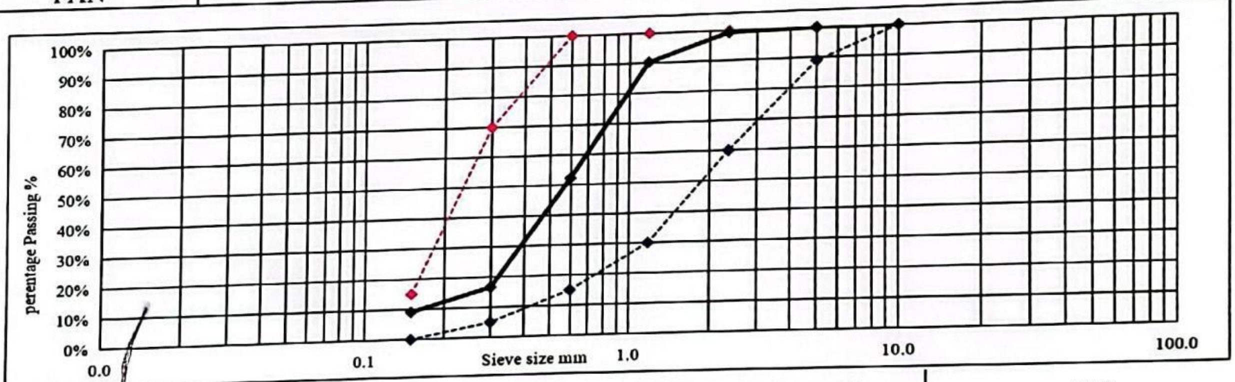
Email: cscecjiangbo@gmail.com

## Sieve Analysis for Sand

| | | | |
|---|---|---|---|
| Location: | Lukaya | Sample Date: | 4-Jan-2024 |
| | | Job ref: | mix design |
| Material description: | NATURAL SAND | Sand Size: | 5mm |
| | | Date: | 6-Jan-2024 |

| | | | |
|---|---|---|---|
| Test method: | BS882 1992 table 4 | Initial dry mass(g) | 1002.9 |
| | | Mass after washing on 0.075mm sieve(g) | 957.8 |

| Sieve size:(mm) | Sand 5 mm Lower limit | Upper limit | Wt. Retained on size | Cumulative mass Retained on size | Cumulative percentage retained on size | Percentage Passing |
|---|---|---|---|---|---|---|
| | | | | | 0.0% | 100.0% |
| 14.0 | — | — | 0 | 0 | 0.0% | 100.0% |
| 10.0 | 100% | 100% | 0.0 | 0.0 | 0.0% | 100.0% |
| 5.0 | 89% | 100% | 0.3 | 0.3 | 0.7% | 99.3% |
| 2.36 | 60% | 100% | 6.5 | 6.8 | 9.7% | 90.3% |
| 1.18 | 30% | 100% | 90.4 | 97.2 | 47.7% | 52.3% |
| 0.60 | 15% | 100% | 381.6 | 478.8 | 83.4% | 16.6% |
| 0.30 | 5% | 70% | 357.4 | 836.2 | 90.9% | 9.1% |
| 0.15 | 0% | 15% | 75.5 | 911.7 | 99.0% | |
| PAN | | | 80.9 | 992.6 | | |




| | |
|---|---|
| Fine modulus(M=(A2.36+A1.18+A0.6+A0.3+A0.15-5A4.75)/(100-A4.75)) | 2.3 |

**For the Representative(CSCEC):**

**Tested by;**

**Name & Signature;**........Hamza..........

**Date;**........6/01/24........

**Approved by;**

**Materials & QC Engineer;**..........

**Date;**........07/01/2024........

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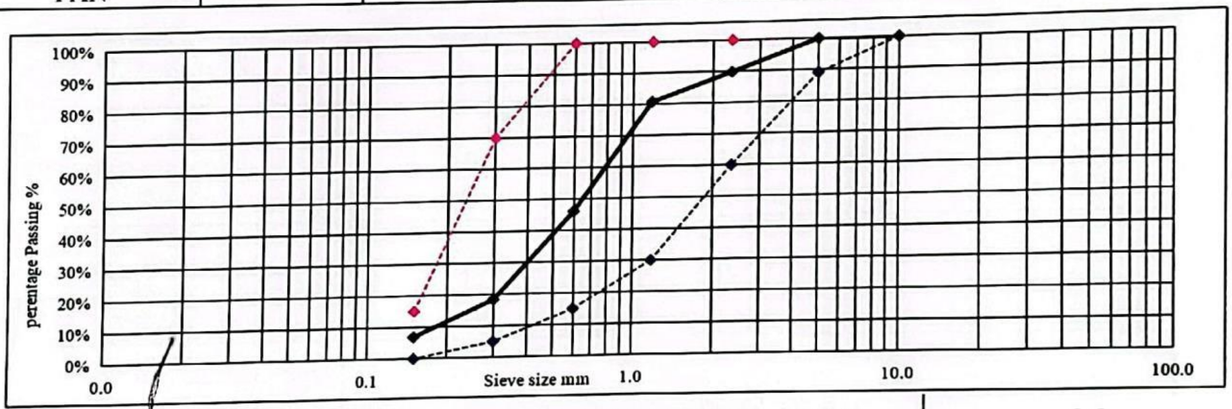
**Email: cscecjiangbo@gmail.com**

# Sieve Analysis for Sand

| | | | |
|---|---|---|---|
| Location: | Lukaya | Sample Date: | 4-Jan-2024 |
| Material description: | NATURAL SAND | Job ref: | Stone pitching |
| | | Sand Size: | 5mm |
| | | Date: | 6-Jan-2024 |

| Test method: | BS882 1992 table 4 | | Initial dry mass(g) | 1100.0 | | |
|---|---|---|---|---|---|---|
| | | | Mass after washing on 0.075mm sieve(g) | | | 961.6 |
| Sieve size:(mm) | Sand 5 mm Lower limit | Upper limit | Wt. Retained on size | Cumulative mass Retained on size | Cumulative percentage retained on size | Percentage Passing |
| 14.0 | — | — | 0 | 0 | 0.0% | 100.0% |
| 10.0 | 100% | 100% | 0.0 | 0.0 | 0.0% | 100.0% |
| 5.0 | 89% | 100% | 1.5 | 1.5 | 0.1% | 99.9% |
| 2.36 | 60% | 100% | 110.4 | 111.9 | 10.2% | 89.8% |
| 1.18 | 30% | 100% | 100.1 | 212.0 | 19.3% | 80.7% |
| 0.60 | 15% | 100% | 381.4 | 593.4 | 53.9% | 46.1% |
| 0.30 | 5% | 70% | 305.0 | 898.4 | 81.7% | 18.3% |
| 0.15 | 0% | 15% | 126.2 | 1024.6 | 93.1% | 6.9% |
| PAN | | | 77.9 | 1102.5 | 100.2% | |




| | |
|---|---|
| Fine modulus(M=(A2.36+A1.18+A0.6+A0.3+A0.15-5A4.75)/(100-A4.75)) | 2.6 |

**For the Supervisor's Representative:**

| | |
|---|---|
| **Tested by;** | **Approved by;** |
| **Name & Signature;**.......Hamza........ | **Materials & QC Engineer;**.......... |
| **Checked by;** | |
| **Name & Signature;**.......6/01/24....... | **Date;**.......07/01/2024....... |

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# SILT CONTENT OF NATURAL SAND BS 812 PART2 1975

| | | | |
|---|---|---|---|
| Sample Reference: | N/A | Sampling Date: | 4-Jan-2024 |
| Location: | Lukaya | Testing Date: | 6-Jan-2024 |
| Sample Description: | Natural sand | Technician: | Lab Team |
| | | Material Source: | Lukaya |
| Specimen Number | 1 | 2 | 3 |
| Clay Reading, mm (after 20 mins or max. 30 mins sedimentation) | 102 | 102 | |
| Sand Reading, mm (top edge of indicator) | 91 | 90 | |
| Silt content | 10.8 | 11.8 | |
| Rounded to the next whole number | 11 | 12 | |
| Average of the rounded values (rounded to the next whole number) | 11 | | |

**For the Representative(CSCEC):**

| | |
|---|---|
| **Tested by;** | **Approved by;** |
| **Name & Signature;** Ahmer. | **Materials & QC Engineer;** [signature] |
| **Date;** 6/01/24 | **Date;** 07/01/2024 |

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# Summary of Natural Sand Test Results

| | | | |
|---|---|---|---|
| Sample Reference: | N/A | Sampling Date: | 4-Jan-2024 |
| Location: | Lukaya | Testing Date: | 6-Jan-2024 |
| Sample Description: | Natural sand | Technician: | Lab Team |
| | | Material Source: | Lukaya |

| Test Property | | Results | *Standard & Specification* |
|---|---|---|---|
| Finess Modulus | - | 2.5 | *BS882 1992 table 4* |
| Silt content | % | 11 | *BS 812 PART2 1975* |
| Sand Equivalent | % | 72 | *ASTM D 2419: 95* |
| Water Absorption | % | 0.69 | *BS 812 Part 2 1995* |

**For the Representative(CSCEC):**

| | |
|---|---|
| **Tested by;** | **Approved by;** |
| **Name & Signature;**......Hamza........ | **Materials & QC Engineer;**.......... |
| **Date;**......6/01/24...... | **Date;**......07/01/2024...... |

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# SAND EQUIVALENT TEST

Ref: ASTM D 2419: 95

| | | | |
|---|---|---|---|
| Sample Reference: | | Sampling Date: | 4-Jan-2024 |
| Location: | Lukaya | Testing Date: | 6-Jan-2024 |
| Sample Description: | NATURAL SAND | Technician: | Lab Team |
| | | Material Source: | Lukaya |

| Specimen Number | 1 | 2 | 3 |
|---|---|---|---|
| Clay Reading, mm (after 20 mins or max. 30 mins sedimentation) | 117 | 116 | 121 |
| Sand Reading, mm (top edge of indicator) | 84 | 82 | 84 |
| Sand Equivalent = 100*Sand Reading /Clay Reading | 71.8 | 70.7 | 69.4 |
| Rounded to the next whole number | 72 | 71 | 69 |
| Average of the rounded values (rounded to the next whole number) | 71 | | |

**For the Supervisor's Representative:**

| | |
|---|---|
| **Tested by;** | **Approved by;** |
| **Name & Signature;** Hamza | **Materials & QC Engineer;** |
| **Date;** 6/01/24 | **Date;** 07/01/2024 |

| | |
|---|---|
| Technician | Materials Engineer |
| Sign: Hamza | Sign: |
| Date: 22/01/2024 | Date: 23/01/2024 |

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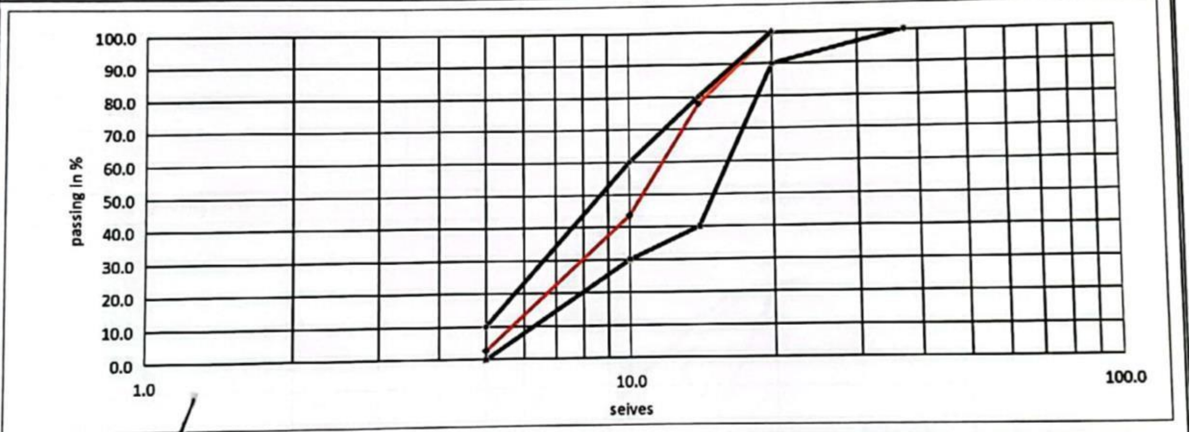
## SIEVE ANALYSIS OF COARSE AGGREGATES(BS EN 933-1:1997)

| | | | |
|---|---|---|---|
| Sample Ref: | Sample A | Method | Dry Sieving |
| Location | | Sample Date | 15 Jan 2024 |
| Source: | Zirobwe quarry | Testing Date: | 17 Jan 2024 |
| Initial wt.before washing | 4601.0 | Description: | (5-20 mm) Aggregates for Concrete |
| Dry wt.after washing | / | Tested by | Lab Team |

| Sieve size Standard | Partial Retained | cumulative Retained | cumulative Retained %age | Passing | Governing Specification Passing (BS 882:1992 Table 3) | |
|---|---|---|---|---|---|---|
| mm | g | g | % | % | Lower Limit | Upper Limit |
| 37.5 | 0.0 | 0 | 0.0 | 100.0 | 100 | 100 |
| 20.0 | 19.0 | 19 | 0.4 | 99.6 | 90 | 100 |
| 14.0 | 999.0 | 1018 | 22.1 | 77.9 | 40 | 80 |
| 10.0 | 1574.0 | 2592 | 56.3 | 43.7 | 30 | 60 |
| 5.0 | 1884.0 | 4476 | 97.3 | 2.7 | 0 | 10 |
| 2.36 | 120.0 | 4596 | 99.9 | 0.1 | | |




Remarks

**For the Representative (CSCEC)**

| Materials Technician | | Materials Engineer | |
|---|---|---|---|
| Sign: | Hamza. | Sign: | [signature] |
| Date: | 17.01.24 | Date: | 18/01/2024 |

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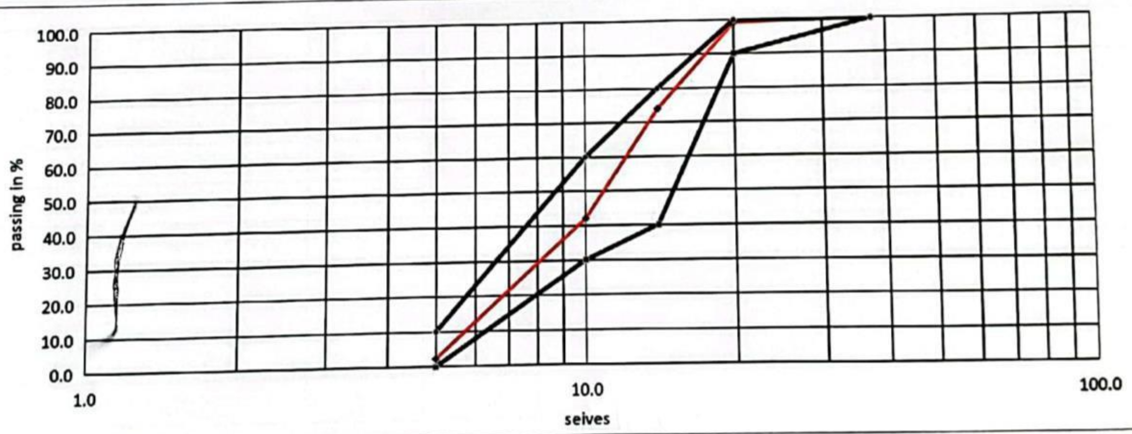
## SIEVE ANALYSIS OF COARSE AGGREGATES(BS EN 933-1:1997)

| | | | |
|---|---|---|---|
| Sample Ref: | Sample B | Method | Dry Sieving |
| Location | | Sample Date | 15 Jan 2024 |
| Source: | Zirobwe quarry | Testing Date: | 17 Jan 2024 |
| Initial wt.before washing | 4528.0 | Description: | (5-20 mm) Aggregates for Concrete |
| Dry wt.after washing | | Tested by | Lab Team |

| Sieve size Standard | Partial Retained | cumulative Retained | cumulative Retained %age | Passing | Governing Specification Passing (BS 882:1992 Table 3) | |
|---|---|---|---|---|---|---|
| | | | | | Lower Limit | Upper Limit |
| mm | g | g | % | % | | |
| 37.5 | 0.0 | 0 | 0.0 | 100.0 | 100 | 100 |
| 20.0 | 32.0 | 32 | 0.7 | 99.3 | 90 | 100 |
| 14.0 | 1145.0 | 1177 | 26.0 | 74.0 | 40 | 80 |
| 10.0 | 1446.0 | 2623 | 57.9 | 42.1 | 30 | 60 |
| 5.0 | 1802.0 | 4425 | 97.7 | 2.3 | 0 | 10 |
| 2.36 | 97.0 | 4522 | 99.9 | 0.1 | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| Pan | | | | | | |
| Wash Loss | | | | | | |
| Total | | | | | | |
| % Grading Error [g]: | <1% | | Equals weight loss/gain during grading. | | | |




Remarks

**For the Representative (CSCEC)**

| Materials Technician | | Materials Engineer | |
|---|---|---|---|
| Sign: | Hamza | Sign: | [signature] |
| Date: | 17/01/24 | Date: | 18/01/2024 |

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## FLAKINESS INDEX (FI)

## AVERAGE LEAST DIMENSION (ALD) BS 812: SECTION 105.1 1990

| | | | |
|---|---|---|---|
| Sample Ref | N/A | Sample Date | 15 Jan 2024 |
| Location | | Testing Date: | 17 Jan 2024 |
| Source | Zirobwe quarry | Technician | **Lab Team** |
| Sample Description | (5-20 mm) Aggregates for Concrete | | |

| | | Fractioned Guaged | | | | | |
|---|---|---|---|---|---|---|---|
| Passing Sieve | mm | **50** | **37.5** | **28** | **20** | **14** | **10** |
| Retained on Sieve | mm | **37.5** | **28** | **20** | **14** | **10** | **6.3** |
| Slot width | mm | | | | | | |
| % Retained (X) | | | 0.0 | 1.0 | 34.0 | 43.0 | 22.0 |
| (a) Mass retained | g | | 0 | 32.0 | 1145.0 | 1446.0 | 741.2 |
| (b) Mass to be gauged (X>5%) | g | | | | 1145 | 1446 | 741.2 |
| (c ) Riffled mass | g | | 0 | 32 | 1145 | 601.5 | 334 |
| (d) Correction factor (b/c) | | | | | 1.000 | 2.404 | 2.219 |
| (e) Mass passing Slot | g | | 0 | 0 | 155.0 | 71.2 | 80.2 |
| (f) Mass retained on gauge | g | | | | 990.0 | 1274.8 | 563.2 |
| (g) Corrected mass passing gauge (d*e) | g | | | | 155.0 | 171.2 | 178.0 |

| | | |
|---|---|---|
| Sum of Mass retained | g | 3364.2 |
| Sum of Corrected Mass passing slots | g | 504.1 |
| Flakiness Index FI = $(M_3/M_2)*100$ | % | **15.0** |

Remarks

**For the Representative (CSCEC)**

| | |
|---|---|
| Materials Technician | Materials Engineer |
| Sign: Hamza | Sign: [signature] |
| Date: 17/01/2024 | Date: 18/01/2024 |

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**RELATIVE DENSITY AND WATER ABSORPTION FOR COARSE AGGREGATES**

**TEST METHOD BS 812: Part 2 : 1995**

| | | | |
|---|---|---|---|
| Location: | 0 | Sampling Date: | 15 Jan 2024 |
| Material Source: | Zirobwe quarry | Tested Date: | 21 Jan 2024 |
| Sample description | (5-20mm) Coarse aggregates | Tested By: | Lab Team |

| Specimen reference | | | 1 | 2 | Average |
|---|---|---|---|---|---|
| Mass of Saturated Surface-dry aggregates in air | A | g | 2000.1 | 2023.6 | |
| Mass of basket + Sample in Water | B | g | 1245.6 | 1260.8 | |
| Mass of Oven-dryaggregates | D | g | 1993.5 | 2015.8 | |
| **Particle density on an oven-dry basis** | $P_d = \frac{D}{A-(B-C)}$ | $Mg/m^3$ | 2.642 | 2.643 | 2.642 |
| **Particle density on a saturated and surface-dry basis** | $P_s = \frac{A}{A-(B-C)}$ | $Mg/m^3$ | 2.651 | 2.653 | 2.652 |
| **Apparent Particle density** | $P_a = \frac{D}{D-(B-C)}$ | $Mg/m^3$ | 2.665 | 2.670 | **2.668** |
| **Water Absorption** | $W_{abs} = 100x\left(\frac{A-D}{D}\right)$ | | 0.3 | 0.4 | **0.36** |

Remark:

**For the Representative (CSCEC)**

| | |
|---|---|
| Materials Technician | Materials Engineer |
| Sign: Hamza | Sign: [signature] |
| Date: 21/01/24 | Date: 22/01/2024 |

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## LOOSE DENSITY FOR COARSE AGGREGATES

### TEST METHOD BS 812: Part 2 : 1995

| | | | |
|---|---|---|---|
| Location: | | Sampling Date: | 15 Jan 2024 |
| Material Source: | Zirobwe quarry | Tested Date: | 16 Jan 2024 |
| Sample description | (5-20mm) Coarse aggregates | Tested By: | Lab Team |

| Specimen reference | | | 1 | 2 | Average |
|---|---|---|---|---|---|
| Volume of the cotainer | A | g | 10000.0 | 10000.0 | |
| Mass of empty container | B | g | 3151 | 3151 | |
| Mass of container + Sample | C | g | 17485 | 17488 | |
| Mass of sample | D = (C - B) | g | 14334.0 | 14337.0 | |
| **Loose Density** | $P_d = \frac{D}{A}$ | $Mg/m^3$ | 1.433 | 1.434 | **1.434** |

Remark:

**For the Representantives (CSCEC)**

| Materials Technician | Materials Engineer |
|---|---|
| Sign: Ahmza. | Sign: [signature] |
| Date: 16/01/2024 | Date: 17/01/2024 |

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## RODED DENSITY FOR COARSE AGGREGATES

**TEST METHOD BS 812: Part 2 : 1995**

| | | | |
|---|---|---|---|
| Location: | | Sampling Date: | 15 Jan 2024 |
| Material Source: | Zirobwe quarry | Tested Date: | 16 Jan 2024 |
| Sample description | (5-20) mm | Tested By: | Lab Team |

| Specimen reference | | | 1 | 2 | Average |
|---|---|---|---|---|---|
| Volume of the cotainer | V | $m^3$ | 10000.0 | 10000.0 | |
| Mass of empty container | T | g | 3151 | 3151 | |
| Mass of container + Sample (AGG +SAND) | G | g | 18251 | 18326 | |
| Mass of sample | D = (G - T) | g | 15100 | 15175 | |
| **Roded Density** | $P_d = \frac{D}{V}$ | $Mg/m^3$ | 1.510 | 1.518 | 1.514 |

Remark:

**For the Representantives (CSCEC)**

| Materials Technician | Materials Engineer |
|---|---|
| Sign: Hmza . | Sign: [signature] |
| Date: 16/01/24 | Date: 17/01/2024 |

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## LOS ANGELES ABRASION VALUE (LAAV)

### TEST METHOD ASTM C131-2001

| | | | |
|---|---|---|---|
| Location: | Zirobwe quarry | Sampling Date: | 15 Jan 2024 |
| Material Source: | Zirobwe quarry | Tested Date: | 18 Jan 2024 |
| Sample description | Concrete Agg | Tested By: | Lab Team |

| Sieve Size | | Mass of indicated sizes (g) | | | |
|---|---|---|---|---|---|
| Passing | Retained on | Grading to be used | | | |
| | | A | B | C | D |
| 37.5mm | 25.0mm | 1250±10 | | | |
| 25.0mm | 19.0mm | 1250±10 | | | |
| 19.0mm | 12.5mm | 1250±10 | 2500±10 | | |
| 12.5mm | 9.5mm | 1250±10 | 2500±10 | | |
| 9.5mm | 6.3mm | | | 2500±10 | |
| 6.3mm | 4.75mm | | | 2500±10 | |
| 4.75mm | 2.36 mm | | | | 5000±10 |
| Total | | 5000±10 | 5000±10 | 5000±10 | 5000±10 |

| | | | | | |
|---|---|---|---|---|---|
| Sample Description | Concrete Agg(5-20)mm | | | | |
| Grading Used | Grading B | | | | |
| Specimen reference | | 1 | 2 | Average | |
| Mass of tray + test specimen (g) | | 5104.7 | 5204.9 | | |
| Mass of tray alone (g) | | 156.1 | 258.2 | | |
| Mass of original test specimen (g) | $M_1$ | 4948.6 | 4946.7 | | |
| Mass of material retained on 1.7mm sieve (g) | $M_2$ | 4032.5 | 4023.5 | | |
| Mass of material passing 1.7mm sieve (g) | $M_1$-$M_2$ | 916.1 | 923.2 | | |
| **LAA Value (%)** | $\frac{M_1 - M_2}{M_1} x100$ | 18.5 | 18.7 | 18.6 | |

**Remark:**
Grading A was used since it is one suitable for Graded Crushed Stone and Natural Gravel for Base Course

**For the Representative(CSCEC)**

| | |
|---|---|
| Materials Technician | Materials Engineer |
| Sign: Hamza. | Sign: |
| Date: 18/01/24 | Date: 19/01/2024 |

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## AGGREGATE IMPACT VALUE ($AIV_{dry}$)

## TEST METHOD BS 812 : Part 112 : 1990

| | | | |
|---|---|---|---|
| Location: | | Sampling Date: | 15 Jan 2024 |
| Material Source: | Zirobwe quarry | Tested Date: | 17 Jan 2024 |
| Sample description | 14/10mm | Tested By: | Lab Team |

| Specimen reference | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Number of blows | n | 15 | 15 | | |
| Mass of tray + test specimen (g) | | 1215.4 | 1221.4 | | |
| Mass of tray alone (g) | | 874 | 864 | | |
| Mass of original test specimen (g) | $M_1$ | 341.4 | 357.4 | | |
| Mass of material passing 2.36mm sieve (g) | $M_2$ | 58.2 | 58.9 | | |
| Mass of material retained on 2.36mm sieve (g) | $M_3$ | 283.2 | 298.5 | | |
| Aggregate Impact Value (in %) - Dry | $m = \frac{M_2}{M_1} x100$ | 17.0 | 16.5 | | |
| AIV - mean value (%) | | 16.8 | | | |

Remark:

**For the Representative (CSCEC)**

| | |
|---|---|
| Materials Technician | Materials Engineer |
| Sign: Hamza. | Sign: [signature] |
| Date: 17/01/2024 | Date: 18/01/2024 |

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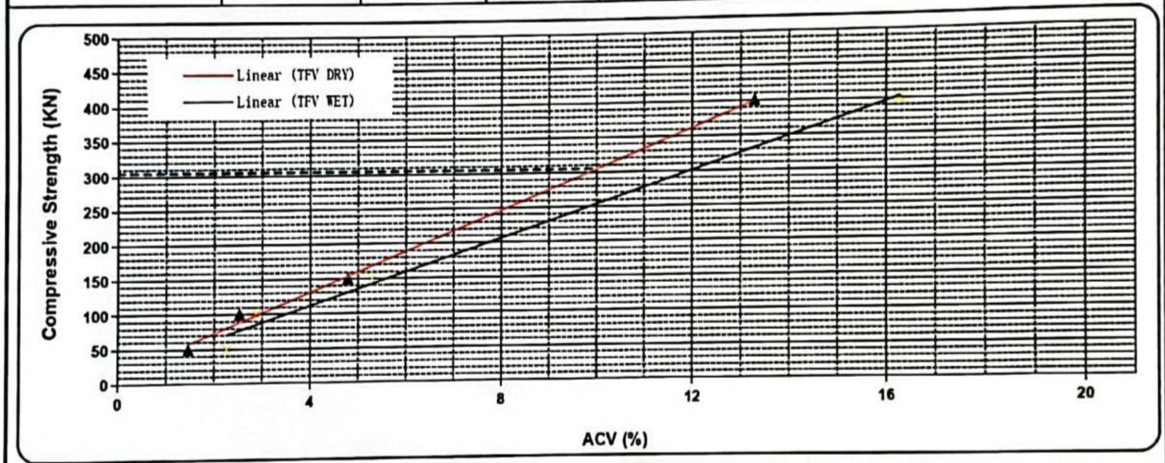
| | | | |
|---|---|---|---|
| SAMPLE STATION | N/A | SAMPLE NO. | N/A |
| MATERIAL TYPE | Concrete AGG | DATE SAMPLED | 15-Jan-24 |
| MATERIAL SOURCE | Zirobwe quarry | DATE TESTED | 20-Jan-24 |
| MATERIAL DESRIPTION | (5-20)mm | SAMPLED BY | Lab Team |

# DETERMINATION OF TEN PERCENT FINES VALUE

BS 812 Part 111 : 1990

| Sample Number | Method | Compressive Strength (KN) | Load (min) | Weight of total specimen (W1 g) | Weight of fine Passing 2.36 mm (W2 g) | Aggregate Crushing Value (W2/W1*100%) | Remark |
|---|---|---|---|---|---|---|---|
| A-1 | Dry condition | | 50 | 2428.1 | 35.5 | 1.46 | |
| A-2 | | | 100 | 2420.2 | 61.2 | 2.53 | |
| A-3 | | | 150 | 2417.6 | 115.7 | 4.79 | |
| A-4 | | | 400 | 2419.4 | 321.7 | 13.30 | |
| B-1 | Soaked condition | | 50 | 2451.0 | 55.4 | 2.26 | |
| B-2 | | | 100 | 2480.4 | 71.2 | 2.87 | |
| B-3 | | | 150 | 2481.3 | 131.4 | 5.30 | |
| B-4 | | | 400 | 2474.3 | 402.7 | 16.28 | |




| | |
|---|---|
| Compressive Strength for 10% Fines values in Dry condition ( TFV Dry): | 305 KN |
| Compressive Strength for 10% Fines values in Soaked condition ( TFV Wet): | 254 KN |
| TFV Ratio Wet / Dry Test (%) | 83 % |
| ACV (%) | 13 |

Representative (CSCEC)

| Lab Technician | Materials Engineer |
|---|---|
| Sign: Hamza. | Sign: [signature] |
| Date: 20/01/2024 | Date: 21/01/2024 |

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**Ref. Test Method:BS EN 12390-3: 2002**

| | | | |
|---|---|---|---|
| **Concrete Class** | C25/20 | **Cube Dimension** | 150 x 150x 150 |
| **Mix Description** | | **Cement Type** | Tororo Portland CEM I 42.5 N |

| Proportions by weight | CEMENT | Water | Agg(5-20) | Sand | W/C ratio |
|---|---|---|---|---|---|
| | 8.3 | 4.2 | 19.7 | 14.8 | 0.50 |
| % | 17.7 | 8.8 | 41.9 | 31.5 | |

| Casting Date | Testing Date | % Papyrus Ash. | Av. Slump (mm) | Compressive strength @7 days | Compressive strength @28 days | Porosity % | Setting Time (hrs) initial | Setting Time (hrs) final |
|---|---|---|---|---|---|---|---|---|
| 24-Jan-24 | 21-Feb-24 | 0 | 62 | 30.0 | 39.7 | 9.38 | 5.0 | 8.0 |
| 1-Feb-24 | 29-Feb-24 | 2 | 88 | 29.6 | 38.5 | 7.38 | 5.2 | 8.3 |
| 1-Feb-24 | 29-Feb-24 | 4 | 73 | 29.1 | 37.7 | 2.84 | 5.2 | 8.5 |
| 1-Feb-24 | 29-Feb-24 | 6 | 60 | 28.3 | 37.2 | 1.20 | 5.4 | 8.5 |
| 1-Feb-24 | 29-Feb-24 | 8 | 63 | 27.6 | 36.8 | 0.86 | 5.3 | 8.6 |
| 25-Jan-24 | 22-Feb-24 | 10 | 73 | 26.5 | 35.9 | 0.34 | 5.5 | 8.8 |

**For the Representative (CSCEC)**

| | |
|---|---|
| Materials Technician | Materials Engineer |
| Sign: Hamza . | Sign: |
| Date: 29/02/2024 | Date: 29/02/2024 |

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## CONCRETE MIX DESIGN USING ACI 211.1-91 METHOD

**DESIGN METHOD:** ***ACI COMMITTEE 211.1-91 ACI Committee 211, Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete, ACI 211.1-91, American Concrete Institute, Farmington Hills, Michigan, 1991.***

### (1) STIPULATIONS FOR PROPORTIONING.

| | | | | |
|---|---|---|---|---|
| (a) Concrete Strength/Cylinderical/ (Mpa) | = | 21.3 | | *Cylinderical Strength, 150 x 300mm* \| Cube = Cylinder/0.85= 25.1 |
| (b) Type of Cement | = | OPC | | *OPC 42.5 N/mm2, Portland Cem I* |
| (c) Maximum Nominal Size of Aggregate | = | 19 | mm | *as per ACI standards* |
| (d) Minimum Cement Content | = | 320 | kg/m³ | *for 20mm Nominal size as per ACI 302* |
| (e) Max. Water-Cement ratio | = | 0.50 | | *from ACI 211.1-91, Table A1.5.3.4(b) for Severe conditions* |
| (f) Exposure conditions | = | Severe | | |
| (g) Workability, Slump (mm) | = | 50 | mm | *from ACI 211.1,1991, Table A1.5.3.3* |
| (h) Method of Concrete Placing | = | Chute | | *Non-Pumpable* |
| (i) Placing & Mixing Condition | = | Good | | *from ACI 318-19* |
| (j) Type of Coarse Aggregate | = | Crushed | | *Angular Aggregate* |
| (k) Maximum Cement Content | = | 500 | kg/m³ | *as per Unganda General Specification, Section 6404 (a)* |
| (l) Fine Aggregate Type | = | Natural Sand | | |

### (2) TEST DATA FOR MATERIALS:

| | | | | |
|---|---|---|---|---|
| (a) Cement Used | = | *OPC 42.5 N/mm2, Portland Cem I* | | |
| (b) Specific Gravity of Cement | = | 3.150 | | |
| (c) Specific Gravity of :- | | | | |
| (1) Coarse Aggregate at Oven Dry Condition | = | 2.642 | | *Combined CA* |
| (2) Fine Aggregate at Oven Dry Condition | = | 2.605 | | |
| (d) Oven Dry Rodded unit weight :- | | | | |
| (1) Coarse Aggregate (CA) | = | 1,514 | kg/m3 | *Combined CA* |
| (e) Water Absorption:- | | | | |
| (1) Coarse Aggregate (CA) | = | 0.36 | % | |
| (2) Fine Aggregate (FA) | = | 0.74 | % | |
| (f) Moisture Content of Aggregate:- | | | | |
| (1) Coarse Aggregate (CA) | = | 0.31 | % | |
| (2) Fine Aggregate (FA) | = | 0.80 | % | |
| (g) Sieve Analysis:- | | | | |
| (1) Coarse Aggregates (CA) | = | | | |

*Grading Requirments for Coarse Aggregates*

| US Sieve mm [1] | Analysis of Coarse Aggregate Fractions I (5-20mm) [2] | | Percentage of Different Fractions I 100% [3] | 100% [3] | Specification *BS EN 933-1:1997 Graded 19-4.75mm* [7] |
|---|---|---|---|---|---|
| 37.5 | 100 | | 100 | 100 | 100-100 |
| 20 | 99 | | 99 | 99 | 90-100 |
| 14 | 76 | | 76 | 76 | 40-80 |
| 10 | 43 | | 43 | 43 | 30-60 |
| 5 | 2 | | 2 | 2 | 0-10 |

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# Appendix B:

**Casting of cubes with the different design mix proportion**