ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN INHIBITING SPALLING IN REINFORCED CONCRETE

MARK ALVIN KASULANE

M22B32/016

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

February, 2026

UGANDA CHRISTIAN UNIVERSITY
A Centre of Excellence in the Heart of Africa

ABSTRACT

Reinforced concrete is one of the most widely used construction materials due to its durability and strength, but it faces challenges when continuously penetrated by water, which corrodes the reinforcing concrete bars, leading to subsequent spalling, or the loss of concrete cover.

This research examined the use of Sugarcane Bagasse Ash (SCBA) as a partial replacement for cement to inhibit spalling caused by corrosion. Properties of SCBA were determined, and its influence on concrete was evaluated. SCBA's effectiveness in chloride-induced accelerated corrosion tests was assessed. In the case of the control mix, the duration of the first corrosion was about 2.5 hours, while for the 5% SCBA mix, the duration was 15.7 hours, thus indicating that the corrosion resistance had been substantially enhanced.

DECLARATION

I, **KASULANE MARK ALVIN, M2232/016,** hereby declare that this is my original work, is not plagiarised and has not been submitted to any other institution for any award.

KASULANE MARK ALVIN

SIGNATURE…………………………………… DATE…………………………………………

APPROVAL

I certify that this report was written by KASULANE MARK ALVIN, and I fully accept that he has been under supervision and so submitted to the Faculty of Engineering, Design and Technology at Uganda Christian University in partial fulfilment of the requirements for an award of a Bachelor of Science in Civil and Environmental Engineering.

Signed: …………………………………………

Date: ………………………………………….

Mr. Zzigwa Marvin,

Academic Supervisor.

ACKNOWLEDGEMENT

First of all, I give my utmost gratitude to Almighty God for the strength, wisdom, and direction that made it possible for me to complete this research project.

To the project supervisor, Mr. Zzigwa Marvin, my heartfelt gratitude for your great support, for the feedback you always give that makes one think, and for sharing your know-how; these have all been the basics throughout the study.

My project partner, Khan Gak Ngaw, is also to be recognised for their hard work, support, and participation in the entire research process.

I can’t thank my family and friends enough for being there, for their encouragement, for their patience, and for their support from moral support throughout my academic journey.

Finally, I appreciate the Department of Engineering Design and Technology for the facilities, resources, and technical assistance that were necessary for the successful completion of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

1. ACV Aggregate Crushing Value
2. AIV Aggregate Impact Value
3. BS British Standard
4. C-S-H Calcium Silicate Hydrate
5. C_2S Dicalcium Silicate
6. C_3S Tricalcium Silicate
7. C_4AF Tetracalcium Aluminoferrite
8. DOE Department of Engineering
9. FI Flakiness Index
10. FM Fineness Modulus
11. FRP fibre-reinforced composite
12. GGBFS Ground Granulated Blast Furnace Slag
13. ITZ Interfacial Transition Zone
14. KSL Kakira Sugar Works Limited
15. LOI Loss In Ignition
16. LAA Los Angeles Abrasion
17. NT BUILD Nordic Test Method for Building Materials
18. OPC Ordinary Portland Cement
19. PPC Pozzolana Portland Cement
20. RC Reinforced Concrete
21. RHA Rice Husk Ash
22. SCBA Sugarcane Bagasse Ash

23. SCB Sugarcane Bagasse
24. SCM Supplementary Cementitious Material
25. SRC Sulphate-Resistant Cement
26. TFV Ten Per Cent Fines Value
27. W/C Water-Cement ratio
28. XRF X-Ray Fluorescence

CHAPTER 1: INTRODUCTION

1.1 Background

Concrete is one of the primary construction materials used in most modern infrastructure today. But the performance of reinforced concrete in bridges and water-adjacent structures is often affected by aggressive physical and chemical processes in the environment (Modi, P et al., 2015).

Spalling is defined as the detachment or flaking off of the concrete cover due to the buildup of internal stress. When these tensile forces exceed the tensile strength of the concrete, it results in the exposure of the internal reinforcement bars (Moccia et al., 2021; Liu et al., 2021). Water ingress is mainly detrimental to concrete durability due to corrosion of reinforcing steel, especially when it is highly permeable. As water ingresses through the concrete, it's used as the transport medium for harmful ions, especially chlorides and sulphates (Moccia et al., 2021).

Equation for the corrosion of steel due to water ingress:

$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe\ (OH)_3$

These ions pass through the porous concrete matrix and initiate chemical reactions within it, leading to the formation of corrosion products that occupy more volume than the original steel rebar. As more of the corrosion product is formed, the space in the concrete is not adequate, which causes internal stresses in the concrete matrix to build up, resulting in cracks which increase in size as more corrosion products are formed and as the process continues, their loss of cohesion of binders and eventually loss of material, i.e., spalling, in which chips of concrete detach from the surface (Liu et al., 2021). So much to this degradation, along with giving away the structural efficiency degradation of concrete, gradually exposes the embedded steel and, under accelerated corrosion, thereby reducing the lifespan and safety of concrete infrastructure in hydraulic environments (Thomas et al, 2020).

The significance that spalling brings to reinforced concrete is twofold: some issues constitute worsening and abnormal structural performance, while others are detrimental to the safety of occupants. Upon the loss of the concrete cover caused by spalling, there is a risk of corrosion developing, thus reducing the cross-sectional area and characteristics of concrete and embedded steel reinforcement (Bihamba, 2024; Liu et al., 2021). When reinforcement is exposed to the environment due to spalling, corrosion is accelerated by the condition and then sets in rather quickly because of the absence of the protective concrete cover that would block moisture and oxygen (Mehta & Monteiro, 2014).

This weakens the structure further and shortens the service life immensely (Liu et al., 2021). Falling concrete fragments also make spalling dangerous in a living setting, especially outdoors or in high-traffic areas (Zhang et al., 2017). Concerning maintenance, the frequency of repair count and cost is raised and intensified if allowed to persist (Neville, 2011). Spalling further impairs the concrete by tarnishing its beauty and depreciating the functions of structures such as water tanks or retaining walls by causing leakage and surface degradation (Bihamba, 2024).

"Recent studies on sustainable building materials have suggested the use of adding agricultural waste ash to concrete as additives to increase its longevity and durability" (Ahmad J et al, 2021).

Sugarcane bagasse ash (SCBA) is produced when sugarcane bagasse, a byproduct of the sugar industry is burnt at controlled temperatures producing a powder that, is rich in amorphous silica (SiO2) which contained about 65% which interacts with Ca $(OH)_2$, a result of cement hydration, this creates more calcium silicate hydrate (C-S-H) gel, which increases strength and decreases porosity hence minimizing chloride and moisture infiltration (Azmatullah et al, 2019).

Multiple supplementary cementitious materials have been studied extensively in their effectiveness in reducing concrete porosity, improving durability and increasing spalling resistance. Silica fume has been identified as the most effective in reducing porosity with an effectiveness of 50–60% since it has ultrafine particles and high silica content (Tang et al., 2020).

Rice husk ash (RHA) has also been extensively researched, and it's been observed to achieve a 40–55% reduction in concrete porosity due to its high surface area and a greater percentage of reactive silica (Ganesan et al., 2021). Sugarcane Bagasse Ash (SCBA) has been studied; it's been observed to reduce porosity by 30–45% when used at 10–20% replacement, since it acts as both a filler and pozzolan (Kabir et al., 2020). Fly ash has been observed, and it has been seen to offer 20–40% reduction in concrete porosity and durability, especially in long-term performance, while volcanic ash shows 15–30% reduction depending on its fineness and composition (González et al., 2021).

Though silica fume and RHA are more effective, SCBA provides a balance between performance and sustainability and its availability due to the large presence of sugar processing companies (Mohammad et al.,2025).

There are numerous global and local studies that have focused on mitigating corrosion-induced spalling in reinforced concrete, particularly in marine and water-exposed environments. Traditional strategies include the use of methods such as cathodic protection, epoxy-coated rebars, corrosion inhibitors, and surface sealants (Brueckner et al., 2022).

These different methods have been studied and applied in different areas but they have had various short comings such cathodic protection, that has both impressed current and sacrificial anode techniques, has been effective at altering the electrochemical potential of steel reinforcement to inhibit corrosion, but it is expensive since it demands skilled installation, regular maintenance of the anode, and systems are frequently observed to fail within a few years due to rectifier or anode issues (Brueckner et al., 2022; NAP, 2022). Epoxy-coated rebar has also been used as a barrier against chloride ingress, and it's been observed to show superior corrosion resistance compared to bare rebar in laboratory settings, but coating imperfections, pitting at holidays, reduced bond strength, and debonding issues undermine its performance, leading to more aggressive localised corrosion and making repairs challenging (Salah A, 2023). The use of surface-applied coatings, such as epoxy and polyurethane sealants, offers a significant reduction in chloride penetration (lower than untreated surfaces), but they degrade over time from UV exposure and mechanical wear, which necessitates frequent recoating that is often impractical in low-maintenance settings (MDPI 2023).

Even though the measures presented above are quite effective, they are predominantly negative, dependent on skilled workers for their installation and upkeep, and necessitate near-perfect application, thus restricting their utilisation in the remote areas that have inadequate resources for above mentioned purposes (Gómez G.F. et al. 2023). In contrast to the aforementioned methods, the current research advocates for the compatibility of preventive enhancement of concrete durability by incorporating the use of sugarcane bagasse ash, which is readily available in local areas to make the concrete stronger, less porous and resistant to the aggressive ingress of ions like chlorides, sulfates, and water (Zheng C et al., 2023).

The method being suggested is not only sustainable and inexpensive but also practically maintenance-free; it solves the very problems caused by the traditional methods, especially in tropical areas like Uganda, where infrastructure decay is already a major problem threatening the economy.

1.2 Problem Statement

When the reinforced concrete gets in contact with water for a long time, the water, through the microfractures of the concrete, penetrates deep down to the reinforcement (Liu et al., 2021; Zhao et al., 2021). The water, when it reaches the reinforcement, starts a chemical reaction with the steel, resulting in the generation of various corrosion products, including iron (III) oxide. The gradual formation of rust (iron

(III) oxide) consumes several times the original metal volume, which creates internal pressure that is radial and directed towards the outside of the surrounding concrete (Moccia et al., 2021).

The generated radial force eventually excides the tensile strength of the concrete cover, hence cracking it either radially or longitudinally. The process of corrosion and cracking is such that the initial cracks created eventually grow and widen till the concrete cover completely breaks off (Moccia et al., 2021; Ye et al., 2020).

Figure 1 Images showing the start of spalling in a reinforced concrete column(left) and a column with lost concrete cover (right)

Spalling has been a problem in several structures in such as Kulubya hall in Kyambogo University, which gets rainwater that is collected at the top of the butterfly roof and moves down through the slab, CNN hostel in Kauga, Mukono district, and the Nyamwamba Bridge in Kasese District, Western Uganda, which is the main means of transport for the entire Western Uganda area. The reinforced concrete on these structures is often exposed to water from rain, and this results in almost constant water ingress to the reinforced concrete (Bihamba, 2024).

Thus, the present study seeks to find out the extent to which this eco-friendly natural system can be used as a corrosion-related solution that is low-cost, sustainable, and performance-based.

1.3 Main objective

To assess the suitability of sugar cane bagasse ash in inhibitng spalling in reinforced concrete.

Specific objectives

1. To determine the chemical and physical properties of the Sugarcane bagasse ash.
2. To determine the optimum amount of Sugarcane bagasse ash required in the concrete to reduce porosity.
3. To determine the effect of Sugarcane bagasse ash in minimising corrosion-induced spalling in reinforced concrete

1.4 Justification

According to multiple studies, it is stated that the corrosion-induced spalling of reinforced concrete surface was mainly triggered by the expansion of the corroded steel reinforcement inside, which causes tensile stresses that exceed the concrete's tensile strength, the latter being the cause of surface cracking and subsequent spalling of the concrete cover (Liu et al., 2021; Cao et al., 2019). To enhance the durability of reinforced concrete, several agricultural waste materials, such as sugarcane bagasse ash (SCBA), have been proposed due to their high silica content and pozzolanic reactivity (Memon et al., 2020; Jagadesh et al., 2023).

Sugarcane bagasse ash contains reactive silica and alumina, which react with calcium hydroxide during cement hydration in concrete to produce secondary C-S-H gel, which densifies the cement matrix with reduced porosity so that it can restrain the ingress of water or other aggressive agents that can accelerate corrosion (Srinivasan and Sathiya, 2021).

Equation for the hydration of cement:

$2C_3S + 6H_2O \rightarrow C_3S_2H_3$ (C-S-H gel) $+ 3Ca(OH)_2$

It is for the above reason that the pozzolanic reaction between SCBA and calcium hydroxide reduces the amount of free lime, which, if present, would otherwise be undesirable, as its presence raises the permeability of concrete (Muthusamy et al., 2018). Due to the refined pore structure, a physical barrier is made that obstructs the flow of moisture and ions through the concrete matrix, which slows the initiation of corrosion (Kumar et al., 2022). Also, the inclusion of SCBA improves the adhesion at the interface around the reinforcement bars, assisting in bonding, which minimises cracking and spalling under expansion pressure (Khalid et al., 2021).

Equation for the reaction of silica from the sugarcane bagasse ash and calcium hydroxide from the cement reaction

$Ca(OH)_2 + SiO_2 \rightarrow C\text{-}S\text{-}H$

The SCBA also improves the chemical resistance of concrete, which, on the other hand, suffers from typical early-age cracking phenomena related to shrinkage and low tensile capacity (Srinivasan and Sathiya, 2021).

This research aims at the use of SCBA as a concrete addictive to prevent spalling in concrete induced by the ingress of water in the reinforced concrete matrix. The study intends to evaluate the impact of cement replacement by SCBA on the mechanical, durability, and corrosion properties of concrete containing steel reinforcement. The selection of the most suitable mix proportions will be based on the analysis of corrosive exposure and testing of various mix proportions that not only enhance structural strength but also extend the lifespan of reinforced concrete in harsh environments. The findings will provide a foundation for the creation of environmentally friendly and long-lasting construction materials for infrastructures that are prone to corrosion.

1.5 Scope of the Study

1.5.1 Geographical Scope

The research utilised sugarcane bagasse ash (SCBA) obtained from Kakira Sugar Limited (KSL), located in Jinja District, with coordinates 0°30'36.0"N, 33°17'24.0"E (Latitude: 0.5100; Longitude: 33.2900). Cement, fine aggregates, coarse aggregates, and water were all sourced from Stirling Civil Engineering Ltd in Mukono.

1.5.2 Content Scope

The laboratory analysis and literature review are included in this portion of the study to measure the SCBA’s basic properties. The SCBA properties assessed were the chemical composition, mainly the silica content, particle size distribution, specific surface area, and loss of ignition. They were determined by using X-ray fluorescence (XRF) and sieve analysis, among others. This goal sets a basic knowledge on the one hand that the materials can be used in concrete as a pozzolanic additive and reinforcement, respectively, and on the other hand that they can meet the technical requirements for that use.

The study investigated how the addition of Sugarcane Bagasse Ash (SCBA) affected the behaviour of fresh concrete. Workability (slump), consistency, and setting time are the main parameters observed. SCBA’s high surface area and fine particles caused it to reduce water demand, making the concrete mix less workable, especially at higher replacement levels. The standard methods for testing, such as the slump test (BS EN 12350-2) and initial and final setting time (BS EN 196-3), are used to measure the effects. This part of the study enabled findings on how the new materials' pattern concrete affected operations, namely, placement, compaction, and early-age performance, which are very important for both practical application and long-term durability.

In this section, the inhibition of water intrusion and corrosion by SCBA in reinforced concrete was evaluated. Corrosion of metals due to concrete deterioration was a serious concern, and therefore, an accelerated corrosion test was conducted to find the effect of the SCBA on corrosion resistance in reinforced concrete.

CHAPTER TWO: LITERATURE REVIEW

Concrete is created when water, cement, fine aggregate (like sand), and coarse aggregate (like gravel or crushed stone) are mixed in the right proportions and the mass is hardened through a chemical process called hydration. Cement works as a binder that reacts with water to hold the aggregates together. The use of admixtures can give the concrete special attributes either before or after it has set. The strong and tough character of this material, resulting from the combination of the above-mentioned constituents, has led to wide applications in constructions owing to its high compressive strength and flexibility (Neville, A.M. et al., 2020).

2.1 Constituents of concrete

2.1.1 Cement

Cement is a finely powdered inorganic binder that, when mixed with water, undergoes a chemical reaction to produce a hardened matrix that is capable of binding the aggregates together. Hence, it is indispensable in concrete production. When water and cement are mixed, numerous reactions that generate heat (exothermic) happen, resulting in a strong and hard concrete with the stable forms of calcium silicate hydrate (C–S–H) gel and calcium hydroxide as the main by-products. The cement's binding property enables it to capture both fine and coarse aggregates in a solid and durable mass, thus being the cornerstone of civil and structural engineering works most of the time (Neville, A.M., et al., 2020; Mehta, P.K., 2021). More specifically, cement not only provides compressive strength but also influences the factors of setting time, durability, and resistance to environmental degradation, thus being a vital part of concrete.

2.1.1.1 Raw Materials for Cement Production

The production of cement mainly involves two types of raw materials, which are limestone (the source of calcium carbonate) and clay or shale (silica, alumina, and iron oxides suppliers). After being crushed, the two materials mixed in the right proportions are then fed into the rotary kiln, where they are heated to temperatures of approximately 1450°C, and a clinker is produced, which is then finely ground with a minor quantity of gypsum (calcium sulphate), the latter being the one that controls the setting time. In some cases, the cement industry uses more raw materials like bauxite, iron ore, or even waste from other industries, such as fly ash and slag, to improve performance or sustainability. The materials must be mixed in very precise ratios to keep the chemical balance required for the best cement compounds to be formed (Pavithra et al., 2020; Siddique R et al, 2022).

2.1.1.2 Cement Types Most Commonly Used in Building

Cement is selected based on the demands of the particular construction project. The types of cement are the most commonly used in various construction projects.

i. Ordinary Portland Cement (OPC): It is the most prevalent type of cement in the market, which is used for almost all construction projects.
ii. Portland Pozzolana Cement (PPC): It is a cement type that contains pozzolanic materials like fly ash or calcined clay. It provides durability, sulphate resistance,

and low heat of hydration, which makes it a suitable choice for various construction projects of special purposes.

iii. Rapid Hardening Cement (RHC): This is the kind of cement that has a very early strength, which makes it also suitable for fast construction and makes the area for doing the construction tolerant of bad weather and working conditions.

iv. Sulphate-Resistant Cement (SRC): This kind of cement is used in places where concrete is likely to be attacked by the high sulphate content in the soil or water (Siddique R et al, 2020; IS 269:2021; ASTM C150/C595).

2.1.1.3 Chemical composition of cement

The properties and suitability of cement are determined by its chemical composition, which primarily consists of oxides formed during clinker formation. The table below shows the chemical composition of cement.

Table 1: Composition of cement

Compound	Chemical formula	Composition (%)
Tricalcium silicate	$3CaO\cdot SiO_2(C_3S)$	45-60
Dicalcium silicate	$2CaO\cdot SiO_2(C_2S)$	15-30
Tricalcium aluminate	$3CaO\cdot Al_2O_3$ (C_3A)	6-12
Tetracalcium Aluminoferrite	$4CaO\cdot Al_2O_3\cdot Fe_2O_3$ (C_4AF)	6-10
Calcium oxide	Ca0	60-67
Silicon dioxide	SiO_2	17-25
Aluminium oxide	Al_2O_3	3-8

Iron oxide	Fe_2O_3	0.5-6
Magnesium oxide	MgO	0.1-4
Sulphur trioxide	SO_3	1-3

(Mehta, P.K. et al, 2021)

If ordinary Portland cement (OPC) is not designed and cured properly, concrete made with it typically suffers from high permeability, which is one of the main disadvantages of ordinary Portland cement concrete. This permeability simulates a very slow process of water penetration through the concrete cover as far as the steel reinforcement that is located inside the concrete. Once the water comes into contact with the steel, it will first attack the passive oxide layer, and thus, corrosion will be initiated. The process of rust (iron oxide) formation is accompanied by volume expansion of up to 600%—that is, the original steel's volume pushing the already stressed concrete, leading to cracking and eventually, spalling (NRMCA, 2021).

Cement paste is subject to shrinkage and micro-cracking due to the effects of cooling, drying, and hydration. The micro-cracks are often not visible on the surface, but they become the routes through which water can infiltrate the concrete matrix. The opening of the cracks facilitates the rapid penetration of water, thus accelerating the process of steel corrosion, which ultimately leads to the cracking and detachment of the surface concrete layer (Liu et al., 2024).

2.1.2 Aggregates

2.1.2.1 Fine Aggregates (Sand)

Fine aggregates refer to those materials that can pass through a 4.75 mm sieve, and their commonest occurrence is in natural sand, crushed stone sand, or manufactured sand. The role of fine aggregates is to fill the voids among the coarse aggregates and help out in the mixing and cohesiveness of the concrete. According to standards set by the international community, fine aggregates must be clean, amorphous, and contain no organic or clayey impurities, which usually are detrimental to the strengthening and setting of the concrete (ASTM C33/C33M-18). Besides this, fine aggregates are also an important factor in deciding the surface finish, pumpability, and water requirement of the concrete. The availability of well-graded sand guarantees a mix that is dense with very little bleeding and segregation (Pavithra et al., 2020).

Fine aggregates are very significant in the determination of concrete's lifespan and structure. Nonetheless, sand properties deficiency can still significantly cause strength loss and later on corrosion-based spalling in reinforced concrete. Purity of the sand is one of the biggest concerns, along with the silt, clay, and organic matter. Those impurities will affect the bond of cement paste and aggregate surfaces and thus lower concrete strength and increase its permeability. Permeable concrete will allow the passage of moisture to the steel that has been embedded and thus corroded before spalling occurs (Ohorongo Cement, 2024).

Moreover, not well-graded or too fine sand will cause the mix to draw more water, thus imposing a higher water-cement ratio and pore formation after the product dries. The latter will be a conduit for aggressive chlorides and CO_2 to access the steel and start the latter's corrosion. Corrosion is a fundamental and unavoidable process that occurs when metal reacts with environmental factors. The process takes place in several stages, starting from corrosion initiation to corrosion propagation. At the beginning of the process, the corrosion area is mostly inactive and undetectable. However, the result of this stage is the presence of a corroding agent in the hidden areas and progressive rust growth. The next stage is the oxidation and reduction of the steel surface. The reaction causes the formation of ferrous and ferric (rust). An increase in the volume of iron oxides (rust) is the main factor that causes the detachment of the concrete cover, which is often called spalling (Zheng et al., 2023).

Furthermore, the sand's particle size and shape, as well as their texture, influence the microstructure of the concrete, especially in the interfacial transition zone (ITZ) between the aggregate and the cement paste. Rounded, Smooth sand particles form a weaker ITZ that is more likely to develop micro-cracks, which serve as pathways for contaminants. The micro-cracks may become unnoticed until the corrosion and spalling are well advanced (Li et al., 2022).

2.1.2.2 Coarse Aggregates (Gravel/Crushed Stone)

Coarse aggregates consist of particles that are larger than 4.75 mm, and their size ranges from 10 mm to 40 mm, depending on the purpose of use. They are composed mainly of crushed granite, limestone and river gravel. Concrete's compressive strength, volume stability, and durability are defined by coarse aggregates. Their particle shape, texture, and grading can be viewed as three main factors that determine workability, water demand, and interlock in the concrete matrix to a great extent (Siddique R. et al, 2020; Siddique R. et al, 2022). For structural works, a maximum aggregate size of 20mm is normally used, whereas 10mm aggregates are recommended for heavily reinforced or precast elements to ensure better flow and compaction. The use of well-graded coarse aggregate results in the lowest possible void content and thus the highest density of the concrete matrix.

Corse aggregates not only contribute to the strength but also play a major role in the durability of concrete. Their properties, for instance, size, permeability, and cracking, determine the initiation and spread of corrosion-induced spalling. Among various factors, the aggregate size and grading are the main ones. Poorly graded coarse aggregates can result in segregation and the formation of voids, which, in turn, prevent the concrete matrix from being properly compacted. This leads to an increase in permeability within the concrete, thus allowing water to penetrate the concrete, causing the steel reinforcement to rust (Zhou et al., 2022).

Moreover, angular or imperfectly shaped aggregates with rough surfaces may help in developing mechanical bonding that is strong, but at the same time, they can create stress spots and micro-cracks in the concrete during drying and handling, which, in terms of cracking, would be a more negative effect. These micro-cracks, especially if they occur at the aggregate-mortar boundary (the interfacial transition zone or ITZ), become very accessible paths for water and ions to reach the steel reinforcement. As corrosion occurs, the rust formed occupies a larger volume and applies internal pressure, resulting in cracking and eventually spalling of the concrete cover (Liu et al., 2021).

Further, the porosity and water absorption of the aggregates are other important factors. Water can easily be absorbed through highly porous coarse aggregates, thereby increasing the effective water-cement ratio in the mix, which leads to the reduction of concrete strength and durability. The areas of deteriorated concrete are less resistant to external forces that make them more prone to corrosion and subsequent spalling (Zhou et al., 2022).

To sum it up, the use of poor-quality or improperly selected coarse aggregates can cause a number of problems, such as the creation of internal cracks, weak interfacial zones, higher permeability, or the occurrence of harmful chemical reactions. These conditions lead to the weakening of the steel.

2.2 Use and Proportioning in Concrete Mix

Aggregates are batched by means of a definite ratio according to the concrete grade and the necessary characteristics for the concrete. The standards of mix design (like M25 or C25/30) would generally involve a fine-to-coarse aggregate ratio of 1:2 or 1:2.5, based on the workability desired and the kind of aggregate used. The water-to-cement ratio, cement content, and aggregate gradation must be so determined as to avoid segregation, allow for proper compaction to get the desired strength and durability of the concrete, and achieve the intended target speed, and thus Proper blending of different aggregate sizes results in better packing of aggregates within the concrete matrix, eventually leading to a decrease in the demand for cement and water. Consequently, this results in the sustainability and cost-effectiveness of the concrete mix being improved (Mehta P.K. et al, 2021). On the other hand, the use of improperly graded or dirty aggregates can lead to excessive shrinkage, loss of strength, and lower overall performance of concrete in the long run.

2.3 Supplementary cementitious materials (SCMs)

2.3.1 Definition and Role of Supplementary Cementitious Materials (SCMs)

Supplementary Cementitious Materials (SCMs) are the main component in the composition of concrete as they are fine powders that can be added to the mix or replace a part of cement in concrete to enhance its properties, sustainability, and performance. SCMs can chemically and physically coexist with the main ingredient, calcium hydroxide which is produced during cement hydration, forming more calcium silicate hydrate (C–S–H) gel, the pozzolanic or hydraulic method that need less cement, hence, less carbon dioxide emissions from cement production (Mehta P.K. et al, 2021). The addition of SCMs improves the ability of concrete to resist alkali-silica reactions, chloride and sulphate ingress and also improves workability

2.3.2 Types of SCMs

Natural SCMs

Natural SCMs are sourced from the earth and made from minerals with pozzolanic traits. Calcined clays, volcanic ash, and natural pozzolans like diatomaceous earth and metakaolin are the most frequent materials among natural SCMs. These materials contain large amounts of silica and alumina that react with calcium hydroxide creating the C–S–H gel (Pavithra et al., 2020) which is formed as a secondary product. Ash from volcanoes is a major source of such a material in regions like East Africa, and on top of that, it has been observed that the porosity of concrete is reduced (Siddique R. et al, 2020). The demand for natural SCMs is increasing not only in low-carbon initiatives but also in places where industrial wastes are not available.

Artificial SCMs

Artificial SCMs are produced in the form of industrial wastes or residues that come from manufacturing processes and possess cementitious or pozzolanic properties. The most significant artificial SCMs are:

i. Fly Ash: It is produced when coal is burned in thermal power plants, and it is usually divided into the classes: Class F (low calcium) and Class C (high calcium). It leads to better workability, higher long-term strength, and durability while it reduces water demand and heat of hydration (IS 3812:2013).

ii. Ground Granulated Blast Furnace Slag (GGBFS): It is produced when iron is made in blast furnaces. GGBFS has a slow reaction but it is also the cause of the long-term strength and the concrete's resistance to sulphate and chloride attacks. Moreover, it is responsible for low heat concrete used in massive structures (ASTM C989/C989M-18).

iii. Silica Fume: This is a very fine by-product of the production of silicon or ferrosilicon alloys. Its pozzolanic activity is very high, and it gives a significant improvement in strength, abrasion resistance, and impermeability of high-performance concrete through its addition.

iv. Sugarcane Bagasse Ash (SCBA): This is an agricultural residue that originates from the incineration of sugarcane leaves and stalks. SCBA, when processed to low carbon content and very finely ground, has the potential to be a good pozzolan because of the high silica content. It is namely used for enhancing the durability of concrete and as a source of reduced cement in the concrete mix, thus becoming the favorite material in the tropical regions (Bisht, K. et al, 2021).

v. Rice Husk Ash (RHA): This is a potent pozzolanic material which is produced when rice husks are burnt in a controlled manner. RHA is composed of amorphous silica and it grants concrete resistance to the alkali-silica reaction and chloride penetration; hence the concrete is stronger.

Artificial SCMs have the double advantage of improving concrete performance and encouraging the use of industrial waste, thus being indispensable for green building techniques (Mehta P.K. et al., 2021).

2.4 Sugarcane Bagasse: Source and Properties

Sugarcane bagasse (SCB) is composed of the fibrous material that remains after extracting juice from sugarcane stalks in the sugar-making process. Its composition includes cellulose (40–50%), hemicellulose (25–35%), lignin (15–25%) and small quantities of waxes and ash (Singh et al., 2021). The sugars are mostly produced worldwide in the countries of Brazil, India, Thailand, and Uganda, etc., which means SCBA is generated in huge quantities. About 2.5–3 tons of bagasse are obtained for each 10 tons of sugarcane crushed. The organic nature of SCBA and its high availability make it a very attractive agricultural residue with great potential in the pulp and paper industry and even other industries.

2.4.1 Applications of Sugarcane Bagasse in Other Fields

Apart from being a raw material for ash production, sugarcane bagasse is considered a very extensive resource and is used in many different sectors because of its biodegradability, strength of fibres, and renewability.

Bioenergy and Power Generation: The primary application for steam condensed water (SCB) is a biofuel for cogeneration plants where the bagasse is burned to produce steam and power, mainly in sugar factories, thus affording the plants with energy self-sufficiency (Chandel et al., 2020).

Pulp and Paper Industry: Due to its cellulose content, SCB is being used in the manufacture of sustainable papers, boards, and packaging materials that are biodegradable, which, at the same time, is a greener alternative to wood pulp (Rabelo et al., 2020).

Bioethanol Production: Apart from that, bagasse can be hydrolysed enzymatically to fermentable sugars, which means it will be the major raw material in the production of second-generation ethanol, primarily in bio-refineries that aim at curtailing carbon emissions (Gaurav et al., 2021).

2.4.2 Sugarcane Bagasse Ash (SCBA)

When Sugarcane Bagasse (SCB) is burnt at 500°C to 800°C under controlled conditions, it results in the generation of Sugarcane Bagasse Ash (SCBA), which is a light, fluffy powdery residue that has a lot of amorphous silica in it. SCBA can be prepared and milled into a finer size which is that a part of the SCBA can go through a 45μm sieve, thus it will have a great pozzolanic effect, allowing it to substitute cement in concrete and mortar mixes to some extent.

Advantages of SCBA

High Silica Content: SCBA has about 60% to 80% silicon dioxide (SiO_2), of which most is amorphous, which combines with the $Ca(OH)_2$ released during the hydration of cement to produce more C–S–H gel, thus increasing the strength of the concrete and lowering the permeability (Bisht R. et al, 2021).

Less Carbon Footprint: SCB is paralleled with a part of cement, resulting in decreased CO_2 emissions, thus being a part of green construction practices.

SCBA, the abundant and low-cost material: In sugar mills, SCBA is usually treated as a waste product.

Chemical Composition of SCBA

SCBA's strength as an SCM lies in its rich oxide composition. The table below summarises typical chemical constituents.

Table 2: Supplementary cementitious materials and their effects

Property	Volcanic Ash	Rice Husk Ash (RHA)	Silica Fume	Sugarcane Bagasse Ash (SCBA)	Fly Ash
Source	Naturally occurring (lava dust)	Agricultural waste (rice husks)	Industrial by-product	Agricultural waste (sugarcane)	Industrial by-product (coal combustion)
Silica content (%)	50–65	85–95	>90	60–80	40–60
Pozzolanic activity	Moderate to high	High	Very high	Moderate to high	Moderate to high
Loss on ignition (LOI) (%)	<6	1–6	<3	2–10	<6
Water demand	Low to moderate	High	Very high	Moderate	Moderate
Effect on workability	Slight decrease	Decreases	Decreases	Slightly decreases	Often improves
Effect on strength	Improves gradually	Improves significantly	Long-term strength gain	Improves at optimal dosage	Improves
Effect on porosity to water	Reduces moderately	Significantly reduces	Greatly reduces	Reduces at optimal dosage	Moderately reduces
Environmental impact	Low	Very low	Moderate	Very low	Moderate

(Singh et al., 2021; Bisht K. et al, 2021; Mehta P.K. et al, 2021)

Sugarcane Bagasse Ash (SCBA) is a supplementary cementitious material that has a potential for mitigation of corrosion-induced spalling due to its silica content (60-80%), which is the highest in comparison to other materials; moreover, its moderate to high pozzolanic activity is also a contributing factor. Thus, an increase in the formation of calcium silicate hydrate (C-S-H) results in the densification of the concrete matrix, thus making it less pervious to water and limiting the ingress of corrosive agents as well (Kabir et al., 2020; Ganesan et al., 2021). SCBA has an edge over fly ash in cement application as it can produce similar or improved reductions in porosity and better microstructure with the optimal replacement levels (Zhao & Zhang, 2022). Its finer particle size and greater surface area are responsible for packing density and crack resistance that are better than many traditional pozzolans. The other advantages of fly ash are better workability and long-term durability; however, SCBA, being an agro-waste product, not only offers the advantage of a more sustainable choice but also greater local availability in sugarcane-producing areas, hence has less environmental impact (Kabir et al., 2020). Therefore, SCBA is a good choice on technical grounds as well as for being eco-friendly compared to conventional SCMs like fly ash for making concrete more durable and less prone to spalling.

2.5 Introduction to corrosion-induced spalling in concrete

Corrosion-induced spalling is a phenomenon that takes place when the steel reinforcement embedded in concrete is subjected to corrosion due to the intrusion of chlorides, carbonation, or moisture. The resulting corrosion products (rust) occupy a space they can expand into that is up to six times more than the original steel volume, thereby producing internal stresses that create cracks and finally lead to detachment and spalling of the concrete cover. This whole process is a major factor that weakens the durability, the structural integrity, and the safety overall of the reinforced concrete structures (Bihamba, 2024; Mehta & Monteiro, 2021).

Looking back, different protection and control strategies have been tried out in the past to deal with this problem. Nevertheless, most of these have drawbacks regarding cost, durability, sustainability, or practical use, thus making it necessary to look for new ways, such as those investigated in this research.

1. Utilisation of corrosion inhibitors

Among the many methods of controlling steel corrosion in concrete, corrosion inhibitors like calcium nitrite and amino alcohols are considered the most effective. They prevent corrosion by creating a thin layer of protection on the surface of the steel reinforcements, which in turn inhibits the corrosive reactions (Cao, Hibino, & Goda, 2015; Guo, Zhang, Wang, Tayebi, & Hamawandi, 2022).

Disadvantages of corrosion inhibitors

i. High-performance inhibitors are very costly, which makes them unsuitable for larger projects or those with tight budgets (Guo et al., 2022; Satish, Ravindra, & Anitha, 2024).
ii. The protective effect of inhibitors diminishes over time due to either leaching or chemical decomposition. For example, calcium nitrite may lose its effectiveness in high chloride concentration environments or after several years of exposure (FHWA study; Cao, Hibino, &Goda,2015).

iii. Some inhibitors are either toxic or present long-term environmental risks; thus, their use is associated with sustainability concerns (Liu et al., 2025; Ghoreishiamiri, J.et al., 2020).

iv. Proper mixing is essential for corrosion inhibitors to function effectively. If the mixing is not done correctly, some places may not get the protection they need, which is particularly problematic for large or intricate structures (Cao et al.)

2. **Coatings on Reinforcement or Concrete Surface**

When the rebar is already corroded, the corrosion products are blocked by protective coatings applied either directly to steel rebars (such as epoxy coatings, galvanised steel) or to the surface of hardened concrete (such as silane sealers, bituminous coatings).

Shortcomings with the Use of Coatings on Reinforcement or Concrete Surface

i. Poor Bonding: The epoxy-coated rebars commonly show reduced bond strength with the concrete around them, which affects structural behaviour.

ii. Damage During Handling: Coated rebars may suffer from scratches during their transportation or installation, which can become a source of localised corrosion.

iii. Maintenance Needs: Coatings applied on the surface of materials need to be constantly re-applied and maintained, especially in aggressive environments where they may be easily removed.

iv. Barrier Failure: Over time, coatings may crack or peel off, thus allowing the ingress of chlorides and water.

3. Cathodic Protection

In this electrochemical method, the steel is protected from corrosion by attaching sacrificial anodes or using an impressed current. The method is common in marine or chloride-rich areas.

Shortcomings with the Use of Cathodic Protection

i. High Cost and Complexity: The method needs continuous power supply, monitoring systems and specialised expertise.
ii. Unsuitability for All Structures: It is not economically sound for residential or small structures.
iii. Interference Issues: Impressed current systems might interfere with nearby structures or equipment.
iv. Difficult Retrofit: Installation of cathodic protection in an existing structure is labour-intensive and intrusive.

4. Use of Low-Permeability Concrete Mixes

The other method demonstrated to be efficient was the use of dense concrete mixes consisting of low water-cement ratios, silica fume, or fly ash so as to cut down the permeability and the chloride ingress.

Shortcomings in the Use of Low-Permeability Concrete Mixes

i. Workability Problems: Very low water-cement ratios can lessen workability and augment the chances of poor compaction.

ii. Shrinkage Cracking: The occurrence of early-age shrinkage cracking in high-performance concretes can negate the very reason of low permeability.
iii. Material Availability: The availability and the cost of supplementary cementitious materials (SCMs) such as silica fume and fly ash can be major concerns in certain areas, especially in developing countries, where the situation can be more critical.

5. Stainless Steel or Non-Metallic Reinforcements (e.g., FRP Bars)

This method consists of replacing standard steel with stainless steel, fibre-reinforced composite (FRP), or basalt bars, thus eliminating the risk of corrosion.

Shortcomings in the use of stainless steel and Non-Metallic Reinforcements

i. High Initial Cost: Such materials come at a considerably higher price than conventional steel.
ii. Limited Structural Ductility: FRP bars are not tough and do not yield like steel, affecting the performance during an earthquake.
iii. Specialised Design Considerations: Involves new design strategies, codes, and a workforce with skill levels that may not suit the material.
iv. Recyclability Issues: Certain types of FRP are hard to recycle, or their disposal cannot be assured to be environmentally friendly.

Even though a number of methods have been invented to counteract corrosion-induced spalling, a great number of them fail for different reasons, such as being too costly, not durable enough, and being too complex technically, or simply being unsuitable for rural or developing areas. In this connection, the use of natural, inexpensive and sustainable materials such as sugarcane bagasse ash (SCBA) and bamboo fibre opens a wide range of possibilities. SCBA works on the matrix by improving its durability and density in the process of lowering the porosity and permeability

2.6 Knowledge gap

Corrosion-induced spalling of reinforced concrete has been and still is one of the main reasons for the unreliability of structures, especially in tropical areas where the conditions of high humidity and direct contact with chlorides or carbonation are predominant. Different ways of mitigating this problem have been investigated; among them are coatings, inhibitors, cathodic protection, and low-permeability mixes. However, these methods typically do not meet the expectations due to the high costs, limited durability, maintenance required, or the fact that they are not available in developing countries. On the other hand, still, some research has been conducted on supplementary cementitious materials (SCM) such as fly ash and silica fume. This shows a considerable lack of information that needs to be filled up. The use of sugarcane bagasse ash (SBCA), which is the waste from the sugar industry, has the potential to improve the concrete's properties, namely through its pozzolanic activity which is responsible for increasing the concrete's density and decreasing its permeability hence limiting the entrance of the corroding agents. Most of the studies that were conducted with SCBA were primarily focused on the development of strength and shrinkage and ignored the material's capability to increase corrosion resistance or protect the steel that is inside the concrete. Therefore, my research intends to fill this gap by assessing the feasibility of sugarcane bagasse ash as a corrosion-related deterioration of reinforced concrete solution that is low-cost, sustainable, and performance-based. The research signification is not only in terms of environment and economy, but also in terms of technology as it will make the concrete infrastructure longer live by minimizing the maintenance costs and thereby increasing the lifespan of such facilities.

CHAPTER THREE: METHODOLOGY

In this chapter, the materials that were utilised in this research, along with the experimental methods employed to achieve the study objectives, are discussed in detail. The research addressed the issue of corrosion in concrete by utilising Sugarcane Bagasse Ash (SCBA), a strong pozzolanic material, to prevent water penetration and limit further corrosion by inhibiting the formation of soluble iron oxide.

To obtain a clear picture of the SCBA's properties, a wide range of tests were performed, such as X-Ray Fluorescence (XRF) analysis for elemental composition, Chapelle test for pozzolanic activity, Loss on Ignition (LOI) for organic content, sieve analysis for particle size distribution, and specific gravity measurements. Besides, the rheological properties of fresh mixes with different SCBA replacement levels were tested by the slump method to assess their workability and consistency. The mature concrete was then evaluated in terms of the mechanical performance (compressive strength) and durability (water absorption and accelerated corrosion resistance) through destruction testing. Finally, the mix design ratio most suited for the desired performance and compatibility of the materials was established.

The combination of these experimental protocols was laid down systematically so that the data obtained was highly reliable and thus supported the case of using sugarcane bagasse ash (SCBA) as a green solution for the longevity of concrete structures that are exposed to harsh environments.

3.1 Research Design

The research employed an experimental study to gather data, since the objective is to evaluate the efficacy of sugar cane bagasse ash in mitigating corrosion-induced spalling in reinforced concrete. The experimental investigation to acquire data goes as follows,

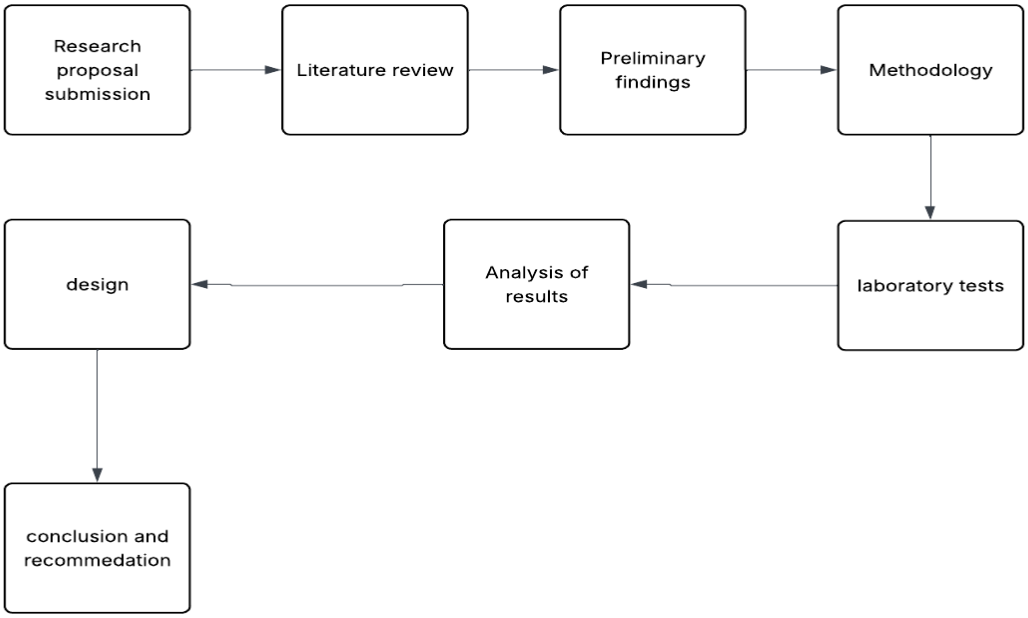


Figure 2 Research design

For this research, the use of C25 concrete as the base mix for the project was mainly because it is a standard concrete grade applied for structural purposes, which is used for buildings like Kyambogo University, including Kulubya Hall, where corrosion-induced spalling is a real problem. The use of C25 concrete made it possible to create laboratory conditions that are very similar to practical situations in the field, yet it was still possible to evaluate the impact of the Sugarcane Bagasse Ash (SCBA) through a reliable platform.

Material acquisition and preparation

3.1.1 Sugarcane Bagasse Ash

Sugarcane bagasse is a fibrous by-product created after sugarcane juice has been extracted in sugar manufacturing. For the research, the bagasse ash was acquired from Kakira Sugar Limited (KSL) located in Jinja district. It primarily consists of cellulose, hemicellulose, and lignin, along with small amounts of ash and residual sugars.

Figure 3: Kakira's bagasse cogeneration power plant

Activated sugarcane bagasse was used in this study. The material was mixed into the cementitious mixtures in blends of 0%, 5%, 10%, 15%, and 20% by weight of cement, based on optimal amounts gained by Bayapureddy Y et al, who found the optimal amount of sugarcane bagasse ash in concrete as 15%. When sugarcane bagasse was heated at temperatures between 700 °C and 750°C, it was transformed into sugarcane bagasse ash. This ash is pozzolanic since it contains amorphous silica, thus qualifying it as a supplementary cementitious material for partial replacement of cement in concrete. The ash was first dried in an oven at 105±5. The ash was sieved using a 75 µm sieve to remove the coarse and unburnt particles, and to ensure uniformity of the mix with the cement

3.1.2 Cement

The binder used in this research was ordinary Portland cement and was purchased from a local supplier in Ntinda, Kampala district. This type of cement can be used with supplementary cementitious materials to enhance the properties of concrete. In this research, the addition of SCBA was aimed at improving the crack resistance, ductility, water resistance and resistance of reinforced concrete to spalling. The cement type used complied with Ugandan specifications US EAS 18 – 1 for cement.

3.1.3 Sand

The sand was procured from the Stirling labs located along the Kampala-Jinja highway and in Mbalala.

3.1.4 Coarse aggregates

These are larger particles used in concrete, and they were acquired from the Stirling Laboratory located in Mbalala.

Figure 4: Aggregates used for casting concrete

3.2 Laboratory tests

3.2.1 Tests performed on the aggregates

To ensure that the quality of the aggregates used does not compromise the quality of the concrete, the following tests were conducted on the aggregates to ensure that they comply with the standards for cast concrete structures.

3.2.1.1 Tests on the fine aggregates (Sand)

These are the tests that were conducted on the fine aggregates to ensure that they comply with the required standards for concrete

1. Sieve Analysis

Sieve analysis is important because it determines the particle size distribution of fine aggregates, which directly affects the workability, strength, and durability of concrete or mortar. Aggregates that are well-graded give better compaction, lower voids, and reduced cement consumption. In contrast, poorly graded aggregates can bring about segregation and weak concrete.

A sample of fine aggregates was dried and then passed through different standard sieves that are arranged from largest to smallest mesh size. The sizes of the sieves commonly used for this purpose were 4.75 mm to 150 µm. The amount left on each sieve was recorded, and the cumulative percentage of material passing was worked out. Then a grading curve was created to check if the aggregate is up to standard in accordance to BS EN 12620.

2. Silt Content Test

This test is very critical because the presence of excess silt in fine aggregates not only covers the sand particles but also decreases the bond between the cement paste and the aggregates, resulting in lower strength and higher shrinkage in concrete. Therefore, it is recommended that most standards keep the silt content below 6–8% for fine aggregates.

Firstly, a sample of sand was taken and put into a measuring cylinder, then the water was poured in until it reached a marked line. The content of the cylinder was shaken well and then allowed to settle for about 2 hours. The height of the silt layer lying above the sand was measured and related to the total height of the sand sample, thus giving the percentage of silt through a formula.

$$silt\ content = \frac{height\ of\ the\ silt\ layer}{height\ of\ the\ sediment} \times 100\%$$

3. Fineness Modulus (FM) Test

The fineness modulus (FM) is a number that denotes the average particle size of fine aggregates. Its significance lies in its ability to guide concrete mix proportions. A lower value of FM corresponds to finer sand, which necessitates more water; conversely, a higher FM points to coarser sand, which aids in workability but might reduce cohesiveness. FM is typically in the range of 2.3 and 3.1 for fine aggregates.

The fineness modulus (FM) was determined from the sieve analysis results. The cumulative percentages of material retained on the different sieves in the standard set (for sizes from 150 μm to 4.75 mm) were summed up and divided by 100. The fineness modulus obtained from this process was then applied in the calculations of concrete mix design.

$$fineness\ modulus = \frac{cumulative\ weight\ retained\ on\ sieves}{total\ weight\ of\ the\ sample} \times 100\%$$

3.2.1.2 Tests on the coarse aggregates

1. **Sieve Analysis**

Sieve analysis of coarse aggregates is critical since it provides information about the particle size distribution, which in turn affects concrete's strength, void ratio, and workability. It has been observed that well-graded aggregates will reduce voids and, consequently, the amount of cement paste required for the concrete will also diminish; thus, its durability will be improved. On the other hand, poorly graded aggregates can cause segregation and honeycombing.

A representative dried coarse aggregate sample was passed through a set of standard sieves that typically range in size from 80 mm down to 4.75 mm. Each sieve's retained weight was recorded, and the cumulative passing percentage was derived. A grading curve was generated for checking the conformity of the aggregate size with standard specifications for coarse aggregates as specified in BS EN 12620.

2. Aggregate Strength Tests (BS EN 12620)

Aggregate Impact Value (AIV): This test is significant since it provides information about the aggregate's resilience to sudden impacts or heavy loads. The aggregates having lower AIV are more durable and hence, are preferred for concrete.

A small amount of aggregate was put into a mould, and through a standard hammer, the aggregate received 15 blows repetitively. The AIV was based on what percentage of the fines (those passing the 2.36 mm sieve) produced and calculated using the formula below

$$AIV = \frac{aggregate\ weight\ that\ passing\ through\ a\ 2.36\ mm}{weight\ of\ the\ oven\ dried\ sample\ of\ aggregate} \times 100\%$$

Figure 5: Aggregate impact value test

Aggregate Crushing Value (ACV): This is critical as it measures the aggregate's strength against compression, which is very important for structural concrete. Low ACV means that the aggregates are stronger.

$$ACV = \frac{aggregate\ weight\ that\ passing\ through\ a\ 2.36\ mm}{weight\ of\ the\ oven\ dried\ sample\ of\ aggregate} \times 100\%$$

A sample of aggregate was taken and placed in a cylindrical mould. The sample was then subjected to a gradually increasing compressive load until the sample failed. The portion of the sample that went through a 2.36 mm sieve was weighed, and its weight was expressed as a percentage of the original sample weight.

Flakiness Index (FI): The significance of the Flakiness Index (FI) lies in the fact that the use of flaky aggregates, characterised by thin and elongated particles, produces a negative impact on workability, compaction, and strength of concrete. The codes specify a ceiling on the percentage of flaky particles.

The particles of the aggregate were screened through a series of sieves, followed by checking with a flakiness gauge. The FI was determined by the proportion of flaky particles (those with a thickness less than 0.6 of the mean size of the particles) which are counted.

$$flakiness\ index = \frac{total\ mass\ passing\ through\ the\ gauge}{total\ mass\ retained\ on\ all\ the\ sieves} \times 100$$

3. Water Absorption Test

Water absorption is important because it measures the porosity of aggregates, which influences durability and strength. High water absorption means more porous aggregates, which can weaken concrete and increase shrinkage and permeability. Most standards limit the water absorption of coarse aggregates to below 2%.

A dried sample of aggregates was weighed (W1) and then immersed in water for 24 hours. After removing surface moisture with a cloth, the sample was weighed again (W2). The percentage increase in weight due to water absorption is calculated as

3.3 Concrete mix formula

The table below highlights the mix formula for the concrete cubes that were to be cast. The formula focuses on the percentages of the cement and the sugarcane bagasse ash in the concrete. The formula for the neat mix of the concrete is based on the Department of Engineering's (DoE) mix design concrete procedure, which highlights procedures for generating a concrete mix design based on the concrete class required and the properties of the materials.

Table 3 Concrete mixes at varying SCBA percentages

	Percentage of sugarcane bagasse ash				
MATERIALS (kg)	0%	5%	10%	15%	20%
SUGARCANE BAGASSE ASH	0	0.24	0.48	0.72	0.96
CEMENT	4.8	4.56	4.32	4.08	3.84
FINE AGGREGATES	8.13	8.13	8.13	8.13	8.13
COARSE AGGREGATES	13.52	13.52	13.52	13.52	13.52
WATER	2.16	2.16	2.16	2.16	2.16

Based on the cement mix design, the total amount of sugarcane bagasse needed was 15 kilograms, 64.8kgs of cement, 123 kgs of fine aggregates, 68 kgs of coarse aggregates and 33 liters of water.

3.3.1 Determining the chemical and physical properties of sugarcane bagasse ash

The ash was produced using an electric kiln. The bagasse was fired using an electric kiln at 600 to 700°C for 2-4 hours to ensure that all organic matter was removed and to ensure total activation of the amorphous silica in the bagasse.

3.3.2 Tests to be conducted on the sugarcane bagasse ash

3.3.2.1 Chemical tests

1. **X-ray fluorescence test (XRF), BS EN 10315: 2006**

This test was conducted to determine the elemental composition of the SCBA. For this research, the main components being looked at were silica, alumina and iron oxides contained within the ash, which promote pozzolanic activity in the concrete.

In this test, the sample was first prepared by grinding it into a fine powder and pressing it into a pellet or placing it in a sample holder. Once inside the XRF spectrometer, the sample was then exposed to a beam of primary X-rays, which caused the atoms in the material to become excited and emit secondary (fluorescent) X-rays. These emitted X-rays have energies that are characteristic of specific elements. A detector measured the energy and intensity of these fluorescent X-rays, and specialised software analysed the data to determine the types and quantities of elements present in the sample.

2. **Chapelle test for pozzolanic activity, BS EN 196 -9**

This test was done to determine the pozzolanic reactivity by measuring the amount of calcium hydroxide consumed by a sample material.

In the test, a known quantity of the pozzolanic material (SCBA) was mixed with an excess of calcium hydroxide and distilled water in a sealed container. The mixture was then heated in a water bath at 90 ± 1°C for 16 hours to accelerate the reaction between the pozzolan and calcium hydroxide. After cooling, the solution was filtered, and the remaining calcium hydroxide in the filtrate was determined through chemical titration using hydrochloric acid. By comparing the amount of calcium hydroxide added initially with the amount remaining after the test, the amount that had reacted with the pozzolan is calculated.

3. Loss of ignition test BS EN 15935: 2012

This experiment was conducted to determine the organic content in the material, and for this research, the raw form was used due to the increased presence of organic matter in its natural state.

When heated, the organic substances, carbonates, or other volatile materials were usually either burned off or underwent decomposition. The crucible was then weighed again after the cooling effect of a desiccator. The amount of mass lost during ignition, which is the difference between original and final weights, was recorded as "loss on ignition." It was scaled as the percentage of the starting weight of the sample.

$$loss\ of\ ignition = \frac{(W2 - W3)}{W2 - W1} \times 100\%$$

Where:

W1 = weight of the empty crucible

W2 = weight of crucible + dry SCBA before ignition

W3 = weight of crucible + residue after ignition

3.3.2.2 Physical characteristics of the Sugarcane bagasse ash

1. **Particle size distribution, BS EN 933 -1:1977**

This process was done through sieve analysis, which is a very effective method to determine the fineness and grading of SCBA, and thus its performance as a supplementary cementitious material in concrete. Critical factors in this respect include fineness and grading.

In this test, the SCBA sample being used for the analysis was first oven-dried, then its weight was carefully recorded, and it was eventually inserted into a series of around standard test sieves of different mesh sizes, starting from the largest to the smallest. The sieves were stacked, and a mechanical shaker was used to vibrate the specimen for a specific time. The purpose of this vibrating process was to allow the finer particles to get through the mesh while retaining the coarser ones. When the sieving was done, the portion of the material that was retained on each sieve was then weighed individually. The resulting weights were subsequently calculated as a percentage of the total sample weight to identify the size distribution of particles.

2. Specific gravity, BS 812: Part 2: 1995

The procedure of this test was to compare the density of a given material to that of other materials, water in most cases. This density value was the first to get a better understanding of the SCBA density characteristics, which in turn determines its behaviour in mix design as well as its efficiency of being used as a partial cement replacement. The method for testing the density of powdered materials, such as SCBA, is through the use of a pycnometer. Initially, the pycnometer was to be weighed empty, then a known mass of the dry SCBA sample was put in and weighed again. Then water was added to fill the pycnometer, making sure that no air bubbles were trapped, and the total mass was recorded. Another measurement of the pycnometer filled only with water is taken as well. The specific gravity was determined by the recorded weights, comparing the volume of the displaced water to the mass of the SCBA sample.

$$specific\ gravity = \frac{weight\ of\ the\ sugarcane\ bagasse}{weight\ of\ an\ equal\ volume\ of\ water}$$

3.3.3 Determining the properties of fresh concrete on the addition of sugarcane bagasse ash (SCBA)

1. Slump test, BS 1881: part 102: 1983

This particular test was employed to evaluate the fresh concrete's workability and uniformity. This was the case, especially for low-grade concrete, which suffers from workability to a great extent and hence is an important factor for determining durability. The slump test was to be conducted following BS 1881: Part 102: 1983 by filling a standard slump cone, placed on a flat non-absorbent surface, with fresh concrete in three equal layers. Each layer was compacted by tamping 25 times with a 16 mm diameter steel rod, evenly distributing the strokes to remove air voids. After the final layer was levelled off with the top of the cone, the cone was carefully lifted vertically to allow the concrete to slump. The slump was measured immediately as the vertical distance between the top of the cone and the highest point of the slumped concrete, indicating the workability of the mix.

Figure 6 : Slump test for concrete

3.3.4 Determining the resistance of the hardened concrete to spalling at varying proportions of sugarcane bagasse ash (SCBA)

Metallic cube moulds were cleaned and lubricated for easy placement of the concrete. The dimensions of the cube moulds to be used were 150 mm x 150 mm x 150 mm, which follows the specifications of BS EN 12390 -2: 2000. The moulds were then oiled to prevent the concrete from sticking to the cubes. The concrete moulds were then filled with concrete in layers and compacted for uniformity, and left for 24 hours before curing in water.

3.3.5 Curing of the cubes BS EN 12390 – 3: 2002.

The concrete cubes were kept in a curing tank to gain strength after being removed from the moulds, and the tests on the cubes were to be done at 7 days, 14 days and 24 days. This process was important to ensure complete hydration of the cement and ensure compressive strength gain.

3.3.6 Compressive strength test BS 1881: Part 108:1983

After the curing period, the cubes were to be subjected to a compressive strength test. The cubes were loaded at a constant rate until failure occurred. The maximum load at which failure occurs was then recorded, and the compressive strength calculated.

The specimens were dried on the surface to remove moisture before the test and positioned in the middle of a compression testing machine with a calibrated load. The load was applied steadily and without shock at a fixed rate until the specimen's breakdown occurred. The maximum load at failure was recorded, and the compressive strength was calculated by dividing this load by the cross-sectional area of the cube.

$$compressive\ strength = \frac{maximum\ force\ at\ the\ failure\ point}{area\ of\ the\ concrete\ cube}$$

Figure 7: Compressive strength test for concrete cubes

3.3.7 Water absorption test BS 812: Part 2: 1995

The water absorption test on concrete blocks was conducted as per BS 812: Part 2: 1995 by first oven-drying the concrete blocks at 105 ± 5°C until a constant mass is achieved, then cooling them to room temperature and recording the dry mass. The blocks were then fully immersed in clean water at room temperature for 78 hours to ensure complete saturation. After immersion, the blocks were then removed, surface water was wiped off with a damp cloth without extracting moisture from the pores, and the saturated surface-dry mass was recorded. The water absorption percentage was calculated by taking the difference between the saturated surface-dry mass and the dry mass, dividing by the dry mass, and multiplying by 100.

$$water\ absorption\ = \frac{wet\ weight\ of\ substance - dry\ weight\ of\ the\ substance}{dry\ weight\ of\ the\ substance} \times 100\%$$

3.3.8 Accelerated corrosion test (NT BUILD 365-89)

The four concrete cylinders, with a diameter of 100mm and a length of 200mm, each with concrete cylinder having a steel bar of 10mm thickness located at the centre of the concrete cylinder and 50mm off the base of the concrete, were used for the test. These concrete specimens were cast according to the standards outlined in BS EN 12390-3:2002 and NT BUILD 356. The concrete cylinders were then cured in water for 28 days to allow the concrete to attain the maximum compressive strength. The specimens were then connected to a 12V power supply and placed in a 3% NaCl solution, and the current flowing through each of the specimens was measured using a multimeter and recorded

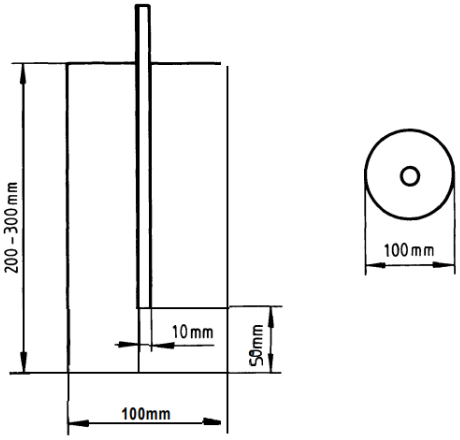


Figure 8 Sample dimensions for the Accelerated corrosion test

Specimen preparation

The specimens to be used for the test were each cast with a 10 mm-thick steel bar embedded 150mm deep into a 200 mm-long concrete cylinder. The exposed section of the steel bar was then covered in epoxy, and the concrete cylinders were then cured in water for 28days to enable the concrete to attain the maximum strength.

Cell assembly

A fine stainless-steel mesh was placed around the middle of each cylinder so that it covers the length of the rebar covered with the electrolyte, and a container was used to make a reservoir for the electrolyte. A 3.5% NaCl solution was used to fill the reservoir and to ensure that there is a good connection with the concrete surface and the stainless-steel cathode. The embedded rebar, being the anode, was connected to the positive terminal of the DC power supply, while the stainless-steel mesh was connected to the negative terminal as the cathode.

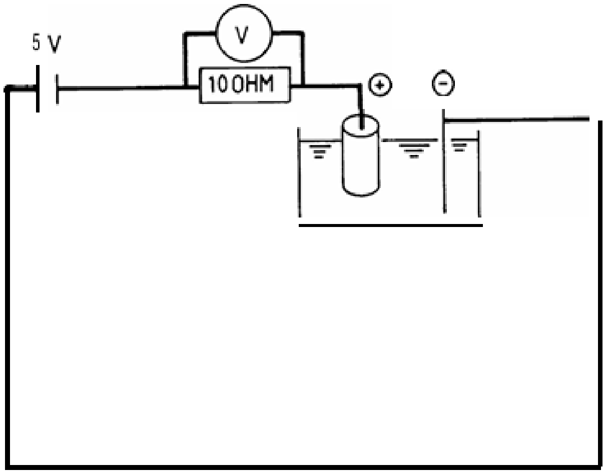


Figure 9 Accelerated corrosion test setup

Monitoring and recording

A digital multimeter was used to measure the current that was flowing through each of the specimens, and the readings were taken every 2 hours for the first 12 hours. and after that, the current was recorded every 12 hours for 4 days.

The battery's voltage was constantly checked to make sure it was providing the needed voltage across the specimens.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

A summary is provided in this section of the results obtained from various laboratory tests conducted to assess the application of Sugarcane Bagasse Ash (SCBA) in preventing corrosion spalling of concrete. The tests included the identification and examination of both fine and coarse aggregates, a chemical and physical analysis of SCBA, and concrete performance tests such as slump, compressive strength, water absorption, and accelerated corrosion.

4.1 Fine Aggregates

The fine aggregates showed a bulk specific gravity of 2.633 and 0.463% water absorption. The silt content was noted to be 4.3%, which was still below the limit prescribed by BS EN 12620 (Specification for aggregates from natural sources for concrete). These findings point out that the fine aggregates are quite good in terms of high density and low water absorption, so they are proper for use in reinforced concrete.

Table 4 Fine aggregate lab results

Fine aggregate results		
Property	**Test Result**	**Typical Standard Requirement / Limit**
Water Absorption	0.46%	<1% is considered excellent
Silt Content (Fines)	4.30%	≤10% is common for most applications
Bulk Specific Gravity	2.633	> 2.00

4.2 Coarse Aggregates

The coarse aggregates were found to have a bulk specific gravity of 2.622 and 0.3% water absorption. The mechanical strength parameters of the coarse aggregates that included Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Los Angeles Abrasion value, and the ten per cent fines value, were all determined to rank the suitability of the aggregates for concrete use according to BS EN 12620 (Specification for aggregates from natural sources for concrete).

Table 5 Coarse aggregate lab results

Coarse aggregate results		
Property	**Test Result**	**Typical Standard Requirement / Limit**
Water Absorption	0.30%	<1% is considered excellent
Ten Per Cent Fines Value (TFV)	209.7 kN	> 110 kN is a common specification threshold
Wet/Dry Strength Variation	98%	> 75% is typically required
Aggregate Crushing Value (ACV)	16%	≤20% for high-strength concrete
Aggregate Impact Value (AIV)	16.40%	≤18% for high-strength concrete
Los Angeles Abrasion (LAA)	17%	≤20% for high-quality concrete
Bulk Specific Gravity (OD)	2.622	> 2.00

4.3 Chemical and Physical Characterisation of Sugarcane Bagasse Ash

Through chemical analysis, SCBA was revealed to possess 92.55% total silica and alumina, which not only fulfilled the ASTM C618 specification but also exceeded it by 22.55%. This parameter thus recognised its very effective pozzolanic potential. Loss on Ignition (LOI) at 9.038% was a bit over the ASTM limit but still within the tolerance range. The Chapelle test demonstrated that the lime consumption of 3.382% Mg $Ca(OH)_2$ was capable of giving the required pozzolanic activity. The specific gravity of 2.705 and grading modulus of 0.61 indicate fine particle size and high reactivity from the physical aspect. These properties imply that SCBA will help in the formation of more calcium silicate hydrate (C–S–H) gel, which will consequently refine pore structure and reduce permeability further.

Table 6 Composition of sugarcane bagasse ash

Parameter	Units	(Sugarcane bagasse ash)
Silicon dioxide	% m/m	72.62
Aluminum Oxide	% m/m	4.71
Iron (III) Oxide	% m/m	19.93
Potassium Oxide	% m/m	1.04
Calcium Oxide	% m/m	1.02

Chlorine	% m/m	0.31
Manganese (II) Oxide	% m/m	0.25
Europium (III) oxide	% m/m	0.006
Titanium dioxide	% m/m	0.003
Chromium (III) oxide	% m/m	0.002

4.4 Concrete Mix Design and Performance

Concrete was designed for Class 25/20 with a cement content of 375 kg/m^3 and a water-cement ratio of 0.5. The slump value of 90 ± 30 mm indicated medium workability appropriate for reinforced concrete use. The air content, 2%, and the fine and coarse aggregates mix proportions were within standard design limits. The parameters mentioned above ensured a good combination of strength and workability.

4.5 Discussion of Findings

The results give a unanimous voice that the local materials used are fit for the manufacture of their structurally sound and durable concrete. The chemical composition and the pozzolanic behaviour of SCBA imply that it can be replaced to a partial extent with cement for improving microstructure and decreasing permeability, thus reducing corrosion of the steel embedded. The mechanical test results of the aggregates gave confirmation of the materials' suitability for load-bearing applications, whereas the controlled mix design proved sufficient strength and workability. The results of this study back the assumption that SCBA can increase the corrosion resistance and durability of reinforced concrete, thus participating in the development of eco-friendly and economical construction practices.

4.5.1 Effect of the sugarcane bagasse ash on the workability of the concrete

The observed variation in slump with increasing Sugarcane Bagasse Ash (SCBA) replacement can be attributed to the physical and chemical characteristics of SCBA, particularly its high specific surface area, porosity, and water absorption capacity. At low replacement levels, the slump initially increases before decreasing at moderate levels and then rising again at 20% replacement.

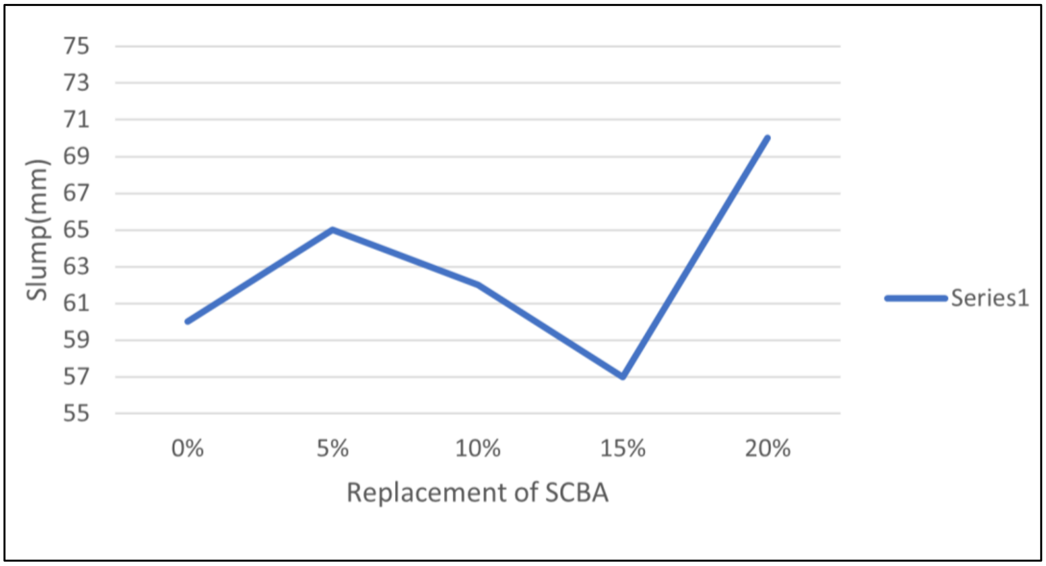


Figure 10 Workability of different percentages of SCBA

The control mixture was surpassed by the 5% of SCBA with respect to the slump. The reason for this was the micro-filler effect of the very finely powdered SCBA particles that fill the voids in concrete and thus lower the friction within the aggregates in fresh concrete. The resulting mix became more easily workable at small replacement percentages, as the increased packing leads to better lubrication of the mix (Olutoge et al., 2021; Waryoba et al., 2022).

The slump steadily drops between 10% and 15% of SCBA. The typical SCBA has a very porous and irregular surface, which causes it to absorb more water than usual. With the increase of SCBA content, more water is sucked by the ash particles, thus less free water is left in the cement paste. This results in lower workability and thereby slump reduction at moderate replacement levels (Srinivas et al., 2020; Nguyen et al., 2023). The reduction in slump at this point is indicative of the higher water requirement of the SCBA-modified mixes because of light, highly absorptive ash particles present in the mix.

The slump at the 20% SCBA increments suddenly. However, such behaviour can happen when the higher bulk of lightweight SCBA particles is changing the rheology of the mix, thus producing a more cohesive but less dense paste core, which is contrary to what happens typically with pozzolanic replacements. This process can lead to the reduction of interparticle friction, thus making the mix flow more freely. On top of that, a slight increase in mixing water or variations in the fineness of the ash at such high replacement ratios may cause a dramatic increase in workability (Kumar & Rai, 2021; Mehta & Siddique, 2022). The literature also reveals instances of similar unexpected increases in slump at higher SCBA content, where the authors have attributed the phenomenon to the changes in paste lubrication and the reduced interference of aggregates.

4.5.2 Effect of replacement of cement with Sugarcane bagasse ash on the compressive strength of concrete

The compressive strength readings at 7, 14, and 28 days not only plot a remarkable track of the ascending trend but also mark the open road that the increasing percentage of cement replacement by Sugarcane Bagasse Ash (SCBA) has led. The mix with no addition of SCBA (0%) reflects the normal drying and hardening process of Portland cement and gives the following compressive strengths: at 7 days, 20.2±0.34 MPa; at 14 days, 23.3±0.59 Mpa and at 28 days, 29.7±0.46 Mpa, which serves as the reference point for the comparison. The strength of the control mix is overtaken by the five per cent SCBA replacement mix in all curing periods; 28-day strength of the latter reaching 39.8±0.78 Mpa, the highest among all mixes. It is the great abundance of amorphous silica in the SCBA which caused the pozzolanic reactions and thus the more and more C–S–H formation. Furthermore, the very small size of the SCBA particles gives rise to an effect of micro-filler, which increases the packing density and decreases the internal voids, creating a denser concrete microstructure with greater strength. Other research findings corroborate the present findings and report that the low levels of SCBA have very little effect on mechanical properties, which are mainly attributed to better particle packing and pozzolanic reactivity (Srinivas et al., 2020; Mehta & Siddique, 2022; Nguyen et al., 2023).

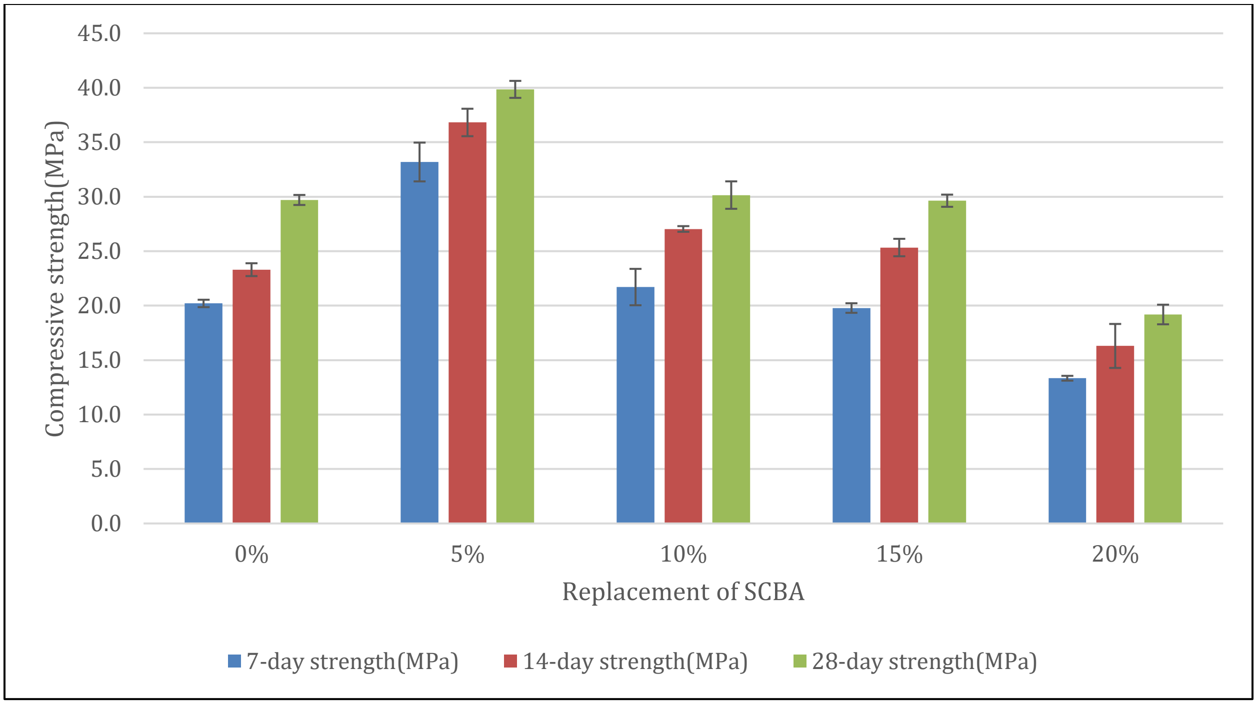


Figure 11 Compressive strength at different SCBA replacement percentages

A gradual decline of compressive strength from 39.8±0.78 MPa to 30.1±1.26 MPa, though still within the limits of acceptability, is observed as the replacement percentage goes up to 10%. This is because the quantity of cement that can react with water and produce strength is getting less and less; thus, the SCBA at this level can only contribute its pozzolanic reaction to partially cover the loss of cementitious material. Besides, the higher water requirement of SCBA because of its very porous and irregular surface contributes to its reduced strength through decreased workability and compaction. The literature provides evidence, by Olutoge et al. (2021) and Waryoba et al. (2022), that moderate SCBA partial replacement could result in lower compressive strength, mainly because of cement dilution and the pozzolanic reaction not being fully developed.

Compressive strength at 15% SCBA replacement is the lowest, with a 28-day value of 29.6±0.56 MPa. The little amount of pozzolanic activity that is taking place at this stage is not enough to make up for the large amount of cement loss. The sugarcane bagasse ash (SCBA) that is mixed into the concrete is treated mainly as an inert filler; thus, the internal porosity increases due to poor particle packing, which results in matrix weakening. This decline is in line with the earlier studies, which have shown that the use of more SCBA is linked to improved mechanical properties being harder to obtain because of the effects of the dilution of cement, ash fineness and reactivity variances (Kumar & Rai, 2021). Concrete with 20% SCBA replacement has the least compressive strength of all the curing times, as its strength at 28 days has fallen to 19.1±0.9 MPa. The main reason for the mentioned large decrease is the excessive cement replacing, which practically stops the bond of the C--S--H gel, the strength-giving compound in concrete. Besides, there are unreacted SCBA particles which form weak zones in the microstructure and thus affect the load-bearing capacity negatively. The high replacement levels usually create conditions that are not favourable for the ash to react because of the insufficient calcium hydroxide that is available for the reaction with it; this has been widely documented as a limiting factor of the use of SCBA in high percentages (Nguyen et al., 2023; Mehta & Siddique, 2022). In summary, it is confirmed that the trend in general points to 5% of cement being replaced with SCBA as the point of production of compressive strength because of the positive contribution from both pozzolanic and filler effects. The Replacement levels for sugarcane bagasse ash between 10% and 15% showed a progressive decrease in the overall compressive strength due to a reduction in the cement content and insufficient ash reactivity, while at 20% of SCBA replacement leads to a significant decline in strength, demonstrating that high SCBA contents are not suitable where high structural performance is required.

The t-test shows that there is a significant difference between the performance of the control mix and the mix with 5% sugarcane bagasse ash and this is attributed to the addition of the ash to the concrete mix

4.5.3 Effect of replacement of cement with Sugarcane bagasse ash on the water absorption of concrete

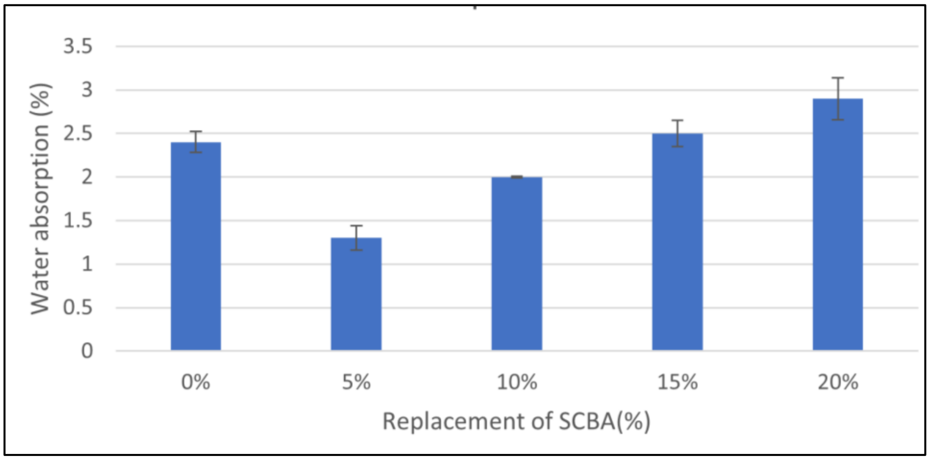


Figure 12 Water absorption at different SCBA replacements

The findings indicate that water absorption undergoes a decrease treatment first at the level of 5% SCBA replacement, then it goes down from 2.4±0.12% at 0% SCBA to 1.3±0.14% at 5%, after that it goes up stepwise from 10% to 20% with the final values of 2.0±0.01% at 10%, 2.5±0.15% at 15%, and 2.9±0.24% at 20%. The reduction at 5% is largely attributed to the micro-filler effect of fine SCBA particles that fill voids within the concrete matrix and make a denser, less permeable structure (Mehta & Siddique, 2022). This results in a reduction of the paths for water to infiltrate the concrete, thus leading to lower absorption at this optimum level. Nevertheless, when the SCBA content is increased beyond 5%, the water absorption starts to rise again. Heavy SCBA additions bring in more ash particles that are porous and less reactive, thus increasing the number of voids inside the matrix and at the same time decreasing its density (Nguyen et al., 2023). The higher replacement levels cause dilution of the cement, thus resulting in lower hydration products and making the concrete more permeable. Such behaviour has been reported in studies showing that high SCBA usage increases porosity and water absorption due to insufficient pozzolanic activity (Mehta & Siddique, 2022; Nguyen et al., 2023).

4.5.4 Effect of SCBA on the corrosion resistance of the reinforced concrete

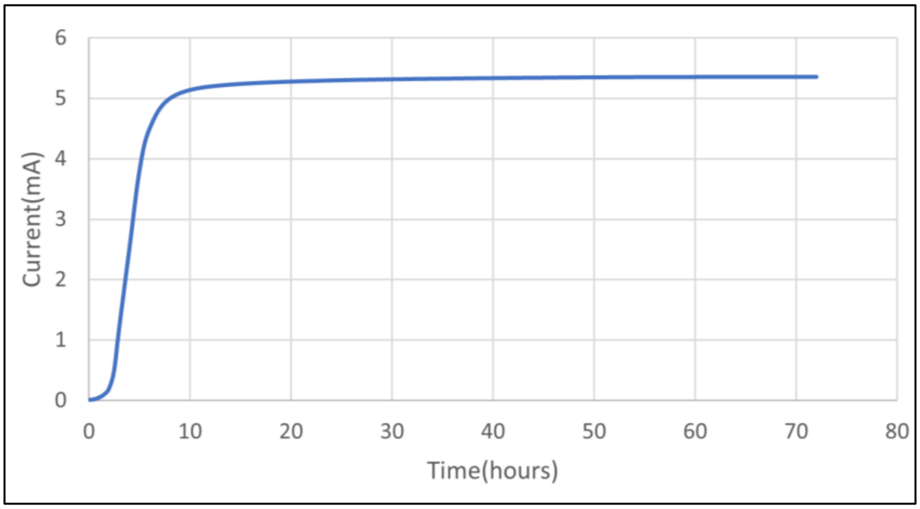


Figure 13 Corrosion currents for the control specimen

The control mix with no replacements (0% replacement) showed a very clear rapid increase in the corrosion current reaching at about 2.3 hrs its first critical time (Lin and Cheng, 2013; NT BUILD 356, 1989). In the experimental data the current goes up very sharply from 0.01 mA at first to 1.2 mA at the 3-hour point. The current jumps so quickly that it lets us conclude that chloride ions in the external 3.5% NaCl solution penetrated through the concrete cover very easily and got to the rebar steel surface fast. When the chloride ion concentration at the steel surface exceeded the point where the oxide layer was depassivated, active corrosion began (Lin and Cheng, 2013). The current then continuously moved up to around 5.3 mA where it was stable, meaning that corrosion was taking place. The control mix kept its permeability because of the absence of supplementary cementitious materials (SCMs), so ion ingress encountered no barriers, and the ions quickly got to the steel, and the depassivation occurred, resulting in a high corrosion rate as indicated by the higher final steady-state current (Caré and Raharinaivo, 2007).

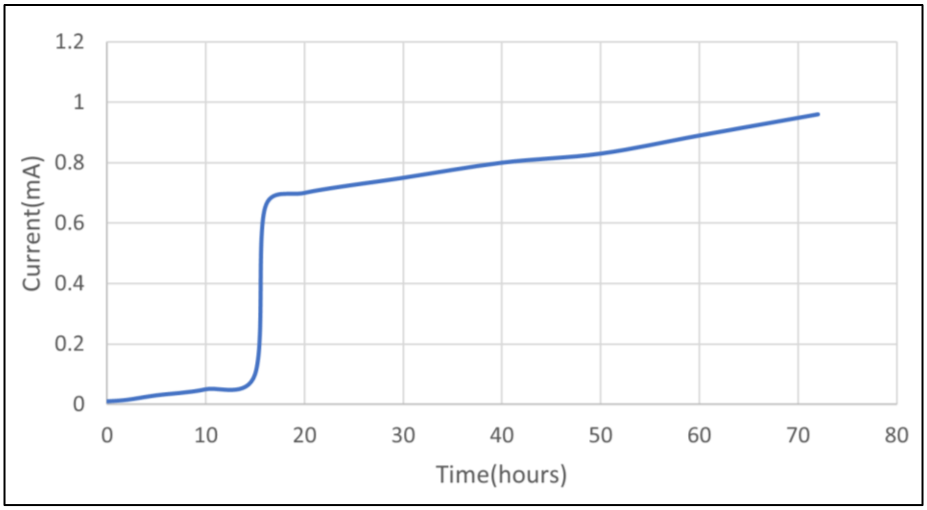


Figure 14 Corrosion currents for the optimised concrete

In a very different view, the blend of 5% Sugarcane Bagasse Ash (SCBA) substitution reveals large enhancement in corrosion resistance. The first critical time of this corrosion process is postponed more than significantly and takes place in the interval between 15 and 16 hours which is shown through the current increase from 0.1 mA to 0.65 mA. The scientific and technical explanation for this postponement boils down to the pore blocking and pozzolanic activities of the SCBA. The ultrafine dispersed SCMs like SCBA get into a reaction with calcium hydroxide ($Ca\ (OH)_2$), which is the main constituent formed when cement hardens, and so gets into the formation of the new C-S-H gel (Lin and Cheng, 2013). This secondary reaction refines the pore structure thus reducing both the volume as well as the connectivity of capillaries within the cement paste. As a result, the movement of chloride ions towards the steel surface is greatly slowed down, thus increasing the time required for the chlorides to reach the critical threshold concentration, which is the cause for the delayed initiation of corrosion reported in the test data.

In addition, the 5% SCBA mix shows up to the end of the test a corrosion rate that is very much lower compared to that in the control. The current in the 5% mix remains at 0.96 mA after 72 hours, which is more than five times lower than the plateau current in the control mix (~5.36 mA). This implies that even though the protective layer is beaten, the dense microstructure created by SCBA is still hindering ion flow enough to not support the corrosion reaction, thus leading to reduced corrosion current density (Lin and Cheng, 2013). The outstanding performance of mixes containing SCMs is in agreement with the results of Lin and Cheng (2013), who indicated that materials such as fumed silica and slag not only improve compactness but also stop rebar corrosion. Thus, the 5% SCBA substitution improves the durability of the concrete by both delaying the onset of corrosion and suppressing its rate post-initiation.

4.6 Optimised Concrete Mix Design

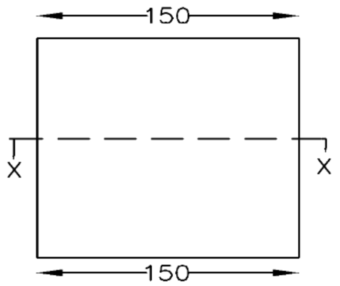
The concrete mix design is carried out according to the standard volumetric proportioning methods which are suitable for concrete class 25/20 and additionally, the incorporation of 20% bagasse ash is proposed to replace the cement partially. First, the design is done with the intended strength class of concrete and the choice of Ordinary Portland Cement (OPC 42.5) as the binder. A water-cement ratio (W/C) of 0.5 is implemented to achieve the required workability and strength. The cement content for one cubic meter of concrete is determined to be 375 kg and therefore, the mixing water is calculated to be 187.5 kg. A nominal air content of 2% is accounted for in the volumetric calculations.

The concrete mix design considers the addition of bagasse ash at a 5% replacement of cement weight. The bagasse ash part was added as shown on the design sheet (noted as included in the cementitious material entry) when the cement content of 375 kg was used as the basis. The moisture corrections were done to ensure the correct field batching depending on the actual aggregate moisture.

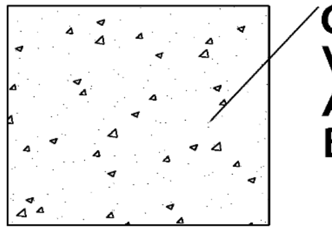
This method assures that all aspects of the designed concrete mix have been taken into consideration, i.e. aggregate gradation, moisture corrections, volumetric displacement of cementitious materials, and accurate mass-to-volume conversions; all of which are required for the production of consistent and reliable concrete with 5% bagasse ash.

Table 7 Composition of optimised concrete mix for 1m^3

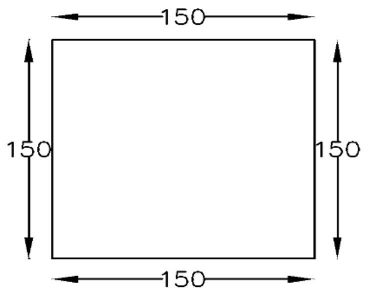
COMPOSITION OF THE MIX	FOR 1 M^3
CEMENT TYPE: PPC	375 kg
WATER	191 kg
SUGARCANE BAGASSE ASH	18.8 kg
AGGREGATES /Ø 14 - 20 mm	442 kg
Ø 10 - 14 mm	212 kg
Ø 10-6 mm	354 kg
Natural Sand	763 kg



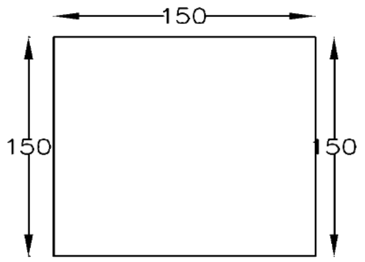
PLAN



SECTION X-X

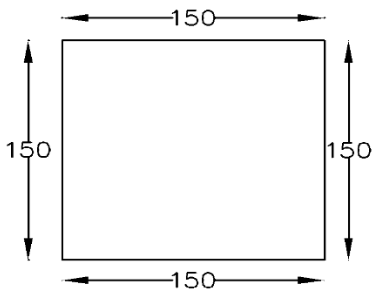


EAST END ELEVATION



FRONT ELEVATION

Scale 1:100



WEST END ELEVATION

PROJECT NAME
ASSESSING THE
SUITABILITY OF
SUGAR CANE
BAGASSE ASH IN
PREVENTING SPALLING

DRAWING NAME
TYPICAL CONCRETE
BLOCK

NAME
KASULANE MARK
ALVIN
M22B32/016

SCALE
1:100

A3

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The first objective was successfully achieved through laboratory characterisation tests, including particle size distribution, specific gravity, and oxide composition analysis. The Particle size distribution results showed that Sugarcane bagasse ash is a highly fine, sandy–silt-like powder, with a substantial proportion passing the 0.150 mm and 0.075 mm sieves, confirming its suitability as a micro-filler with high fines content which supports good packing ability within the concrete matrix. Chemically, SCBA contains high proportions of silica (SiO_2) of about 97% qualifying it as a pozzolanic material capable of participating in secondary hydration reactions. These combined properties validated the classification of the SCBA used as a reactive, filler-effective supplementary cementitious material, thereby fully achieving Objective 1.

This objective was met by analysing the water absorption, slump, and compressive strength trends across the SCBA replacement levels at 0%, 5%, 10%, 15%, and 20%. The data consistently indicated that 5% SCBA replacement produced the highest compressive strength and the lowest water absorption values, confirming the densest pore structure at this level. The reduction in absorption at 5% is attributed to the micro-filler effect of the very fine SCBA particles, which effectively fill voids and refined capillary pores, resulting in reduced permeability. Beyond 10–20%, water absorption increased, and slump values decreased sharply, reflecting poor workability and excessive fines that disrupt proper packing and compaction. These trends confirm that

5% SCBA is the optimum replacement for achieving minimum porosity, fully satisfying the second objective.

From the accelerated corrosion tests, chloride breakthrough timings, and current–time curve analysis were aspects that made this goal possible. To put it differently, the experiments gave proof that the use of SCBA reduced the corrosion rate and thus the spalling hazard by significantly delaying the start of corrosion. The breakthrough time of the chloride ion was prolonged from about 2.5 hours in the case of the 0% SCBA specimen to around 15.7 hours for the 5% SCBA specimen, which clearly points to the very slow penetration of chlorides. The 5% SCBA concrete, in addition, showed the corrosion current plateau lower and more gradual during the 72 hours of monitoring, which is a sign of less electrochemical activity near the steel reinforcement. This is the effect of the pore refinement and the reduced permeability, which are both attributes of the 5% replacement level. Thus, the results reaffirm that, particularly at 5% is the most effective in preventing spalling caused by corrosion, thus fully achieving the third objective.

5.2 Recommendations

1. Future researchers should increase the corrosion test duration beyond 120 hours to capture long-term corrosion behaviour, secondary corrosion stages, and the full progression toward spalling, which could not be fully observed within the current test window.
2. I recommended the use of advanced corrosion monitoring methods, such as the linear polarisation resistance, electrochemical impedance spectroscopy, and half-

cell potential mapping, to provide more detailed insight into the corrosion rate and steel–concrete interface conditions.

3. Further studies should incorporate fibres such as polypropylene, basalt, or steel to examine whether SCBA combined with fibres provides better crack control, delayed crack propagation, and improved resistance to corrosion-induced spalling.
4. It is necessary for researchers to examine various combinations of SCBA and fibres as well as their different dosages to find out if the hybrid systems have any synergistic effects in terms of reducing porosity and improving durability, and if such effects are larger than those associated with SCBA alone.
5. Next, the research should be directed toward SCBA processing improvement through methods that induce controlled burning, very fine grinding or chemical activation, to get it more reactive as a pozzolan and thus better suitable for durability-related applications. To better understand the mechanisms responsible for the reduced porosity and improved corrosion resistance, researchers should incorporate techniques such as SEM, XRD, TGA, or MIP to analyse pore structure and hydration products in SCBA-modified concrete.
6. It is also recommended to examine SCBA obtained from different sugar factories or regions, as variations in combustion conditions and silica content may influence performance, enabling the development of more universally applicable guidelines for SCBA use.

This particular concrete is developed for use in such structural components as beams, slabs, columns, stairs, and foundations that are subjected to severe and corrosive environments. Its use is justified by the properties that have been enhanced to give the utmost protection against deterioration. In case of marine environments, wet conditions, or places where chlorides from de-icing salts are present, regular concrete is at the risk of steel reinforcement corrosion leading to a loss of structural integrity. This concrete, on the other hand, does not allow that scenario to happen thanks to the combination of measures including possibly having a low water-cement ratio resulting in reduced permeability, employing supplementary cementitious materials like fly ash or slag for pore structure refinement, and adding possibly corrosion-inhibiting admixtures.

REFERENCES

Ahmed, M., et al. “Optimisation of Hybrid Reinforced Cement Composites Using Agro-Waste and Natural Fibres.” *Materials Today: Proceedings*, vol. 57, no. 3, 2022, pp. 1450–1456. https://doi.org/10.1016/j.matpr.2021.11.299.

Ayenagbo, K., et al. “Corrosion Risks and Control in Reinforced Concrete Structures Exposed to Harsh Environments.” *Case Studies in Construction Materials*, vol. 17, 2022, e01425. https://doi.org/10.1016/j.cscm.2022.e01425.

Bertolini, L., et al. “Durability Design of Reinforced Concrete Structures in Aggressive Environments.” *Cement and Concrete Research*, vol. 146, 2021, 106465. https://doi.org/10.1016/j.cemconres.2021.106465.

Bihamba, M. *Assessment of Corrosion-Induced Damage in Bridge Structures in Uganda*. Makerere University Repository, 2024, MSc Thesis.

Brown, R. P., and R. J. Kessler. *An Accelerated Laboratory Method for Corrosion Testing of Reinforced Concrete Using Impressed Current*. Florida Department of Transportation, Report No. Florida 206, Oct. 1978.

Brueckner, R., et al. “A Review of Developments in Cathodic Protection Systems for Reinforced Concrete Structures.” *MATEC Web of Conferences*, vol. 361, 2022, 02001.

Cao, C., et al. “Modelling of Corrosion-Induced Concrete Cover Cracking and Reinforcement Deterioration.” *Cement and Concrete Composites*, vol. 97, 2019, pp. 202–213. https://doi.org/10.1016/j.cemconcomp.2018.12.011.

Caré, S., and A. Raharinaivo. “Influence of Impressed Current on the Initiation of Damage in Reinforced Mortar.” *Cement and Concrete Research*, vol. 37, no. 12, 2007, pp. 1598–1612. https://doi.org/10.1016/j.cemconres.2007.08.015.

Chandramohan, D., et al. “Mechanical Properties of Bamboo Fibre Reinforced Composites – A Review.” *Materials Today: Proceedings*, vol. 47, 2021, pp. 1095–1100. https://doi.org/10.1016/j.matpr.2021.06.023.

Chen, S., et al. “Recent Progress on the Corrosion Mechanism and Protection of Steel in Chloride Environments.” *Corrosion Science*, vol. 211, 2023, 110831. https://doi.org/10.1016/j.corsci.2023.110831.

Chen, Zheng, et al. "Strength and Chloride Resistance of Mortars Blended with SCBA: The Effect of Calcination and Particle Sizing on Its Pozzolanic Activity." Journal of Materials Research and Technology, vol. 22, 2022, pp. 1423-1435, https://doi.org/10.1016/j.jmrt.2022.11.179.

Ganesan, K., et al. “Rice Husk Ash Blended Concrete: A Review.” *Construction and Building Materials*, vol. 272, 2021, 121942. https://doi.org/10.1016/j.conbuildmat.2020.121942.

González, J. E., et al. “Use of Volcanic Ash in Concrete: A Review of Mechanical and Durability Properties.” *Journal of Building Engineering*, vol. 39, 2021, 102274. https://doi.org/10.1016/j.jobe.2021.102274.

IOP Science. “A Comparative Study on the Microstructure, Hardness and Corrosion Resistance of Epoxy-Coated and Plain Rebars.” *IOP Science*, 2022.

Jagadesh, P., et al. “Performance of Sugarcane Bagasse Ash in Concrete: A Review.” *Materials Today: Proceedings*, vol. 75, 2023, pp. 2125–2131. https://doi.org/10.1016/j.matpr.2023.01.420.

Kabir, M. H., et al. “Sugarcane Bagasse Ash: A Sustainable Cement Replacement Material in Concrete – A Review.” *Cleaner Engineering and Technology*, vol. 1, 2020, 100014. https://doi.org/10.1016/j.clet.2020.100014.

Khalid, N., et al. “Synergistic Effect of Bamboo Fibre and Pozzolans on Durability and Performance of Concrete.” *Journal of Materials Research and Technology*, vol. 15, 2021, pp. 4620–4632. https://doi.org/10.1016/j.jmrt.2021.09.060.

Khan, M. N. N., et al. “Natural Fibre-Reinforced Concrete and Its Applications in Sustainable Construction.” *Sustainable Construction Materials and Technologies*, vol. 12, no. 2, 2020, pp. 1–10. https://doi.org/10.1002/suco.202000150.

Kumar, R., et al. “Durability Improvement in Concrete Using SCBA and Nano-Silica.” *Construction and Building Materials*, vol. 313, 2022, 125502. https://doi.org/10.1016/j.conbuildmat.2021.125502.

Li, X., et al. “Pore Structure and Durability Performance of Concrete with Supplementary Cementitious Materials.” *Materials*, vol. 12, no. 14, 2019, 2294. https://doi.org/10.3390/ma12142294.

Lim, M. Y., et al. “Mechanical and Fracture Behaviour of Bamboo Fibre Reinforced Cement Composites.” *Sustainable Materials and Technologies*, vol. 36, 2023, e00620. https://doi.org/10.1016/j.susmat.2023.e00620.

Lin, Wei-Ting, and An Cheng. “Effect of Polyolefin Fibers and Supplementary Cementitious Materials on Corrosion Behavior of Cement‐Based Composites.” *Journal of Inorganic and Organometallic Polymers and Materials*, vol. 23, no. 4, 2013, pp. 888–896. https://doi.org/10.1007/s10904-013-9866-1.

MDPI. “Effects of Different Coatings on Concrete Elements Due to Chloride Ion Penetration.” *Coatings*, vol. 15, no. 1, 2023, 46.

MDPI. “Research Progress in Corrosion Behavior and Anti-Corrosion Methods of Steel Rebar in Concrete.” *Metals*, vol. 14, no. 8, 2023, 862.

Memon, F. A., et al. “Utilisation of Agro-Waste Materials in Sustainable Construction Composites: A Review.” *Journal of Cleaner Production*, vol. 253, 2020, 119846. https://doi.org/10.1016/j.jclepro.2019.119846.

Tabish, M., Zaheer, M. M., & Baqi, A. (2025). Utilization of agro-based waste as SCM: A systematic study on sugarcane bagasse ash characteristics and pozzolanic reactivity.

Journal of Building Engineering, 109, 113039. https://doi.org/10.1016/j.jobe.2025.113039

Muthusamy, K., et al. “Pozzolanic Reactivity of Agro-Waste: Sugarcane Bagasse Ash in Blended Cement Systems.” *Advances in Civil Engineering*, 2018, Article ID 5085149. https://doi.org/10.1155/2018/5085149.

Mwakatobe, A. R., et al. “Mechanical and Durability Performance of Sisal Fibre Reinforced Cement Composites: A Review.” *Journal of Materials Research and Technology*, vol. 15, 2021, pp. 363–375. https://doi.org/10.1016/j.jmrt.2021.07.057.

National Academies Press. *Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements*. National Academies Press, 2022.

NORDTEST Method: NT BUILD 356. Concrete, Repairing Materials and Protective Coating: Embedded Steel Method, Chloride Permeability. NORDTEST, 1989, www.nordtest.org.

Pillai, R. G., et al. “A Study on Mechanical Properties of Coir Fibre Reinforced Concrete.” *Materials Today: Proceedings*, vol. 33, 2020, pp. 680–683. https://doi.org/10.1016/j.matpr.2020.04.471.

Poursaee, A. *Corrosion of Steel in Concrete: Understanding, Monitoring and Repair*. 2nd ed., Woodhead Publishing, 2022. https://doi.org/10.1016/C2020-0-00017-4.

Rana, A., et al. “Advanced Strategies for Enhancing Concrete Durability: A Review.” *Journal of Building Engineering*, vol. 43, 2021, 102556. https://doi.org/10.1016/j.jobe.2021.102556.

Roy, R., et al. “Performance Evaluation of Jute Fibre as a Reinforcing Material in Concrete.” *Construction and Building Materials*, vol. 330, 2022, 127220. https://doi.org/10.1016/j.conbuildmat.2022.127220.

Salah U. Al-Dulaijan. “A Laboratory and Field Assessment of the Performance of Rebar Coatings.” *Materials (Basel)*, vol. 16, no. 12, 2023, 4270.

Srinivasan, R., and K. Sathiya. “Experimental Study on Bagasse Ash in Concrete.” *International Journal of Engineering Research & Technology*, vol. 10, no. 6, 2021, pp. 231–237.

Tang, W., et al. “Microstructure and Durability of Silica Fume Concrete under Marine Environment.” *Construction and Building Materials*, vol. 241, 2020, 118026. https://doi.org/10.1016/j.conbuildmat.2020.118026.

Ye, H., et al. “Mechanism of Reinforcement Corrosion and Cracking Behavior of Concrete under Coupled Environmental Effects.” *Journal of Materials in Civil Engineering*, vol. 32, no. 6, 2020, 04020147. https://doi.org/10.1061/(ASCE)MT.1943-5533.0003195.

Zhang, Y., et al. “Service Life Prediction and Maintenance of Concrete Structures under Chloride Attack.” *Construction and Building Materials*, vol. 233, 2020, 117296. https://doi.org/10.1016/j.conbuildmat.2019.117296.

Zhao, Y., and W. Zhang. “Influence of Fly Ash on Pore Structure and Permeability of Concrete: A Review.” *Journal of Cleaner Production*, vol. 334, 2022, 130261. https://doi.org/10.1016/j.jclepro.2021.130261.

Zhao, Y., et al. “Use of Natural Fibres in Concrete for Crack Control and Toughness Improvement.” *Construction and Building Materials*, vol. 324, 2022, 126623. https://doi.org/10.1016/j.conbuildmat.2022.126623.

Zhao, Y., et al. “Corrosion Behaviour of Steel in Concrete under Wet–Dry Cycles and Its Effect on Structural Performance.” *Construction and Building Materials*, vol. 281, 2021, 122584. https://doi.org/10.1016/j.conbuildmat.2021.122584.

APPENDICES

Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

In any Correspondence on
this subject please
quote No....................................
DFD 355/2025
24th September 2025

MR. KASULANE MARK ALVIN AND MR. KHAN GAK NGAW
REG NO. M22B32/016 & M22B32/019
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-782-996515

REPORT OF ANALYSIS

Description of the Samples

One sample in a black polythene bag containing Sugarcane bagasse ash sample was submitted by Mr. Kasulane Mark Alvin, on 17th September 2025, and analysed on 22nd September 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Grey powdered substances packed in a black polythene bag.	01	Sample "A" DFD 355/2025

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
		Sugarcane bagasse ash DFD 355/2025
Silicon dioxide	% m/m	72.62
Aluminum Oxide	% m/m	19.93
Iron (III) Oxide	% m/m	4.71
Potassium Oxide	% m/m	1.04
Calcium Oxide	% m/m	1.02
Chlorine	% m/m	0.31
Manganese (II)Oxide	% m/m	0.25
Europium (III) oxide	% m/m	0.006
Titanium di oxide	% m/m	0.003
chromium (III) oxide	% m/m	0.002

Remarks

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

24/09/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

NEAT

COMPRESSIVE STRENGTH RESULTS FOR CLASS 25/20

LOCATION: MUKONO LAB
STRUCTURE:
CLASS OF CONCRETE: 25/ 20
CEMENT CONTENT: 375KG **of OPC CEM I 42.5N**

MIN.STRENGTH REQUIRED

TECHNICIAN	Stirling lab
SAMPLE No.	
Lab. Ref. No	Class 25/20
Date Casted:	2/Oct/25
Date Crushed:	30/Oct/25

CASTING DATE	CRUSHING DATE	SLUMP (mm)	WT OF CUBES (gm)	DIMENSION (mm)	DENSITY KG/M³	AGE (DAYS)	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)	AVERAGE STRENGTH (Mpa)	MIXING PROPORTIONS (M³)
2/Oct/25	9/Oct/25	60	8090	150 x 150x150	2.397	7	690	30.7	30.4	
2/Oct/25	9/Oct/25		8055	150 x 150x150	2.387	7	685	30.4		CEMENT 9 BAGS
2/Oct/25	9/Oct/25		8079	150 x 150x150	2.394	7	675	30.0		14/20MM
2/Oct/25	16/Oct/25		8019	150 x 150x150	2.376	14	770	34.2	34.0	10/14 ..
2/Oct/25	16/Oct/25		7823	150 x 150x150	2.318	14	775	34.4		6/10 ..
2/Oct/25	16/Oct/25		8055	150 x 150x150	2.387	14	750	33.3		
2/Oct/25	30/Oct/25		8054	150 x 150x150	2.386	28	850	37.8	38.3	NATURAL SAND
2/Oct/25	30/Oct/25		8037	150 x 150x150	2.381	28	865	38.4		
2/Oct/25	30/Oct/25		7997	150 x 150x150	2.369	28	870	38.7		

Remarks

FOR TESTING LAB

LAB TECHNICIAN

MATERIALS ENGINEER

STIRLING CIVIL ENGINEERING LTD
15 NOV 2025
P. O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

5% SUGARCANE BAGASSE ASH

COMPRESSIVE STRENGTH RESULTS FOR CLASS 25/20

LOCATION: MUKONO LAB
STRUCTURE:
CLASS OF CONCRETE: 25/ 20
CEMENT CONTENT: 375KG **of OPC CEM I 42.5N**

MIN.STRENGTH REQUIRED

TECHNICIAN	Stirling lab
SAMPLE No.	
Lab. Ref. No	Class 25/20
Date Casted:	2/Oct/25
Date Crushed:	30/Oct/25

CASTING DATE	CRUSHING DATE	SLUMP (mm)	WT OF CUBES (gm)	DIMENSION (mm)	DENSITY KG/M³	AGE (DAYS)	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)	AVERAGE STRENGTH (Mpa)	MIXING PROPORTIONS (M³)
2/Oct/25	9/Oct/25	65	8085	150 x 150x150	2.396	7	705	31.3	33.2	
2/Oct/25	9/Oct/25		8075	150 x 150x150	2.393	7	785	34.9		CEMENT 9 BAGS
2/Oct/25	9/Oct/25		8065	150 x 150x150	2.390	7	750	33.3		14/20MM
2/Oct/25	16/Oct/25		8085	150 x 150x150	2.396	14	860	38.2	36.8	10/14 ..
2/Oct/25	16/Oct/25		8105	150 x 150x150	2.401	14	820	36.4		6/10 ..
2/Oct/25	16/Oct/25		8045	150 x 150x150	2.384	14	805	35.8		
2/Oct/25	30/Oct/25		8222	150 x 150x150	2.436	28	915	40.7	39.9	NATURAL SAND
2/Oct/25	30/Oct/25		8196	150 x 150x150	2.428	28	880	39.1		
2/Oct/25	30/Oct/25		8256	150 x 150x150	2.446	28	895	39.8		

Remarks

FOR TESTING LAB

MATERIALS ENGINEER

STIRLING CIVIL ENGINEERING
LTD
LAB TECHNICIAN
15 NOV 2025
P. O. BOX 790, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

10% SUGARCANE BAGASSE ASH

COMPRESSIVE STRENGTH RESULTS FOR CLASS 25/20

LOCATION: MUKONO LAB
STRUCTURE:
CLASS OF CONCRETE: 25/ 20
CEMENT CONTENT: 375KG **of OPC CEM I 42.5N**

MIN.STRENGTH REQUIRED

TECHNICIAN	Stirling lab
SAMPLE No.	
Lab. Ref. No	Class 25/20
Date Casted:	2/Oct/25
Date Crushed:	30/Oct/25

CASTING DATE	CRUSHING DATE	SLUMP (mm)	WT OF CUBES (gm)	DIMENSION (mm)	DENSITY KG/M^3	AGE (DAYS)	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)	AVERAGE STRENGTH (Mpa)	MIXING PROPORTIONS (M^3)
2/Oct/25	9/Oct/25	62	8000	150 x 150x150	2.370	7	525	23.3	21.7	
2/Oct/25	9/Oct/25		8070	150 x 150x150	2.391	7	450	20.0		CEMENT 9 BAGS
2/Oct/25	9/Oct/25		8045	150 x 150x150	2.384	7	490	21.8		14/20MM
2/Oct/25	16/Oct/25		8030	150 x 150x150	2.379	14	605	26.9	27.0	10/14 ..
2/Oct/25	16/Oct/25		7950	150 x 150x150	2.356	14	605	26.9		6/10 ..
2/Oct/25	16/Oct/25		8014	150 x 150x150	2.375	14	615	27.3		
2/Oct/25	30/Oct/25		8040	150 x 150x150	2.382	28	670	29.8	30.1	NATURAL SAND
2/Oct/25	30/Oct/25		8124	150 x 150x150	2.407	28	710	31.6		
2/Oct/25	30/Oct/25		8032	150 x 150x150	2.380	28	655	29.1		

Remarks

FOR TESTING LAB

		MATERIALS ENGINEER	

STIRLING CIVIL ENGINEERING
LTD
★ 15 NOV 2025 ★
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

15% SUGARCANE BAGASSE ASH

COMPRESSIVE STRENGTH RESULTS FOR CLASS 25/20

LOCATION: MUKONO LAB
STRUCTURE:
CLASS OF CONCRETE: 25/ 20
CEMENT CONTENT: 375KG **of OPC CEM I 42.5N**

MIN.STRENGTH REQUIRED

TECHNICIAN	Stirling lab
SAMPLE No.	
Lab. Ref. No	Class 25/20
Date Casted:	2/Oct/25
Date Crushed:	30/Oct/25

CASTING DATE	CRUSHING DATE	SLUMP (mm)	WT OF CUBES (gm)	DIMENSION (mm)	DENSITY KG/M^3	AGE (DAYS)	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)	AVERAGE STRENGTH (Mpa)	MIXING PROPORTIONS (M^3)
2/Oct/25	9/Oct/25	57	7869	150 x 150x150	2.332	7	435	19.3	19.8	
2/Oct/25	9/Oct/25		7905	150 x 150x150	2.342	7	445	19.8		CEMENT 9 BAGS
2/Oct/25	9/Oct/25		7850	150 x 150x150	2.326	7	455	20.2		14/20MM
2/Oct/25	16/Oct/25		7895	150 x 150x150	2.339	14	550	24.4	25.3	10/14 ..
2/Oct/25	16/Oct/25		7840	150 x 150x150	2.323	14	575	25.6		6/10 ..
2/Oct/25	16/Oct/25		7961	150 x 150x150	2.359	14	585	26.0		
2/Oct/25	30/Oct/25		7885	150 x 150x150	2.336	28	655	29.1	29.6	NATURAL SAND
2/Oct/25	30/Oct/25		7930	150 x 150x150	2.350	28	665	29.6		
2/Oct/25	30/Oct/25		7920	150 x 150x150	2.347	28	680	30.2		

Remarks

FOR TESTING LAB

LAB TECHNICIAN

MATERIALS ENGINEER

STIRLING CIVIL ENGINEERING
LTD
15 NOV 2025
P. O. BOX 798, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

20% SUGARCANE BAGASSE ASH

COMPRESSIVE STRENGTH RESULTS FOR CLASS 25/20

LOCATION: MUKONO LAB
STRUCTURE:
CLASS OF CONCRETE: 25/ 20
CEMENT CONTENT: 375KG **of OPC CEM I 42.5N**

MIN.STRENGTH REQUIRED

TECHNICIAN	Stirling lab
SAMPLE No.	
Lab. Ref. No	Class 25/20
Date Casted:	2/Oct/25
Date Crushed:	30/Oct/25

CASTING DATE	CRUSHING DATE	SLUMP (mm)	WT OF CUBES (gm)	DIMENSION (mm)	DENSITY KG/M^3	AGE (DAYS)	CRUSHING LOAD(KN)	ULTIMATE COMP. STRENGTH (Mpa)	AVERAGE STRENGTH (Mpa)	MIXING PROPORTIONS (M^3)
2/Oct/25	9/Oct/25	70	7780	150 x 150x150	2.305	7	295	13.1	13.3	
2/Oct/25	9/Oct/25		7855	150 x 150x150	2.327	7	305	13.6		CEMENT 9 BAGS
2/Oct/25	9/Oct/25		7745	150 x 150x150	2.295	7	300	13.3		14/20MM
2/Oct/25	16/Oct/25		7730	150 x 150x150	2.290	14	315	14.0	16.3	10/14 ..
2/Oct/25	16/Oct/25		7780	150 x 150x150	2.305	14	400	17.8		6/10 ..
2/Oct/25	16/Oct/25		7725	150 x 150x150	2.289	14	385	17.1		
2/Oct/25	30/Oct/25		7940	150 x 150x150	2.353	28	450	20.0	19.2	NATURAL SAND
2/Oct/25	30/Oct/25		7865	150 x 150x150	2.330	28	410	18.2		
2/Oct/25	30/Oct/25		7950	150 x 150x150	2.356	28	435	19.3		
Remarks										

FOR TESTING LAB

LAB TECHNICIAN

MATERIALS ENGINEER

STIRLING CIVIL ENGINEERING
LTD
★ 15 NOV 2025 ★
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENT	LAB
UGANDA CHRISTIAN UNIVERSITY	KASUL ANE	**Stirling**

PROJECT:	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE
	20% BAGGASSE

Location: .... Sample: .... Lab. Ref.:	**CONCRETE MIX DESIGN** CLASS 25/20	Technician: 15/09/2025

MIX FOR 1M^3			Weight (kg)		Volume (dm^3)	
CEMENT OPC 42.5	375	kg	Wt.c =	375	Vc =	119.05
WATER (W/C)	0.5		Wt.w =	187.5	Vw =	187.5
ADMIXTURE		%	Wt.a =		Va =	
AIR	2	%		20		20
					Total ①	326.55

VOLUME AGGREGATES 1000 - ① = 673.45238 ②

AGGREGATES	% WEIGHT		B. SPEC. Gr. (g./cc)		ABSORPTION abs (%)	MOISTURE w (%)	Correction quantity H2O = abs - w (%) Wc
Ø 14 - 2 mm	25	a	2.622	f	0.301	0.071	0.229
Ø 10 - 1 mm	12	b	2.613	g	0.362	0.058	0.304
Ø 6 - 1(mm	20	c	2.606	h	0.471	0.172	0.298
Ø Nat. Sar mm	43	e	2.633	k	0.473	0.42	0.049

$$\frac{②}{\frac{25}{2.622}+\frac{12}{2.613}+\frac{20}{2.606}+\frac{}{}+\frac{43}{2.633}} = \frac{673.4524}{38.135} = 17.660 \ ③$$

AGGREGATES IN 1 M^3					DRY WEIGHT dwt (kg)	REAL WEIGHT wt=dwt x (1+w/100) (kg)	Correction quantity H$_2$O = dwt x Wc1 % /100 Wc
Ø 14 - 2 mm	25	% X	17.660	③	441.492	441.808	1.012
Ø 10 - 1 mm	12	% X	17.660		211.916	212.040	0.645
Ø 6 - 1(mm	20	% X	17.660		353.194	353.802	1.054
Ø Nat. Sar mm	43	% X	17.660		759.367	762.584	0.375
						Total	3.086

COMPOSITION OF THE MIX						BOX (*)	FOR 1 M^3			IN LAB. 20%	0.028 M3
CEMENT TYPE: PPC				bags	=	7.5	Wt c	375	kg	8.40	kg
WATER							Vw + Wc	190.6	dm^3	5.34	dm^3
BAGGASE										2.10	
AGGREG/	Ø	14 - 20	mm	25	%	8	Wt a.	441.808	kg	12.37	kg
	Ø	10 - 14	mm	12	%	4		212.040	kg	5.94	kg
	Ø	6 - 10	mm	20	%	6		353.802	kg	9.91	kg
	Ø	Nat. Sand	mm	43	%	16		762.584	kg	21.35	kg

STIRLING CIVIL ENGINEERING LTD
15 NOV 2025

REMARKS: Slump ....mm (*) Box volume = 0.036 m3 W/C = ...

FOR LAB

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

Test	Water absorption test	Cast date:	10/02/25
Location		Test date:	10/30/25
sample description	C25 CONCRETE	Age (days)	28
		Temperature(°C)	24
		Density of water	1000 Kg/m^3

Trial mix	Cube dimension (mm)	Oven dried weight (g)	SSD weight (g)	Water absorption (%)	Average water absorption (%)
0%	150x150x150	8124	8299	2.2	2.3
	150x150x150	8116	8307	2.4	
5%	150x150x150	8197	8296	1.2	1.3
	150x150x150	8193	8308	1.4	
10%	150x150x150	7899	8056	2.0	1.7
	150x150x150	8025	8186	2.0	
15%	150x150x150	7855	8056	2.6	2.5
	150x150x150	7890	8075	2.3	
20%	150x150x150	7756	7969	2.7	2.9
	150x150x150	7880	8123	3.1	

TESTING LAB

LAB Technician	Materials engineer

STIRLING CIVIL ENGINEERING LTD
15 NOV 2025
P. O. BOX 798, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT:	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

DETERMINATION OF AGGRGATE'S 10% FINES VALUE DRY AND SOAKED

(BS 812PART 111:112:1990)

MATERIAL SOURCE:	MUKONO CRUSHER	OPERATOR	LAB TEAM
		DATE SAMPLED	12 September 2025
MATERIAL DESCRIPTION:	AGGREGATES	DATE TESTED	14 September 2025

10% FINE VALUE DRY

TEST NO	1	2	
CRUSHING FORCE (KN)	244	244	
WT. OF AGGREG (gm)after crushing (M1)	2807.5	2810	
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2475	2471.5	
WT.AGGREG.(gm) PASSING SIEVE 2.36 mm (M2)	332.5	338.5	
TEN % FINE VALUE (M=M2/M1*100)	11.8	12.0	
AVERAGE RESULTS % (M)		11.9	
AVERAGE CRUSHING FORCE (F)		244.3	

$F= \boxed{\frac{14\quad F}{M\quad +\quad 4}}$ 214.5 DRY 214.5 KN

10% FINE VALUE SOAKED

TEST NO	1	2	
CRUSHING FORCE (KN)	244	244	
WT. OF AGGREG (gm)after crushing (M1)	2799.0	2806.0	
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2453	2462	
WT.AGGREG.(gm) PASSING SIEVE 2.36 mm (M2)	346.0	344.0	
TEN % FINE VALUE (M=M2/M1*100)	12.4	12.3	
AVERAGE RESULTS % (M)		12.3	
AVERAGE CRUSHING FORCE (F)		244.3	

$F= \boxed{\frac{14\quad F}{M\quad +\quad 4}}$ 209.7 SOACKED WET/DRY(%)= 98

SPEC >110 SPEC >75%

f= Maximum force (KN)

of material passing the 2.36mm sieve at the maximum force

SPEC REQUIREMENT 7.5%-12.5% (BS 812-111) (if <or> discard

STIRLING CIVIL ENGINEERING
LTD
FOR TESTING LAB
27 SEP 2025
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT:	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE
0	*0*

A.C.V. LABORATORY TEST RESULT FORM

(BS 812PART 110:1990)

MATERIAL SOURCE:	MUKONO CRUSHER	Oparator	LAB TEAM
MATERIAL DESCRIPTION:	AGGREGATES	Date	14/Sep/25

A.C.V

(A) WT BEFORE CRUSHING (gm)	2811		2795.5
(B) WT AFTER CRUSHING (gm)	2811		2795
(C) WT RETAINED AFTER CRUSHING (gm)	2362		2348
(D) WT PASSING SIEVE 2.36 mm	449		447
A.C.V(%) (D/B)*100	16.0		16.0
AVERAGE RESULTS %	16.0		

NB more than B by 10gms repeat the test

A.I.V

(A) WT BEFORE TEST (gm)	352.5	349.5	367.0
(B) WT AFTER TEST (gm)	352.5	349.5	366.5
(C) WT RETAINED AFTER TEST (gm)	294.5	293	306.0
(D) WT PASSING SIEVE 2.36 mm	58.0	56.5	60.5
A.I.V(%) (D/B)*100	16.5	16.2	16.5
AVERAGE RESULTS %	16.4		

NB If c+d is more than B by 1gms repeat the test

SPECIFIED LIMITS IN ACCORDANCE WITH TYPE OF MATERIAL

FOR TESTING LAB

STIRLING CIVIL ENGINEERING
LTD
27 SEP 2025
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	Stirling

PROJECT	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE
0	*0*

RESISTANCE TO DEGRADATION BY ABRASION AND IMPACT TO LOS ANGELES MACHINE
(AASHTO T96 - 99)

		OPERATOR	LAB TEAM
MATERIAL SOURCE:	MUKONO CRUSHER	TOTAL BY DRY WT. OF THE SAMPLE:1	5,000.0
		TOTAL BY DRY WT. OF THE SAMPLE:2	5,000.5
MATERIAL:	AGGREGATES	DATE SAMPLED:	12/Sep/2025
SPECIFICATION...		DATE TESTED:	14/Sep/2025

Test 1 Grading of Test Samples

SIEVE SIZE		Mass of indicated Sizes,g			Grading
Passing	Retained on	A 12 balls	B 11balls	C 8 balls	D 6balls
mm 20	10				
37.5 (1 1/2in)	25.0 (1 in)	1250 ± 25	......	......	......
25.0 (1 in)	19.0 (3/4 in)	1250 ± 25	......	......	......
19.0 (3/4 in)	12.5 (1/2 in)	1250 ± 10	2500 ± 10	......	......
12.5 (1/2 in)	9.5 (3/8 in)	1250 ± 10	2500 ± 10	......	......
9.5 (3/8 in)	6.3 (3/4 in)	.....	.....	2500 ± 10	......
6.3 (3/4 in)	4.75 (No. 4)	.....	.....	2501 ± 10	......
4.75 (No. 4)	2.36 (No. 8)	.....	.....	......	5000 ± 10
TOTAL:........................		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

Speed of Rotation: 33Rev/min. Max. 500 Rev.

Max.Duration 15 min

Wt after crushing: 4,980.0

Wt after crushing : 4,982.5

GRADING USED FOR TEST:	SAMPLE: 1	SAMPLE: 2		
Wt of Mat. Retained on 1.7mm sieve : gm	4,150.0	4,149.2		
Wt of fine material _ gm	850.0	851.3	Average: %	17.0
Percentage of wear_ %	17.0	17.0	Spec Req	≤30%

FOR LAB

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	**KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019**	**Stirling**
PROJECT	**ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE**	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION: Mukono Quarry	OPERATOR:
SAMPLE No	CHECKED:
TYPE: 14-20 mm	DATE: 12/09/2025

TEST NO		A	B	C
[A] wt. of oven dry sample in air	(gm)	1995.5	1996.5	
[B] wt. of saturated surface dry sample in air	(gm)	2001.5	2002.5	
[C] wt of saturated sample in water	(gm)	1240.0	1241.5	
Bulk Specific Gravity on oven dry basis	$\frac{A}{(B-C)}$	2.620	2.624	
Bulk Specific Gravity on saturated surface dry basis	$\frac{B}{B-C}$	2.628	2.631	
Apparent Specific Gravity	$\frac{A}{A-C}$	2.641	2.644	
Water Absorption(%)=	$\frac{100(B-A)}{A}$	0.3	0.3	

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.622
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.630
APPARENT SPECIFIC GRAVITY	2.643
WATER ABSORPTION	0.3

FOR TESTING LAB

STIRLING CIVIL ENGINEERING
LTD
2 SEP 2025
P.O. BOX 798, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	**KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019**	**Stirling**
PROJECT	**ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE**	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION: Mukono Quarry	OPERATOR:
SAMPLE No	CHECKED:
TYPE: 14-10 mm	DATE: 12/09/2025

TEST NO		A	B	C
[A] wt. of oven dry sample in air	(gm)	1793.5	1793.5	
[B] wt. of saturated surface dry sample in air	(gm)	1800.0	1800.0	
[C] wt of saturated sample in water	(gm)	1113.5	1113.5	
Bulk Specific Gravity on oven dry basis	$\frac{A}{(B-C)}$	2.613	2.613	
Bulk Specific Gravity on saturated surface dry basis	$\frac{B}{B-C}$	2.622	2.622	
Apparent Specific Gravity	$\frac{A}{A-C}$	2.638	2.638	
Water Absorption(%)=	$\frac{100(B-A)}{A}$	0.4	0.4	

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.613
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.622
APPARENT SPECIFIC GRAVITY	2.638
WATER ABSORPTION	0.4

FOR TESTING LAB

STIRLING CIVIL ENGINEERING
LTD
21 SEP 2025
P.O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	**KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019**	**Stirling**
PROJECT	**ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE**	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION: Mukono Quarry	OPERATOR:
SAMPLE No	CHECKED:
TYPE: 10-6 mm	DATE: 12/09/2025

TEST NO		A	B	C
[A] wt. of oven dry sample in air	(gm)	1796.5	1921.5	
[B] wt. of saturated surface dry sample in air	(gm)	1805.0	1930.5	
[C] wt of saturated sample in water	(gm)	1115.5	1193.5	
Bulk Specific Gravity on oven dry basis	$\frac{A}{(B-C)}$	2.606	2.607	
Bulk Specific Gravity on saturated surface dry basis	$\frac{B}{B-C}$	2.618	2.619	
Apparent Specific Gravity	$\frac{A}{A-C}$	2.638	2.639	
Water Absorption(%)=	$\frac{100(B-A)}{A}$	0.5	0.5	

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.606
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.619
APPARENT SPECIFIC GRAVITY	2.639
WATER ABSORPTION	0.5

FOR TESTING LAB

STIRLING CIVIL ENGINEERING
LTD
21 SEP 2025
P. O. BOX 706, KAMPALA (U)

	STUDENT	LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	**Stirling**

PROJECT:	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE

Location: ....
Sample: ....
Lab. Ref.: ....

CONCRETE MIX DESIGN

CLASS 25/20

Technician: ....
15/09/2025

MIX FOR 1M^3			Weight (kg)		Volume (dm^3)	
CEMENT OPC 42.5	375	kg	Wt.c =	375	Vc =	119.05
WATER (W/C)	0.5		Wt.w =	187.5	Vw =	187.5
ADMIXTURE		%	Wt.a =		Va =	
AIR	2	%		20		20
					Total ①	326.55

VOLUME AGGREGATES 1000 - ① = 673.45238 ②

AGGREGATES			% WEIGHT		B. SPEC. Gr. (g./cc)		ABSORPTION abs (%)	MOISTURE w (%)	Correction quantity H2O Wc = abs - w (%)
Ø	14 - 20	mm	25	a	2.622	f	0.301	0.071	0.229
Ø	10 - 14	mm	12	b	2.613	g	0.362	0.058	0.304
Ø	6 - 10	mm	20	c	2.606	h	0.471	0.172	0.298
Ø Nat. Sand		mm	43	e	2.633	k	0.473	0.42	0.049

$$\frac{\textcircled{2}}{\frac{25}{2.622}+\frac{12}{2.613}+\frac{20}{2.606}+\frac{}{}+\frac{43}{2.633}} = \frac{673.4524}{38.135} = 17.660 \; \textcircled{3}$$

AGGREGATES IN 1 M^3							DRY WEIGHT dwt (kg)	REAL WEIGHT wt=dwt x (1+w/100) (kg)	Correction quantity H_2O Wc = dwt x Wc1 % /100
Ø	14 - 20	mm	25	% X	17.660	③	441.492	441.808	1.012
Ø	10 - 14	mm	12	% X	17.660		211.916	212.040	0.645
Ø	6 - 10	mm	20	% X	17.660		353.194	353.802	1.054
Ø Nat. Sand		mm	43	% X	17.660		759.367	762.584	0.375
								Total	3.086

COMPOSITION OF THE MIX						BOX (*)	FOR 1 M^3			IN LAB. 0.060 M3	
CEMENT TYPE: PPC				bags	=	7.5	Wt c	375	kg	22.500	kg
WATER							Vw + Wc	190.6	dm^3	11.435	dm^3
ADMIXTURE											
AGGREGATES	Ø	14 - 20	mm	25	%	8	Wt a.	441.808	kg	26.508	kg
	Ø	10 - 14	mm	12	%	4		212.040	kg	12.722	kg
	Ø	6 - 10	mm	20	%	6		353.802	kg	21.228	kg
	Ø	Nat. Sand	mm	43	%	16		762.584	kg	45.755	kg

STIRLING CIVIL ENGINEERING
LTD
[illegible] SEP 2025
P.O. BOX 796, KAMPALA (U)

REMARKS: Slump ....mm (*) Box volume = 0,036 m3 W/C = ...

FOR LAB

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	**KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019**	**Stirling**
JECT	ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE	

SPECIFIC GRAVITY & WATER ABSORPTION FINE AGGREGATES

(AASHTO ; T84—00)

ASTM DESIGNATION ; C128—97

CATION:	OPERATOR:
MPLE No	CHECKED:
E: Natural sand	DATE: 12/09/2025

TEST NO		A	B	C
wt. of oven dry sample in air	(gm)	513.99		504.43
wt. of pycnometer filled with water	(gm)	1770.3		1770.82
wt. of pycnometer with specimen and water	(gm)	2091.19		2086.32
wt of saturated surface dry sample	(gm)	516.02		507.21
Specific Gravity on oven dry basis	$\frac{A}{(B+S-C)}$	2.634		2.631
Specific Gravity on saturated surface dry basis	$\frac{S}{(B+S-C)}$	2.644		2.646
arent Specific Gravity	$\frac{A}{(B+A-C)}$	2.662		2.670
ater Absorption(%)=	$\frac{100(S-A)}{A}$	0.4		0.6

ERAGE RESULTS	
K SPECIFIC GRAVITY	2.633
K SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.645
ARENT SPECIFIC GRAVITY	2.666
TER ABSORPTION	0.5

R TESTING LAB

STIRLING CIVIL ENGINEERING
LTD
2[illegible] SEP 202[illegible]
P. O. BOX 798, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	KASULANE MARK ALVIN M22B32/016 & KHAN GAK NGAW M22B32/019	**Stirling**

PROJECT	**ASSESSING THE SUITABILITY OF SUGAR CANE BAGASSE ASH IN PREVENTING CORROSION-INDUCED SPALLING IN REINFORCED CONCRETE**			
SAMPLE DISCRIPTION	SAND	Sampling Date		12/09/2025
TEST METHOD	DETERMINATION OF SILT CONTENT			

S.no	**Description**	**Sample 1**	**Sample 2**	**Sample 3**
1	Volume of sample Sand (V2)	4	3.8	4.2
2	Volume of silt layer (V1)	88	98	91
3	Percentage of silt % (V1/V2)*100	**4.5**	**3.9**	**4.6**

FOR TESTING LAB

STIRLING CIVIL ENGINEERING
LTD
27 SEP 2025
P. O. BOX 756, KAMPALA (U)

Test Report

Accelerated Corrosion Test

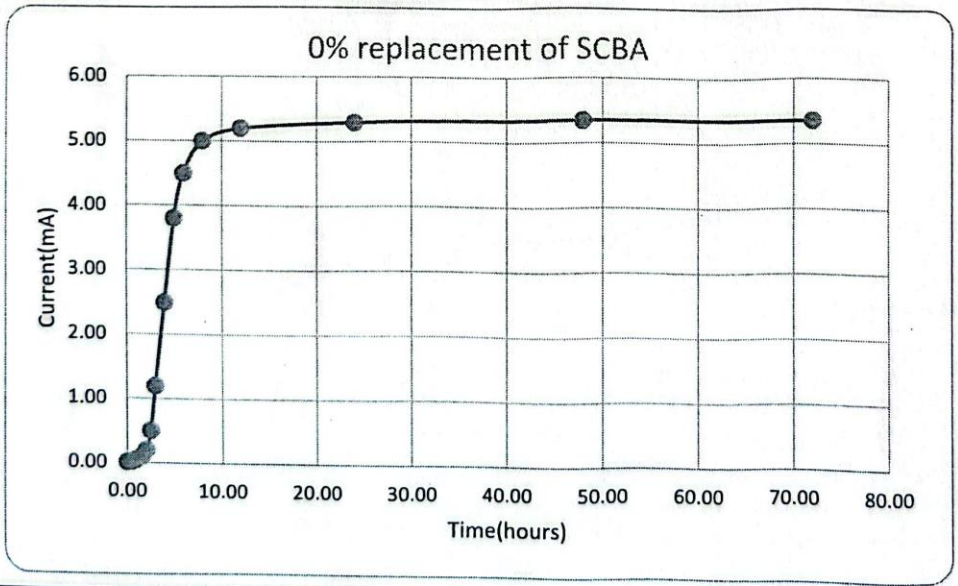
CHC

Project:	ASSESSING THE SUITABILITY OF SUGARCANE BAGASSE ASH IN PREVENTING CORROSION INDUCED SPALLING IN REINFORCED CONCRETE
Client:	MR. Kasulane Mark Alvin

0% replacement(control mix)

Time (h)	Current (mA)	Corrosion Rate (mm/year)
0.00	0.01	0.00000
0.50	0.02	0.00004
1.00	0.05	0.00020
1.50	0.10	0.00060
2.00	0.20	0.00161
2.50	0.50	0.00503
3.00	1.20	0.01448
4.00	2.50	0.04021
5.00	3.80	0.07640
6.00	4.50	0.10857
8.00	5.00	0.16084
12.0	5.20	0.25091
24.0	5.30	0.51147
48.0	5.35	1.03259
72.0	5.36	1.55178

Constants	
Faraday Constant (F)	96485
Molar Mass Fe (g/mol)	55.8
Valence Electrons (n)	3.00
Density of Steel (g/cm3)	7.87
Exposed Area (cm2)	534



Tested by: ALINDA JOVAN	Checked by: MABIRIZI TITUS
SIGN & DATE 25/11/2025	SIGN & STAMP

CHC ANALYSIS UG LIMITED
P.O.BOX 1424
26 NOV 2025
GEOTECHNICAL AND MATERIALS
TESTING LABORATORY

Test Report

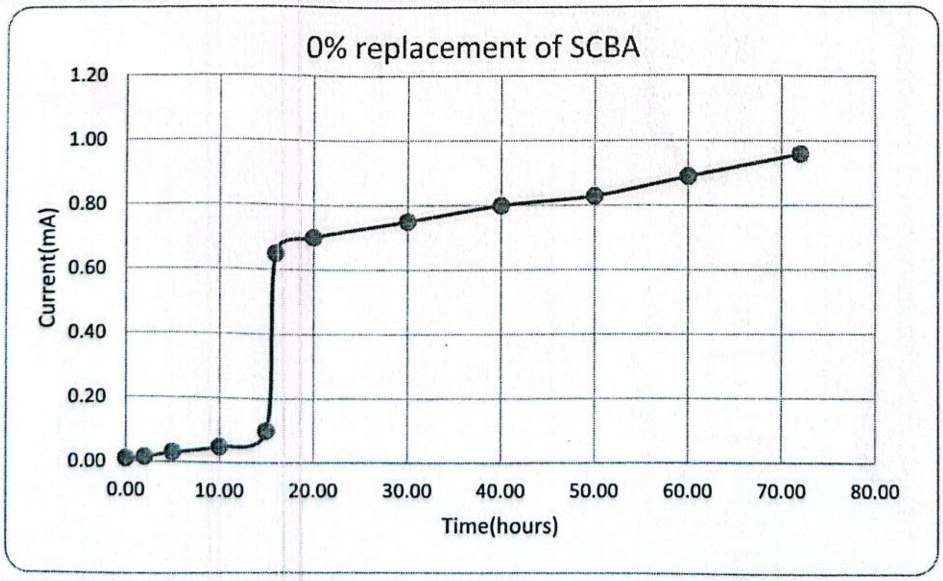
Accelerated Corrosion Test

CHC

Project:	ASSESSING THE SUITABILITY OF SUGARCANE BAGASSE ASH IN PREVENTING CORROSION INDUCED SPALLING IN REINFORCED CONCRETE
Client:	MR. Kasulane Mark Alvin

5% replacement(control mix)		
Time (h)	**Current (mA)**	**Corrosion Rate (mm/year)**
0.00	0.01	0.00000
2.00	0.02	0.00012
5.00	0.03	0.00060
10.00	0.05	0.00201
15.00	0.10	0.00603
16.00	0.65	0.04182
20.00	0.70	0.05629
30.00	0.75	0.09047
40.00	0.80	0.12867
50.00	0.83	0.16687
60.00	0.89	0.21472
72.0	0.96	0.27793

Constants	
Faraday Constant (F)	96485
Molar Mass Fe (g/mol)	55.8
Valence Electrons (n)	3.00
Density of Steel (g/cm3)	7.87
Exposed Area (cm2)	534



Tested by: ALINDA JOVAN	Checked by: MABIRIZI TITUS
SIGN & DATE 25/11/2025	SIGN & STAMP

CHC ANALYSIS UG LIMITED
P.O BOX 1424
26 NOV 2025
GEOTECHNICAL AND MATERIALS
TESTING LABORATORY

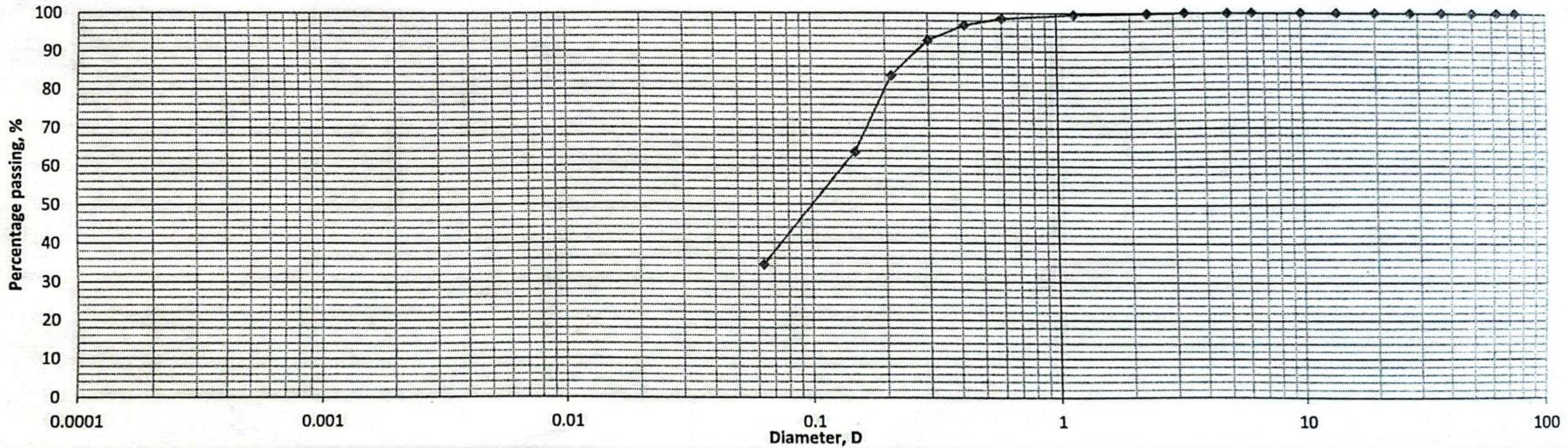
CHC

Test Report

Project:	**ASSESSING THE SUITABILITY OF SUGARCANE BAGASSE ASH IN PREVENTING CORROSION INDUCED SPALLING IN REINFORCED CONCRETE**
Client:	**MR. Kasulane Mark Alvin**
Sample	**Sample 1**

Diameter	75	63	50	37.5	28	20	14	10	6.3	5.0	3.35	2.36	1.18	0.6	0.425	0.3	0.212	0.15	0.063
Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	99	97	93	84	64	34

Particle Size Distribution



TESTED BY: ALINDA JOVAN	CHECKED BY : MABIRIZI TITUS
SIGN & DATE 25/11/2025	SIGN & STAMP

CHC ANALYSIS UG LIMITED
P.O BOX 1424
★ 26 NOV 2025 ★
GEOTECHNICAL AND MATERIALS
TESTING LABORATORY

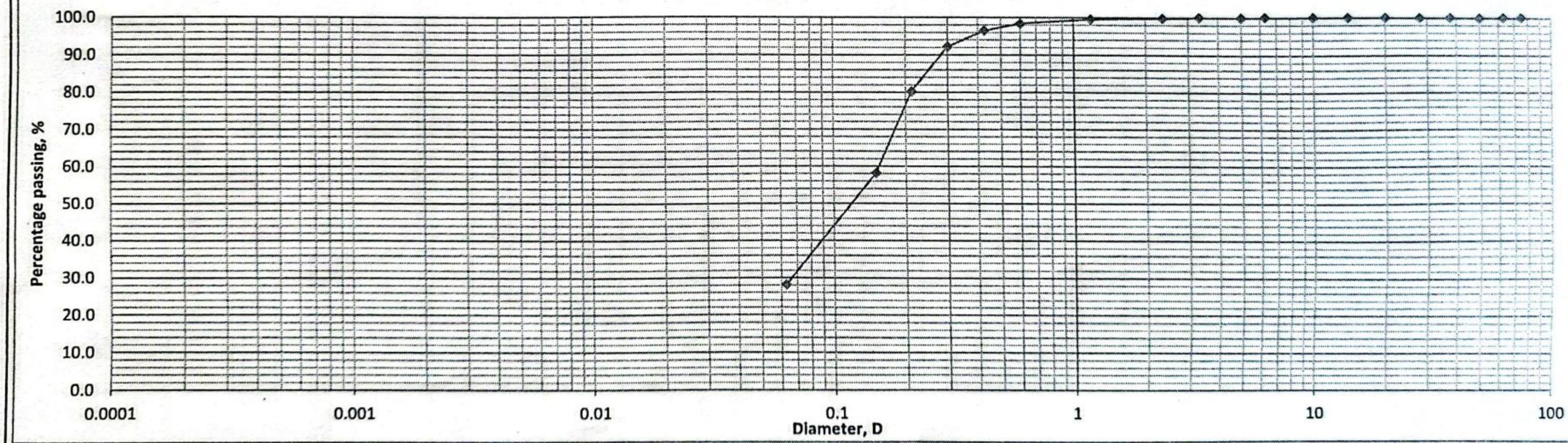
CHC

Test Report

Project:	**ASSESSING THE SUITABILITY OF SUGARCANE BAGASSE ASH IN PREVENTING CORROSION INDUCED SPALLING IN REINFORCED CONCRETE**
Client:	**MR. Kasulane Mark Alvin**
Sample	**Sample 2**

Diameter	75	63	50	37.5	28	20	14	10	6.3	5.0	3.35	2.36	1.18	0.6	0.425	0.3	0.212	0.15	0.063
Percentage	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.6	98.4	96.5	92.2	80.2	58.2	28.2

Particle Size Distribution



TESTED BY: ALINDA JOVAN	CHECKED BY : MABIRIZI TITUS
SIGN & DATE 25/11/2025	SIGN & STAMP CHC ANALYSIS UG LIMITED P.O. BOX 1424 26 NOV 2025 GEOTECHNICAL AND MATERIALS TESTING LABORATORY