OPTIMIZING MECHANICAL PROPERTIES OF CONCRETE USING SUGARCANE BAGASSE ASH

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Thesis submitted in partial fulfillment of the requirements for the degree
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DECLARATION

I declare that this is my own work and this Thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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The supervisors should certify the Thesis with the following declaration.

The above candidate has carried out research for the Master of Science (Major Component Research) Thesis under our supervision. We confirm that the declaration made above by the student is true and correct.

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ABSTRACT

In this study, sugarcane bagasse ash is recognized as a pozzolan, and the examination delves into its impact on the structural properties and durability of concrete. A significant volume of bagasse ash is generated annually in Sri Lanka through the recycling of raw bagasse for power generation in the sugar industry. The bagasse ash utilized in this study was procured from a local sugar factory in Sri Lanka. Diverse methods, such as X-ray diffraction, X-ray fluorescence, and laser particle size analysis, were utilized to evaluate the chemical, physical, and mineralogical characteristics of the bagasse ash. Additionally, a scanning electron microscope was utilized to examine the microstructure. The assessment extended to the examination of hardened properties such as compressive strength, bond strength, tensile strength, ultrasonic pulse velocity, and durability properties including water absorption and penetration of chloride.

The concrete mixtures were formulated by substituting bagasse ash at ratios ranging from 5% to 20% by weight instead of Portland cement. The local ash demonstrated pozzolanic characteristics as per the results of chemical, physical, and mineral tests. Notably, mixtures containing 5% to 15% bagasse ash substitution were identified as optimum replacements for achieving elevated compressive and tensile strength. Simultaneously, the water absorption and rapid chloride permeability test indicated a lower value of up to a 10% ash content percentage than control concrete.

Keywords: Concrete, Sugarcane bagasse ash, Composites, Mechanical properties, Durability

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LIST OF ABBREVIATIONS

Abbreviation	Description
ADB	Asian Development Bank
ASTM	American Society for Testing and Materials
C-S-H	Calcium - Silicate - Hydrate
DSC-TGA	Differential Scanning Calorimetry-Thermogravimetric Analysis
LOI	Loss On Ignition
OPC	Ordinary Portland Cement
PAI	Pozzolanic Activity Index
RCPT	Rapid Chloride Permeability Test
RHA	Rice Husk Ash
SAI	Strength Activity Index
SBAS	Sugarcane Bagasse Ash Sand
SCBA	Sugarcane Bagasse Ash
SCM	Supplementary Cementitious Material
SEM	Scanning Electron Microscopy
SSA	Specific Surface Area
SSD	Saturated Surface Dry
UHPC	Ultra High-Performance Concrete
UPV	Ultrasonic Pulse Velocity
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

Concrete stands as the predominant man-made construction material globally, owing to its widespread application, adaptability to diverse shapes, and resistance to water [9]. The conventional constituents of concrete encompass cement, water, coarse, and fine aggregates [10]. Cement, identified as the second-used substance on the earth than water, takes a major part in the composition of concrete [11]. Quedou et al. projected that global cement demand will soar to 5 billion tonnes by 2050 [12]. This admirable demand, however, has an accompanying cost. The environment and human health are both negatively impacted by cement manufacture. Nearly 10% of the planet's total carbon dioxide (CO_2) emissions are attributed to its production process, which greatly contributes to the greenhouse effect [13]. To reduce the production of carbon dioxide gases, researchers are constantly looking at alternatives that could perhaps replace cement in concrete formulations.

The exploration of incorporating industrial and agricultural byproducts into the construction sector holds immense potential, primarily driven by the goal of reducing CO_2 emissions and fostering sustainability. One such waste material with promising applications is bagasse, a fibrous residue from the sugar refining industry that can serve as an alternative cementing material [14]. In the sugar manufacturing process, bagasse transforms into ash as it is utilized as a fuel to produce steam in boilers for electricity production [15]. This research delves into the chemical and microstructural attributes of Sri Lankan sugarcane ash and its impact on both freshly poured and denser concrete. This experimental inquiry aims to enhance our understanding of ash as a pozzolanic substance, providing reliable information. Furthermore, it seeks to promote the expanded utilization of sugarcane ash as a replacement for cement within Sri Lanka's construction industry.

The main concept of the research study is discussed in this chapter. First, Section 1.1 provides background information about this study. The motivation for the research project is briefly presented in Section 1.2, and the identified problem statement is presented in Section 1.3. In Section 1.4, an aim and objective of the research is looked over followed by Significance of the research in Section 1.5. Finally, Section 1.6 explains the thesis's structure.

1.1 Background

1.1.1 Sugarcane Bagasse Ash

Approximately 1900 million tonnes of sugarcane bagasse are generated annually worldwide, distributed across 124 nations [16]. Notably, 87.4% of global sugarcane production is concentrated in 15 countries, with Brazil leading the pack, followed by India, China, and Thailand [17]. Projections indicate that the annual global sugarcane production will surpass 1.5 billion tonnes [14]. Brazil, as the foremost producer of Sugarcane Bagasse Ash (SCBA) , contributes significantly, producing 2.5 million tonnes annually [18]. India follows closely, being the second producer of sugarcane, contributing approximately 350 million tonnes annually [18]. Figure 1.1 illustrates the top ten countries' production of the SCBA. In the context of Sri Lanka, only about 10% of the annual sugar demand, exceeding 590,000 metric tons in 2019, is met domestically [19]. One of the sugar plantations is operated by Etimale Plantation Ltd. (Pvt), which is located in the Monaragala District of Sri Lanka. This factory, which began operations in 2017, has a capacity of 15,000 L per day of alcohol and 25,000 metric tonnes of sugar annually.

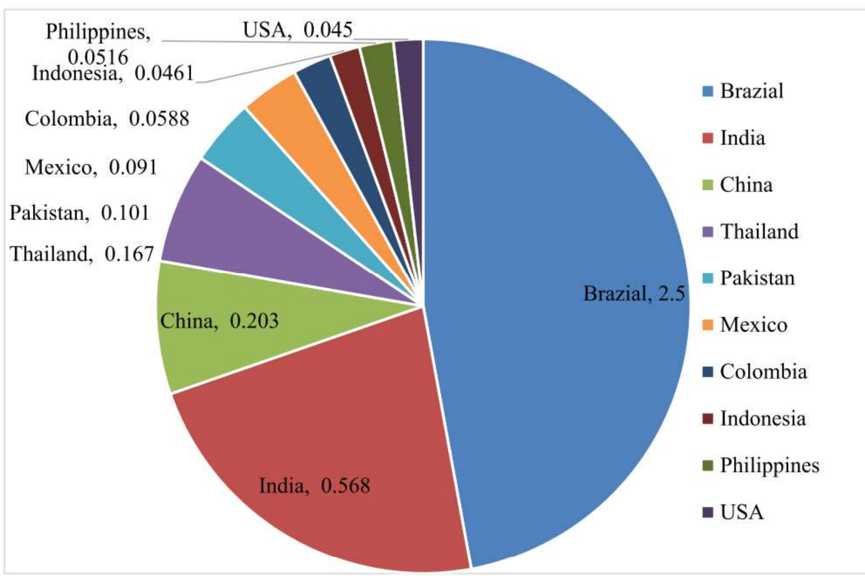


Fig. 1.1: SCBA production (Million tons) [1]

Sugarcane has become one of the most robust plants for agriculture that can grow in hot regions. When sugarcane is harvested, it is crushed in sugar mills to extract the juice. The residual fibrous material is what is referred to as bagasse. Currently, sugar mills employ bagasse as biomass fuel in boilers to produce electricity. Bagasse is burned at controlled temperatures, and the byproduct is referred to as bagasse ash.

However, bagasse ash used to be treated as waste and dumped in ash ponds, landfills, or over farms. The SCBA is viewed as a potential cement alternative that helps in the reduction of waste concerns associated with the recycling of agricultural waste. Fig. 1.2 displays the typical method of manufacturing SCBA from sugarcane crops.

1.1.2 Microstructure Properties of Sugarcane Bagasse Ash

Different countries have different SCBA mineral compositions. This composition varies depending on the soil type, crop type, subsurface water, and other factors [20]. The calcination of SCBA is often connected with the formation of a significant amount of the amorphous state within the temperature range of 600 °C to 700 °C, a condition that significantly enhances its pozzolanic activity. This elevated pozzolanic activity

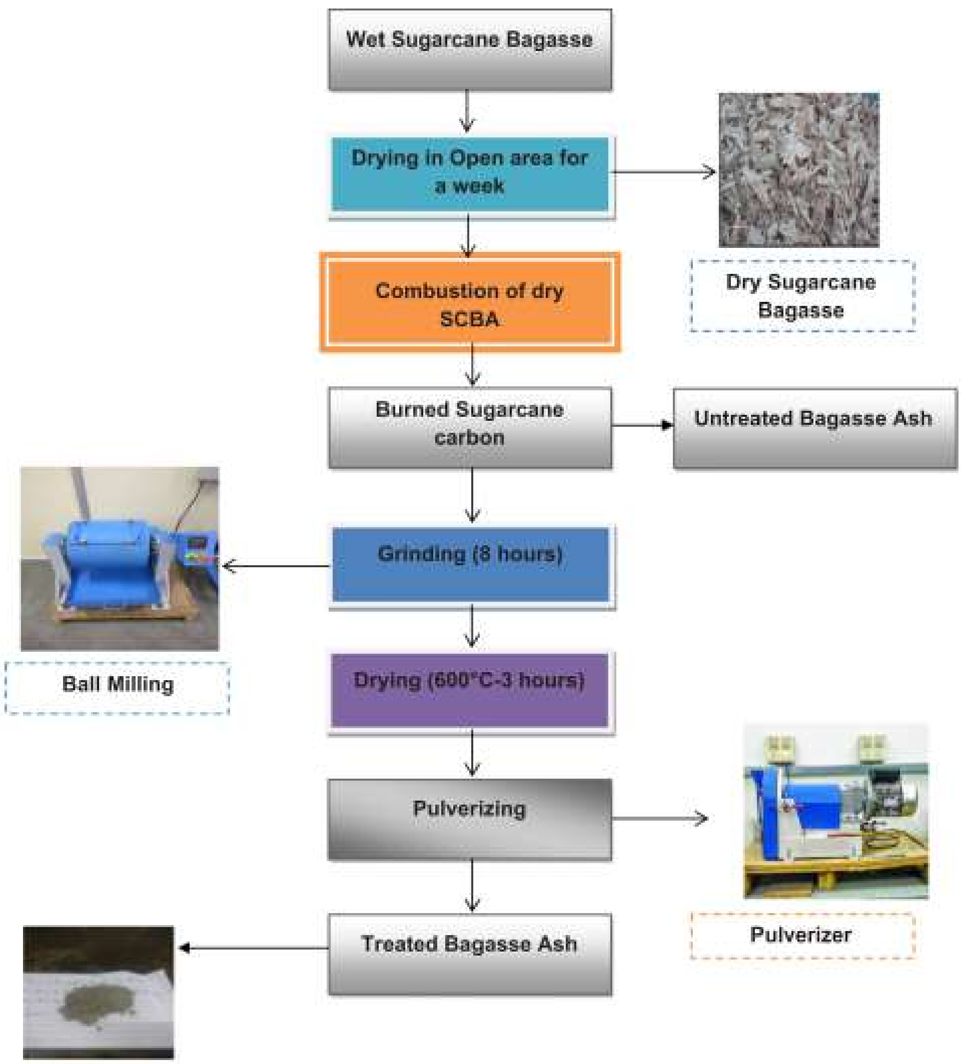


Fig. 1.2: Processing of SCBA [2]

is crucial for the subsequent development of Calcium - Silicate - Hydrate (C-S-H) because of the interaction among the portlandite and SCBA formed during the cement hydration. The development of C-S-H helps to the enhancement of the concretes' mechanical properties [21]. Previous research has suggested how the inherent pozzolanic characteristics of sugarcane ash can offer notable advantages in the production of concrete. The inclusion of this substance has been shown to contribute to both heightened strength and improved durability protection.

1.1.3 Drawbacks of Sugarcane Bagasse Ash

The sugar plants in Sri Lanka that produce electricity have set aside substantial land areas for the disposal of this undesired trash. The hazardous nature of these materials prevents the area near the land disposal from being developed. This raises electrical conductivity, which can impact the quality of the soil and groundwater as well as slow down plant growth and establishment. These contaminants might pollute air and water sources, harming the ecology and risking human life if dumped in open areas [22]. The development of the lung condition known as bagassosis has been associated with exposure to bagasse dust particles [23].

1.1.4 Sugarcane Bagasse Ash as a Substitution for Cement

There has been a lot of research done on SCBA as a cement substitute in the past. According to records, many researchers have tested using SCBA in place of cement in concrete. The impact of substituting SCBA in concrete was researched by Dhengare et al. [24]. The outcome demonstrated that a 15% replacement level was where the maximum compressive strength was obtained. Rambebu et al. [22] tested the influence of sulfates on concrete by substituting cement with bagasse ash between 0% to 20%. Their findings indicated that increasing the bagasse ash content enhanced compressive strength and provided protection against sulfate attack. The authors concluded that an optimal substitution of 6% could effectively replace SCBA. In a study by Jha et al. [25], who investigated SCBA as a cement substitute in ratios from 0% to 20%, it was observed that the slump decreased as the SCBA percentage increased. Various studies [7, 26] have consistently reported improved slump with the substitution of SCBA. Ganesan et al. [6] demonstrated a reduction in slump height with increased SCBA, particularly with a water/cement ratio of 0.53. The optimum percentage for increasing compressive strength, as recommended by Setayesh et al is a 10% SCBA replacement. [27]. With 20% and 30% replacement, Shafiiq et al. [28] and Lee et al. [29] got same observations. With increases in SCBA, there was a decrease in flexural strength values [27, 30]. Similar to how Ganesan et al. [6] achieved 20% replacement, Katare and Madurwar [30] and Shafiq et al. [28] observed 10% and 15% ratios as a maximum tensile strength.

Chindaprasirt et al. [31] studied the SCBA instead for cement in the construction of pavement, exploring substitution levels ranging from 0% to 60%. According to the authors, large SCBA particles had an influence on the quality of the pavement. They also observed that when the concentration of SCBA increased, its mechanical characteristics, unit weight, surface abrasion, and thermal conductivity all reduced. The increasing percentage of SCBA also resulted in a reduction in weight loss attributed to sulfuric acid. The authors added that increased SCBA concentration increased the porosity of the pavement concrete, resulting in higher water absorption. The authors noted that the SCBA content of the pavement concrete was 20% - 40% and that the concrete had good mechanical and durability qualities.

1.2 Motivation

The global construction industry plays a central role in driving development, contributing to the expansion of infrastructure, economic advancement, and urbanization. Concrete stands out as a fundamental construction material, serving as the backbone of contemporary infrastructure. However, the conventional production methods of concrete heavily depend on Portland cement, a component associated with substantial energy consumption and greenhouse gas emissions. In response to environmental considerations and the imperative for sustainable practices, researchers and industries are actively exploring alternative materials and methods to enhance the mechanical properties of concrete while mitigating its environmental impact. Embracing eco-friendly practices not only fulfills corporate social responsibilities but also holds the potential for economic benefits through reduced material costs and improved public perception.

SCBA, a byproduct of the sugarcane industry, emerges as a promising avenue in this context. Incorporating SCBA into concrete production presents an opportunity for the construction industry to realize several advantages. Leveraging its pozzolanic properties, SCBA holds the potential to optimize key mechanical properties of concrete, encompassing strength, durability, and workability. Moreover, the reduced reliance on traditional Portland cement contributes to a significant decrease in carbon emissions during the manufacturing process. The usage of SCBA in concrete also serves as a sustainable means of disposing of agricultural waste. Left unmanaged, bagasse ash poses potential adverse effects on the ecosystem. However, integrating it into concrete allows the construction industry to transform a waste product into a valuable resource, simultaneously addressing waste management challenges and curbing environmental impact.

1.3 Problem Statement

The incorporation of SCBA into cementitious materials, especially in concrete, has garnered considerable attention in recent years. SCBA, possessing pozzolanic properties, can react with water and calcium hydroxide to form a cement matrix, thereby enhancing the mechanical properties of cementitious materials. Despite this, the optimal utilization of SCBA in concrete is still in its nascent stages, necessitating further research to comprehensively understand its properties and potential applications. While past research has predominantly focused on the mechanical characteristics of concrete when incorporating SCBA as a cement substitute, investigations into its durability have not been extensively explored.

The mineral proportions within SCBA can vary from one country to another. Notably, the qualities and impact of SCBA produced in Sri Lanka on concrete performance have not been thoroughly investigated, representing a significant gap in the existing body of knowledge. Addressing this knowledge gap is crucial for achieving a comprehensive understanding of the suitability of SCBA as a pozzolanic substance, especially in the Sri Lankan construction context. Bagasse ash from Sri Lanka may exhibit differences in chemical composition, mineral composition, and microstructure compared to other ashes, potentially influencing its viability as a cement substitute. Consequently, a thorough examination of the characteristics of locally produced SCBA when combined with concrete becomes necessary.

1.4 Aim and Objectives

The primary aim of this research is to assess the feasibility of utilizing SCBA produced from the local sugar plants as a pozzolan and its potential application as a cement replacement in concrete production. This aim will be achieved by undertaking the following objectives

1. Assess the pozzolanic suitability of locally available bagasse ash for usage as a supplementary cement material.
2. Investigate the effect of SCBA on concrete properties, including consistency, setting time, workability, compressive strength, water absorption, and Rapid Chloride Permeability Test (RCPT) .
3. Recommend a percentage of SCBA replacement in concrete mixtures for enhanced mechanical and durability properties.

1.5 Significance of the Research

This research holds significant implications for the construction industry by aiming to assess the viability of incorporating bagasse ash as a sustainable alternative to traditional cement in concrete production. The objectives of this study encompass evaluating the pozzolanic characteristics of locally available Bagasse ash, identifying the most suitable source among different plantations, analyzing the chemical composition of SCBA, and investigating its influence on concrete properties. The findings will contribute valuable insights into the feasibility of SCBA as a supplementary cementing component, offering potential improvements in the mechanical and durable aspects of concrete. Successful implementation of SCBA in concrete could not only increase the sustainability of construction practices but also address environmental concerns by utilizing a byproduct that is currently underutilized.

1.6 Thesis Structure

1. **Chapter 1:** This chapter gives a concise outline of the research project, presenting the background, identifying the research gap, explaining the motivation behind the study, outlining the aim and objectives, and highlighting the significance of the research.

2. **Chapter 2:** This chapter presents the crucial literature reviewed in this research, encompassing the micro-structural properties of SCBA in various countries and Sri Lanka. Additionally, it provides a summary of the mechanical and durable characteristics of SCBA-blended concrete.

3. **Chapter 3:** This chapter outlines the methodology employed in this research project, explaining the various experiments conducted to assess the mechanical and durable characteristics of concrete. These experiments involve replacing cement with SCBA by 5-10

4. **Chapter 4:** Presents the outcomes derived from the conducted experimental study on the micro-structure of SCBA, the mechanical characteristics, and the durability assessment of concrete.

5. **Chapter 5:** The research concludes by summarizing the entirety of its findings. Secondly, recommendations for future research are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 The Effect of Bagasse Ash Processing

2.1.1 Processing Effects on the Pozzolanic Characteristics of Bagasse Ash

A pozzolanic substance should not have more than 34% of its particles retained on the 45 µm sieve to meet American Society for Testing and Materials (ASTM) criteria for experimenting. Quartz was also found close by in the residue, proving that SCBA can potentially persist as a dormant substance [32]. Additionally, Strength Activity Index (SAI) determined by the ratio of the average compressive strength of both the control specimens and to the mortars containing pozzolanic material, should be no greater than 75% [33]. Somna et al. [34] lowered the substance size of the raw ash to the specified minimal pozzolanic reactivity and observed that with grinding time the fineness increased, resulting in a decrease in porosity.

The Loss On Ignition (LOI) is defined as the percentage mass loss of the substance when calculated among 900 °C and 1000 °C by American Concrete Institute standard ACI 116 [50]. Elevated levels of LOI are typically associated with reduced presence of significant oxides. Furthermore, a higher LOI percentage seems to raise the need for water, lowering the compressive strength of SCBA replaced with concrete [35, 36]. The ASTM C618 standard imposes a maximum allowable LOI value of 10% by weight for natural pozzolans [33]. Particles unburnt in SCBA contribute to higher LOI. Research findings indicate a wide-ranging LOI for SCBA, spanning from 0.42% to 10%. Chusilp et al. [37] observed that the highest LOI level of ash (maximum of 20%) had a negligible impact on the hardened properties of mortar at 28 days of moisture curing. Burning duration and temperature significantly influence the LOI value.

Frias et al. [38] looked into three kinds of SCBA for potential use as pozzolans in the manufacturing of cement: a) bottom ash, lacking any pozzolanic characteristics and collected at approximately 750 °C, suggested as a substitute of fine aggregate; b) filter SCBA, possessing low to medium pozzolanic reaction, obtained from ignition gases at 300 °C; c) laboratory SCBA, exhibiting good pozzolanic qualities, produced in an electric furnace. Similar research was conducted by Cordeiro et al. [39]. Bagasse underwent processing in an electric oven with ventilation at 350 °C for 3 hours at a rate of 10 °C/min, as well as at various temperatures between 400 °C and 800 °C for an additional 3 hours. The expulsion of exceptional carbon content indicated that the SAI of SCBA (burned at 400 °C, 500 °C, and 600 °C) increased with rising temperatures. Figure 2.1 illustrates that burning for one hour at 600 °C produced ash with burned carbon (reduced content of SiO_2 but amorphous in nature). White ash, characterized as amorphous, chemically robust, and ultra-fine, was formed with an increase in flame temperature and duration, suggesting enhanced effectiveness for SCBA inclusion as a Supplementary Cementitious Material (SCM) .

2.1.2 The Effect of Treating on Bagasse Ash-Incorporated Concrete

The characteristics of hardened concrete blended with SCBA are significantly affected by various processing techniques, which have been discussed in earlier sections. These processing methods not only enhance the physical characteristics of SCBA but also contribute to its pozzolanic performance, thereby directly enhancing the mechanical characteristics of SCBA mixed with concrete. The connection between compressive strength and particle size is evident, with grinding reducing particle size and subsequently increasing compressive strength. Cordeiro et al. found the same strength in concrete replaced with SCBA ground up to 120 minutes [40]. However, the raw SCBA (35%) significantly decreased compressive strength, with control concrete exhibiting lower strength than concrete ground with SCBA for 240 minutes. Finer SCBA particles, due to their filling effect, enhance the microstructure. Bahurudeen et al. [4] showed that ash grounded to a size of 50 µm was sufficient to achieve the necessary pozzolanic characteristics. Concrete without SCBA and concrete with ground SCBA of similar particle size (50 µm) exhibited comparable compressive strengths. Sieving SCBA through a sieve size of 300 µm also contributes to an enhance in the compressive

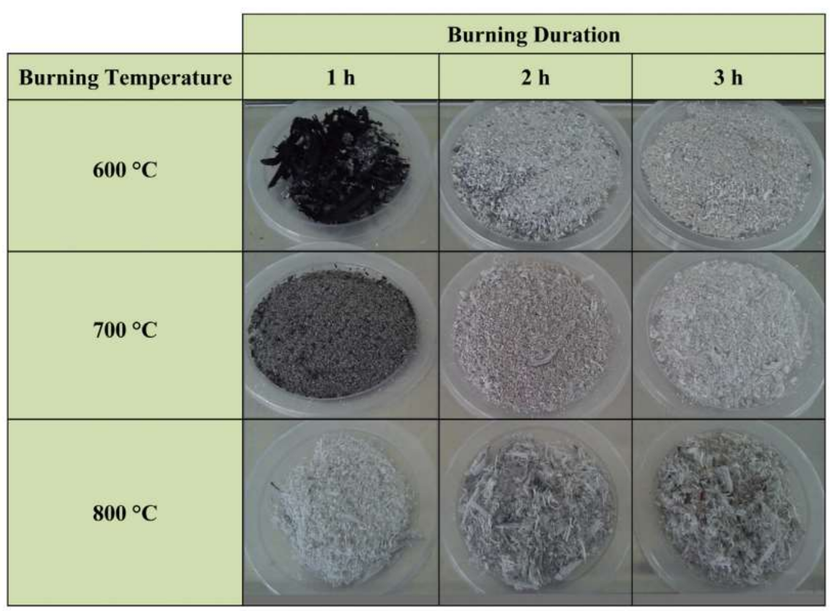


Fig. 2.1: The formation of ashes following calcination at different temperatures [3]

strength of blended concrete.

Recalcination enhances compressive strength by eliminating volatile organic content. Concrete with SCBA demonstrates improved compressive strength after burning at 700 °C [4]. Despite being an energy-intensive and less profitable technology, the thermomechanical approach enhances the characteristics of SCBA-replaced concrete. The addition of SCBA after the process of thermomechanical results in improved compressive strength, involving 45 minutes of grinding and an additional 4 hours of burning at 400 °C [41]. Acid treatment, a primary method for processing agro-waste ash-based pozzolan, has been minimally investigated for its impact on SCBA performance. Lowering the potassium oxide (K_2O) content by soaking SCBA in 0.1 M HCl and one hour burning enhances SCBA qualities. The comparison between concrete with untreated SCBA and concrete with chemically treated SCBA illustrates an 11% compression strength increase [3].

2.2 Physical and Chemical Properties of Bagasse Ash

2.2.1 Physical Characteristics of Bagasse Ash

Several physical characteristics of SCBA have been investigated, including specific gravity, density, particle size, microstructure analysis, and pozzolanic index. The workability of concrete incorporating bagasse ash is impacted by its high Specific Surface Area (SSA) , requiring additional water-reducing admixtures for proper consistency [42]. SCBA exhibits a lower specific gravity than cement, ranging from 2.90 to 3.15, compared to cement's 1.78 to 2.88, implying that substituting cement with SCBA results in a higher volume [43]. Ganeasan et al. [6] observed that ground SCBA are finer than Ordinary Portland Cement (OPC) , with lower density, specific gravity, and median grain size. The SAI of ground bagasse ash, as investigated by Kazmi et al. [44], was three times that of OPC. The untreated SCBA particles exhibit varying sizes and shapes, as shown in Fig. 2.2 with a comparable SSA to Portland cement [45].

Bahurudeen et al. [46] utilized a flask of Standard Le Chatelier and kerosene to calculate the density of SCBA, while Sales et al. [47] followed the IS 1727-2004 standard using kerosene and freshly air-dried SCBA. The SAI is influenced by the fineness of SCBA particles, working as an inert substance with less pozzolanic activity for coarser particles (30 μm D50) [48]. Raw SCBA exhibits low pozzolanic activity, requiring treatment to achieve a fineness similar to OPC (300 - 320 m^2/kg) to enhance SAI [49]. Grinding SCBA in a ball mill transforms it into a mineral admixture, increasing SAI from 60% to 100%. Grinding is crucial for mitigating the adverse effects of crystalline silica, improving ash uniformity and SAI, and increasing SSA. The energy expended in grinding SCBA must be considered when selecting the optimal grinding method. Successfully addressing sustainability challenges related to cement clinker grinding

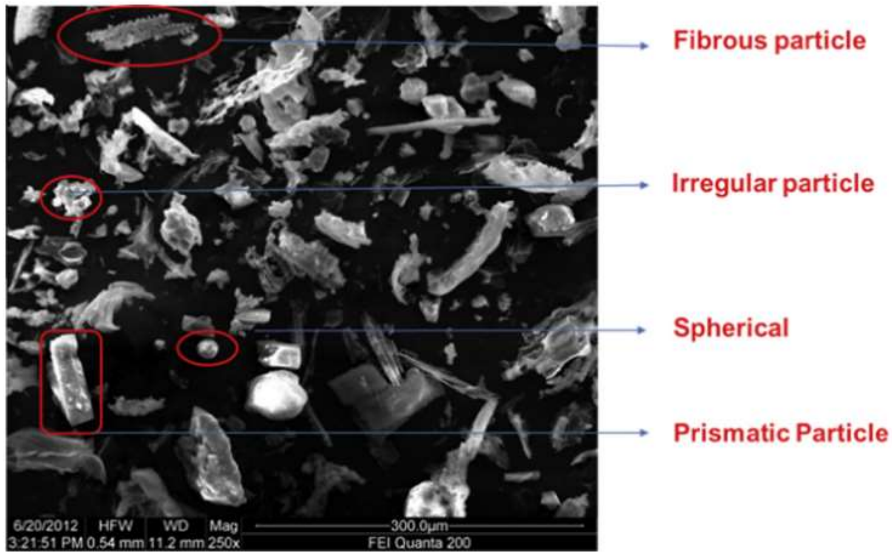


Fig. 2.2: Raw bagasse ash exhibiting various shapes [4]

makes the incorporation of SCBA into cement a feasible prospect in the near future.

2.2.2 Chemical Composition of Sugarcane Bagasse Ash

Understanding the chemical properties of OPC is crucial when considering its substitution with SCBA in concrete. Various elements such as chemical composition, water-to-cement ratio, and cement type influence the hardened properties of cementitious composites. SCBA primarily have of SiO_2, Al_2O_3, and Fe_2O_3, with a high silica concentration (60% - 75%), approximately three times that of OPC. This elevated silica content signifies the reactivity of SCBA, as silica is a key contributor to the strength of concrete [50]. As per ASTM C618-08a standards, the summation of SiO_2 + Al_2O_3 + Fe_2O_3 values exceeding 50 % and 70 % are classified as class C and F pozzolans, accordingly [51]. Another requirement for pozzolans is that the SO_3 content should not exceed 4%. SCBA's LOI concentration ranges from 0.4% to 24.15% [51, 52], and it contains sufficient amounts of Al_2O_3, Fe_2O_3, CaO, and K_2O [34, 36], which are also present in regular Portland cement. As SCBA contains Al_2O_3, Fe_2O_3, and CaO, it can serve as a Supplementary Cementitious Material (SCM) to bind concrete [53].

The SSA and reactivity of bagasse ash are significantly influenced by particle size, with smaller particles exhibiting higher SSA and reactivity [54]. Pozzolanic characteristics, measured by the chemical reaction between water and $Ca(OH)_2$ component of pozzolana and water, indicate the potential to enhance concrete strength. Cordeiro et al.'s investigations [40] revealed that SCBA exhibited Pozzolanic Activity Index (PAI) of a 100%. Optimal pozzolanic activity and conditions of burning were achieved by burning bagasse, and further grinding to an ultrafine consistency increased PAI. Ultrafine ground SCBA for 120 minutes at 600 °C demonstrated 100% PAI. Authors suggest that burning and processing SCBA may increase its content of silica. Compared to Rice Husk Ash (RHA) and fly ash, SCBA has 15% more SiO_2, leading to increased C-S-H gel formation and a higher PAI. In tests conducted by Bahurudeen et al. [36], treated bagasse ash exhibited superior pozzolanic activity.

2.3 Impact on Properties in Fresh State of Concrete

2.3.1 Workability

Integrating SCBA into a concrete mix requires the use of a superplasticizer to maintain workability, as SCBA particles are irregular, angular, and highly porous. The impact of SCBA on concrete workability is outlined in Table 2.1. Concrete mixes containing 10%, 20%, and 30% SCBA required 3.20 kg/m^3, 5.20 kg/m^3, and 6.30 kg/m^3 of superplasticizer, respectively, while the reference concrete achieved a slump of 150 mm to 200 mm without the addition of any superplasticizer [52]. Similar findings were seen by Somna et al. [34] incorporating ground SCBA and recycled aggregate for concrete. Grinding, according to Montakarntiwong et al. [49], can enhance workability by reducing the size of fibrous particles. However, as the replacement percentage increases, the need for superplasticizers also rises to maintain the slump flow [49]. Moreover, as the SCBA content increases, the water demand also rises, although the need for water for the mixture of ground limestone decreases [55]. The concrete mix with SCBA (up to 20%) decreased the superplasticizer amount by 15% compared to the control concrete, resulting in an increased slump when using ultra-fine SCBA (PAI of 100%) [56].

An evident reduction in concrete workability was observed with higher SCBA additions. The mix with 25% SCBA exhibited the lowest workability due to the adsorptive properties of ash [57]. The increased SSA and distribution of non-uniform SCBA substances led to decreased slump flow, attributed to higher friction between the particles. Khalil et al.'s experiment [43] revealed a decrease in water requirement with increasing doses of treated SCBA, resulting in increased workability. However, Gopinath et al. [58] noted a decrease in workability for raw SCBA. Overall, workability tends to decline as the level of SCBA replacement increases, but the use of a superplasticizer and the elimination of fibrous substances can enhance the slump of SCBA-replaced concrete.

2.3.2 Soundness, Consistency and Setting time

The soundness of the control paste decreased from 1.7 mm to 0.9 mm, well below the allowed limit of 10 mm stipulated by both the British Standard EN 196-3 and the

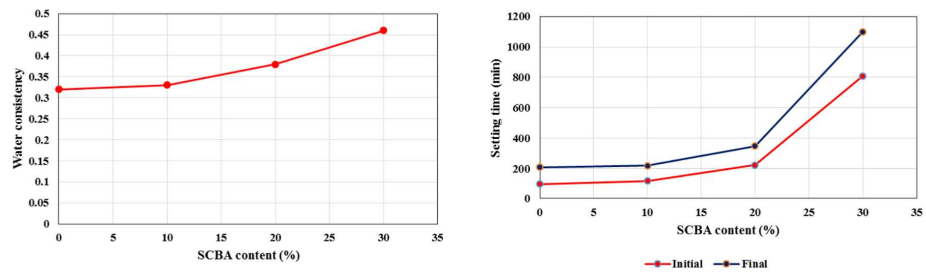
TABLE 2.1: Effect of SCBA on the workability

Authors	SCBA(%)	Workability
Lee et al. [29]	0, 10, 20, and 30	The slump containing SCBA falls between 200 to 300 mm for slump and from 550 to 700 mm for slump flow.
Praveenkumar et al. [59]	0, 5, 10, 15, 20, 25, and 30	Flow value of SCBA blended cement mortars got reduced with an increment of SCBA content.
Kazmi et al. [44]	0, 10, 20, 30, and 40	The flow of mortar decreases with increasing value of SCBA proportion.
Khalil et al. [43]	0, 5, 10, 15, 20, and 25	The slump got increases when SCBA content increased.

Indian Standard IS 4031. The SCBA contributed to this decrease, with a potential explanation lying in the reduction of magnesium and calcium oxides. Bahurudeen and Santhanam [4] also observed a similar trend in soundness.

Due to the hygroscopic nature of bagasse ashes, a higher water requirement is observed to maintain normal consistency as the cement replaced with SCBA increase [6]. Figure 2.3a illustrates an increase in paste consistency with the replacement of OPC by SCBA. For example, consistency rose from 24% to 49% when 40% of the binder was replaced with SCBA [44]. Replacement levels exceeding 10% showed a consistent increase in consistency compared to control samples [60]. Sieving through a 300 μm sieve produced a noticeable variation in consistency for both raw and processed SCBA, with an approximately 16% difference noted in both cases [36].

The inclusion of SCBA slightly delays the setting time, evident in the increment of setting times when OPC is substituted with SCBA. The higher SSA of bagasse ash, leading to increased water adsorption, could contribute to the prolonged setting times [5, 44]. As depicted in Figure 2.3b, both initial and final setting times show a similar trend, increasing with up to 20% substitution of SCBA, but sharply escalating with higher levels of SCBA substitution [5]. While SCBA possesses a higher SSA than cement, enhancing uniformity, the resulting cement paste experiences slightly longer setting times contrasted to the control cement.



(a) (b)

Fig. 2.3: 2.3a Water consistency [5]; 2.3b Initial and final setting time [5]

2.4 Effect of Sugarcane Bagasse Ash on Mechanical Properties

The optimal production of finely ground SCBA, with improved compressive strength, SSA, and enhanced pozzolanic activity, is achieved through vibratory grinding for 120 to 240 minutes [61]. This results in a mortar with a higher packing density that fills voids in the structure of concrete. Additionally, the hydration of silica in an alkaline environment and the pozzolanic reaction between calcium hydroxide and silica contribute to improved compressive strength [5]. The high SSA of SCBA, as reported by Ganesan et al. [6], accounts for the high early strength of up to 20%. Figure 2.4 indicates that the compressive strength of the reference concrete is lesser than 10% SCBA concrete, with a rapid decrease seen at 20% to 30% replacement levels. Chusilpe et al. [37] found that 20% SCBA of the binder has an optimum compressive strength. Adding consecutive amounts of 10%, 20%, and 30% of SCBA improved strength by 104%, 110%, and 107% at 28 days and by 106%, 113%, and 108% at 90 days. The influence of SCBA on compressive strength is detailed in Table 2.2.

Conversely, Rukzon et al. [62] found that concretes replacing SCBA with 30% exhibited high-strength performance, with 28-day compressive strengths ranging between 65.60 and 68.60 MPa, comparing reference concrete by 102% to 106%. Sieved SCBA through a 300 µm sieve displayed more strength compared to control and blended specimens made of RHA curing at 28 and 56 days [63]. Curing with heat also proved to enhance the properties of concrete containing 15% SCBA [64]. In a review by Kolawole et al. [65], the replacement of SCBA enhanced the strength of the system by 80% to 160%, compared with the control concrete without SCBA.

Conversely, with longer curing ages, the ideal replacement level shifts. The pozzolanic processes that occur in the concrete and the production of secondary C - S - H gel assist in explaining this occurrence [66]. A silica-rich SCBA initiates a calcium hydroxide hydration process that results in the formation of secondary C-S-H gel [51]. The development of ettringite needles in the SCBA-replaced concretes can be another explanation for the increase in compressive strength. Implosion, the bursting of uni-

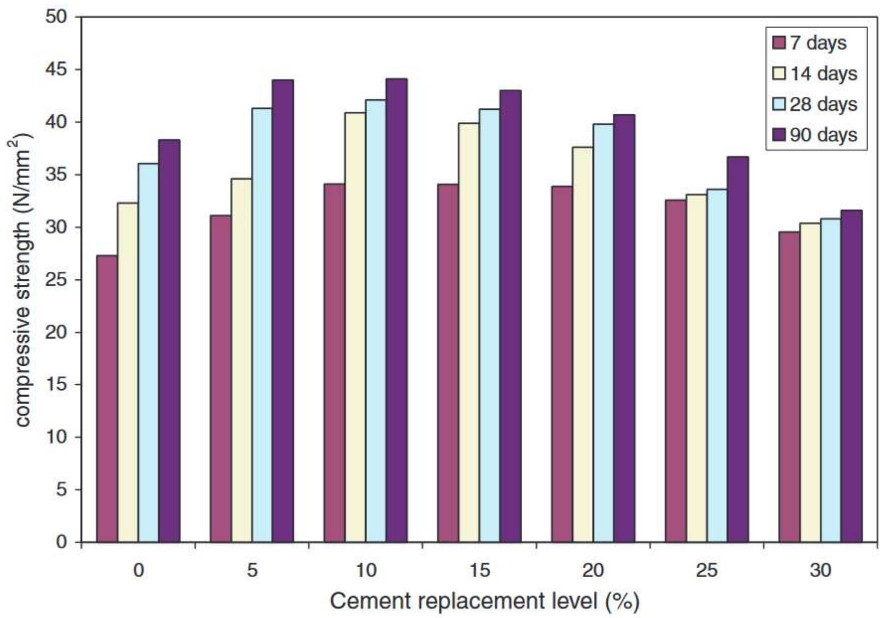


Fig. 2.4: Compressive strength of SCBA replaced concrete [6]

TABLE 2.2: Effect on the compressive strength

Authors	SCBA (%)	Compressive strength
Le et al. [29]	0, 10, 20, and 30	Containing SCBA increased gradually with the SCBA.
Montakarnti wong et al. [49]	0, 20, 30, and 40	Concrete with 20% SCBA replacement shows a higher compressive strength.
Zareei et al. [67]	0, 5, 10, 15, 20, and 25	15%, 20%, and 25% of SCBA replacement shows the compressive strength was decreased by 8%, 24%, and 35%.
Rukzon and Chindaprasirt [62]	0, 10, 20, and 30	10% SCBA replacement of SCBA with cement has a higher compressive strength.
Joshaghani and Moeini [26]	0, 10, 15, 20, 25, and 30	It has been shown that SCBA and nanosilica are beneficial in terms of mechanical strength. However, because of SCBA's moderate reactivity, using it in excess has a negative impact on the strength of specimens.

form spherical bubbles, and the production of large irregular bubbles, which result in a reduction in mechanical characteristics, can all be used to explain why compressive strength decreases with higher SCBA.

The relationship between Ultrasonic Pulse Velocity (UPV) and strength is evident, with higher UPV values indicating greater compressive strength and vice versa [68]. A high UPV signifies a denser material, while a low value indicates a reduction in the dense cementitious matrix. The increase in porosity due to higher amounts of ash has tense to a reduce UPV, aligning with the trend of compressive strength [55]. Similar results were noted by Zareei et al. [67], who found that specimens with 10% ash had higher UPV than control concrete at 180 days. The insertion of SCBA, being lighter than sand, contributes to lower UPV values, as denser media allow ultrasonic waves to travel in a short time [67]. Conversely, a porous material reduces waves speed [69]. Khawja et al. observed a reduction in UPV until 20% integration of SCBA, but a sudden rise above 20% might be linked to foam bubble collapse at higher SCBA rates.

Table 2.3 outlines the effect of SCBA on tensile strength. Srinivasan et al. [7] experimented with the replacement of cement with bagasse ash on flexural strength, finding that an increase in SCBA content led to a decrease in flexural strength after 7 days, with a slight increase at 28 days as shown in Fig. 2.5. Modani et al. [14] noted a reduction in the tensile strength with 10% to 40% SCBA, consistent with Ganesan et al.'s [6] findings, where split tensile strength increased up to 20% before declining. Similar trends were reported by Singh et al. [70] and Praveenkumar et al. [59]. The patterns of tensile strength mirrored those of compressive strength in response to SCBA replacements [60]. In summary, while SCBA significantly increased compressive strength up to a 20% replacement level, its impact on tensile and flexural strength was relatively minor.

TABLE 2.3: Effect on the tensile strength

Authors	SCBA (%)	Impact on the tensile strength
Zareei et al. [67]	0, 5, 10, 15, 20, and 25	Tensile strength decreased as the SCBA concentration in concrete mixtures increased, but not in mixtures containing 5% SCBA where it remained constant.
Jagadesh et al. [41]	0, 5, 10, 15, 20, 25, and 30	It was determined that the flexural strength was equal or lower than the control concrete.
Joshaghani and Moeini [26]	0, 10, 15, 20, 25, and 30	In comparison to other mixtures, 10% SCBA is used as a replacement of cement has a higher flexural strength in concrete.
Klathae et al. [43]	0, 10, 15, and 20	The concrete containing SCBA may have a greater split tensile strength due to its later age and long curing times.

2.5 Durability Properties

The permeability of concrete to water penetration is a crucial criterion for assessing its durability, with connected pores being a primary factor in permeability. Proper cement quantity, water-to-cement ratio, and techniques for curing are essential to reduce permeability in concrete [71–73]. Due to the hygroscopic nature of bagasse ash, Ganeasan et al. [6] seen an improvement in water absorption percentage with a rise in SCBA concentration after 28 days of curing. Rukzon et al. [62] noted a decrease in the water absorption for 10% SCBA at 7, 28, and 90 days of curing, outperforming reference concrete. However, concrete with 20% SCBA showed higher water absorption rates. The same trends were observed in concrete porosity. Ground bagasse ash, replacing 20% to 35% of the binder's weight, can exceed the permeability resistance of concrete with recycled aggregate. The dilution effect with high volumes of ground SCBA (up to 50%) significantly impacts both compressive strength and water permeability of concrete [34].

Concrete with 25% SCBA exhibited a remarkable 44% and 74% reduction in average penetration depth after 28 and 56 days of curing, attributed to the combination of the pozzolanic reaction and fine particles packing [60]. Fig. 2.6 depicts the colorimetric test for the penetration of chloride ion in concrete following 22 aging cycles of both wetting and drying with a NaCl. The technique identifies the existence of free chloride ions, which may indicate a greater sensitivity to reinforcing corrosion. [8]. The study utilized three replacement contents (0%, 30%, and 50%) of Sugarcane Bagasse Ash Sand (SBAS) as a substitute for river sand. The substitution of SBAS significantly impacted the results, with higher substitution levels correlating with lower chloride penetration. The decrease in chloride penetration may be attributed to the chemical effects of SBAS.

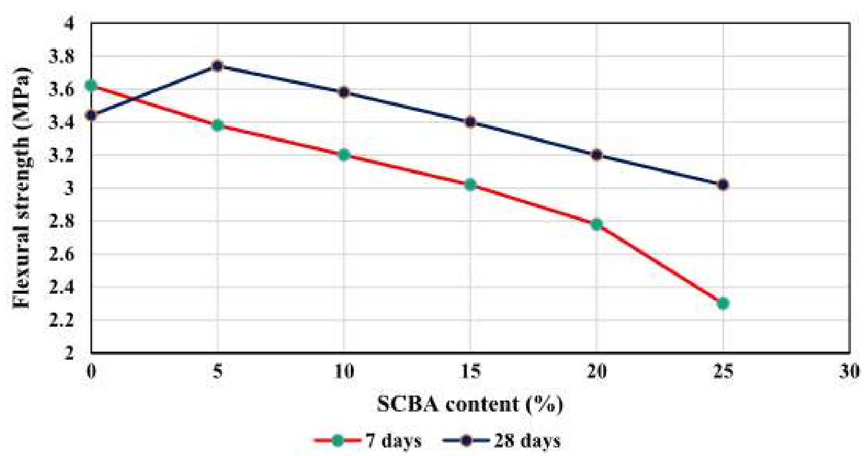
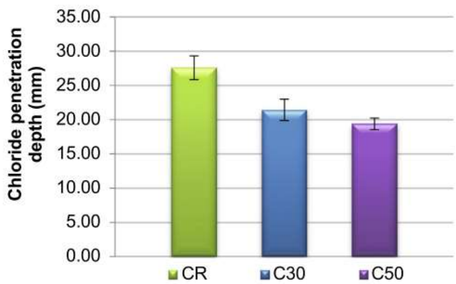
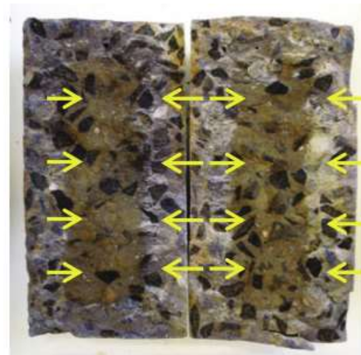


Fig. 2.5: Flexural strength of SCBA blended concretes [7]



(a)



(b)

Fig. 2.6: 2.6a Chloride penetration depth value [8] 2.6b Colorimetric treatment applied to samples [8]

The RCPT was employed to measure the passing total charge, revealing a significant decrease in diffusion from the test of chloride diffusion as SCBA replacement increased up to 25%, followed by a minor increase at 30%. The decline in charges passed may be attributed to pozzolanic effects, and the subsequent minor increase could be associated with the diluting effect [6]. Concrete permeability directly influences chloride penetration, with an observed decrease in overall charge passed as SCBA replacement levels increase [60]. Moreover, processed SCBA-blended specimens outperformed concrete mixed with RHA across all curing durations [63]. The removal of interconnecting pores in the system, resulting in a dense cement matrix resistant to chloride ion ingress, explains the improvement in chloride penetration resistance [60]. The diffusion of chloride ions within the ternary concretes was reduced by the addition of 10% and 20% untreated SCBA, likely due to the pozzolanic reaction of SCBA altering the cementitious matrix [74]. The reactance of SCBA and consequent pore refinement resulted in a significant reduction in the total charge passed. SCBA-blended concrete demonstrates higher resistance to permeability, water absorption, and improved resistance to chloride penetration. Table 2.4 summarizes the effect of SCBA on the durability characteristics of concrete.

2.6 Summary of the Previous Studies

As described in the current review, processing strategies serve an important role in improving the characteristics of bagasse ash. To lower the fraction of carbon-rich substances that are fibrous and raise the SSA of SCBA, methods such as screening, crushing, combustion, and chemical processing are used. These processing techniques contribute to higher pozzolanicity. The choice of processing techniques and conditions depends on industrial demand and the desired level of reactivity. It is essential to balance these factors while considering the environmental impact of processing. Grinding

TABLE 2.4: Impact of SCBA on the durability properties

Authors	SCBA (%)	Impact on the durability
Rukzon et al. [62]	0, 10, 20, and 30	Cement substitution of 10% SCBA absorbs less water.
Joshaghani et al. [?]	0, 10, 15, 20, 25, and 30	The addition of SCBA enhances the performance of mortars during transportation.
Arnas-Piedrahita et al. [35]	0, 5, 10, 15, 20, 25, and 30	The addition of SCBA concentration up to 25% of SCBA, the SCBA blended concrete specimens constantly decrease.
Bahurudeen et al. [4]	0, 5, 10, 15, 20, and 25	In comparison to control concrete, concrete that used 5% SCBA as a cement substitution exhibited less permeability.
Lee et al. [29]	0, 10, 20, and 30	The absorption capacity of pozzolanic containing concrete gradually decreased with the curing ages.
Garrett et al. [27]	0, 10, 20, and 30	Increasing water absorption was observed with the increasing SCBA.
Mahima et al. [75]	0, 5, 10, 15, 20, and 25	The concrete's permeability demonstrated a significant reduction with an increase in SCBA substitution, highlighting the superior pozzolanic performance of SCBA.

and burning, for example, consume more energy compared to sieving. Sieving, with a simple 300 µm operation, can achieve the required reactivity cost-effectively compared to more energy-intensive methods like grinding and calcination. Therefore, optimizing processing conditions is crucial.

Understanding the accessibility of SCBA to existing cement plants is necessary. SCBA requires less transportation to cement plants than conventional materials like fly ash and slag. This accessibility study helps assess the logistic advantages of SCBA utilization. Increased industry acceptance of SCBA is vital, considering its economic and energy-efficient nature for replacing cement with locally available materials. This might open the path for greater SCBA uses in the construction industry. Controlling quality at the point of production is critical for the cement and ready-made concrete sectors to embrace SCBA. While the assessment highlighted SCBA's promise as a sustainable cement alternative, further research is required before it can be widely used in the field.

CHAPTER 3

METHODOLOGY AND EXPERIMENTAL STUDY

3.1 Methodology

The investigation's findings revealed compelling evidence regarding the feasibility of producing SCBA in Sri Lanka, with its potential to serve as a valuable pozzolan and a potential replacement for conventional cement as the primary binding agent in concrete production. The methodological process has been shown in Fig. 3.1.

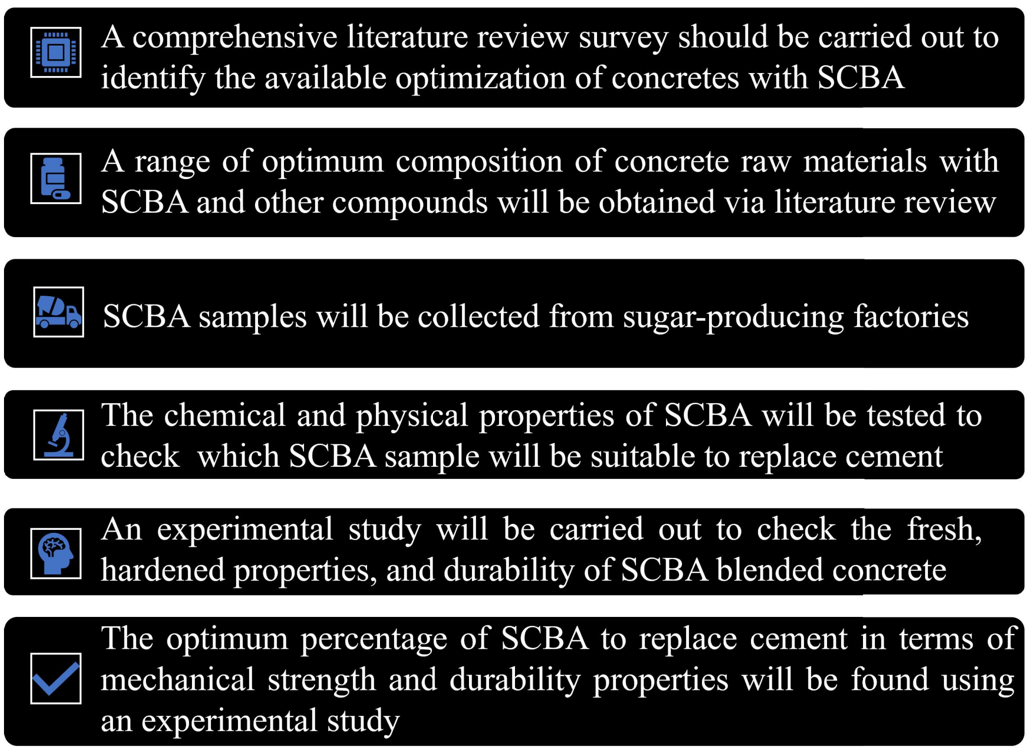


Fig. 3.1: Methodology

3.2 Materials

In this present experiment, the properties of hardened concrete samples were examined when cement was partially replaced by SCBA at various ratios. The materials employed in this study include:

3.2.1 Cement

In this experiment, OPC that conformed with SLS 107: 2015, 42.5 N, was utilized. The chemical composition and physical characteristics of OPC were evaluated by referring to the supplier's certificate, and the relevant details are presented in Table 4.2.

3.2.2 Sugarcane Bagasse Ash

The SCBA was acquired from Etimale Plantation Ltd. (Pvt) in Monaragala District, Sri Lanka. This plantation utilizes solid biomass bagasse for steam production in a boiler during sugar processing, thereby generating electrical power. The residual ash resulting from burning bagasse, a solid biomass fuel, at temperatures varying from 700 °C to 800 °C in a combustion chamber is collected from the dump site. SCBA may be obtained from two different process areas. Heavy SCBA, also known as bottom ash, is recovered from the boiler that incinerates sugarcane bagasse, as depicted in Fig. 3.2a. Furthermore, before the discharge of exhaust gas into the atmosphere, finer dust fragments are collected in the electrostatic precipitator, creating top ash, becoming light, as shown in Fig. 3.2b. To eliminate moisture, the bagasse ash underwent oven-drying at 105 °C for 24 hours. The collected top bagasse ash comprises both fine and coarse unburned particles. Subsequently, the dried ash was sieved according to BS 812 Part 103.1: 1985, using 150 µm sieve to eliminate unburned particles and achieve a particle size between 0 and 150 µm. The coarser sample of SCBA was removed from the sieve, as illustrated in Fig. 3.3a, while the oven-dried sample sieved through 150 µm is shown in Fig. 3.3b.

3.2.3 Coarse Aggregate

As the coarse aggregate, locally produced granite material with fineness modulus and specific gravity of 2.1 and 2.73 was used, which was retained on a 5 mm sieve after passing through a 20 mm sieve.

3.2.4 Fine Aggregate

River sand was employed, graded to pass through a 5 mm sieve, exhibiting a fineness modulus of 5.49 and a specific gravity of 2.61.

3.2.5 Water

For this experiment, tap water was used.

(a) Bottom ash-collected from the bottom of the boiler

(b) Top ash - collected from electrostatic separators

Fig. 3.2: SCBA sample collection

(a) Top ash sample of SCBA

(b) SCBA sieved through 150 µm

Fig. 3.3: SCBA collected sample and treated sample

3.2.6 Admixture

The deliberate exclusion of superplasticizers in this experiment was aimed at assessing the workability of concrete when subjected to SCBA.

3.3 Concrete Mix Design

In this research, a total of 90 cube samples, 45 cylindrical samples, and 15 rectangular beams were cast for various tests. The specific allocation of samples for each test is provided in Table 3.1. The control mixture, consisting of 100% OPC, was denoted as SB0/Control to establish a reference point. Four batches were prepared to explore the potential of replacing cement with treated SCBA, with each batch incorporating 5%, 10%, 15%, and 20% SCBA. The concrete was designed as stated to the BRE mix design approach, involving comprehensive calculations, tables, and diagrams. The design process was guided by the target mean strength of 25 MPa at 28 days. The mix ratios for 1 cubic metre of concrete in Saturated Surface Dry (SSD) condition are outlined in Table 3.2. The moisture correction was calculated for every mix and adjusted for the water and cement ratio. There were not any considerable variations in the water and cement ratio. Mixing was carried out according to the guidelines of BS 1881: Part 125: 1986, using a laboratory drum mixer with a capacity of 260 L.

The mixing sequence involved adding half of the coarse aggregates to the drum mixer, as shown in Fig. 3.4a, then fine aggregates, and then the other half of the coarse aggregates. After 30 seconds of drum mixing, half of the water was added within 15 seconds. The entire batch was mixed for 2.5 minutes, and then the mixer's contents were covered for a 10-minute break. OPC and SCBA mix was then introduced to the wet mix, followed by a second 30-second mix. Over the next 30 seconds, the remaining water was added, and mixing continued for an additional 2.5 minutes. The concrete was manually mixed thoroughly after the completion of the mixing process to ensure homogeneity before being poured onto a clean, non-absorbent surface for sampling. The specimens for the investigation were divided into five batches and included 90 150 mm cubes, 15 150 mm diameter cylinders with a height of 300 mm, 30 100 mm diameter cylinders with a height of 200 mm, and 15 150 mm x 150 mm x 750 mm rectangular beam prisms. After 24 hours, the test specimens were demolded and cured in water, as shown in Fig. 3.4b, until the testing date.

TABLE 3.1: No. of sample used in each testing for each mix

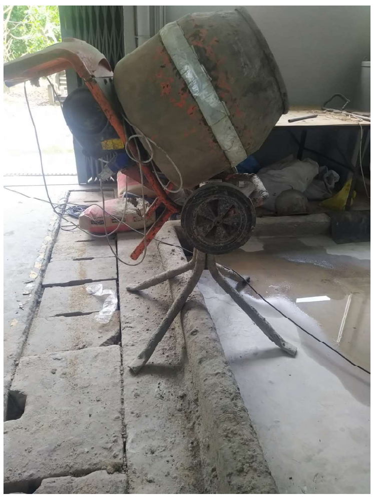
Tests	Mould	No. of samples		
		7 Days	28 Days	90 Days
Compressive strength	Cube	3	3	3
Flexural strength	Beam		3	
Split tensile strength	Cylinder		3	
Water absorption	Cube	3	3	3
Rapid chloride penetration	Cylinder		3	
Bond strength	Cylinder		3	
Ultrasonic pulse velocity	Cube	3	3	3

3.4 Chemical and Physical Examination of Sugarcane Bagasse Ash

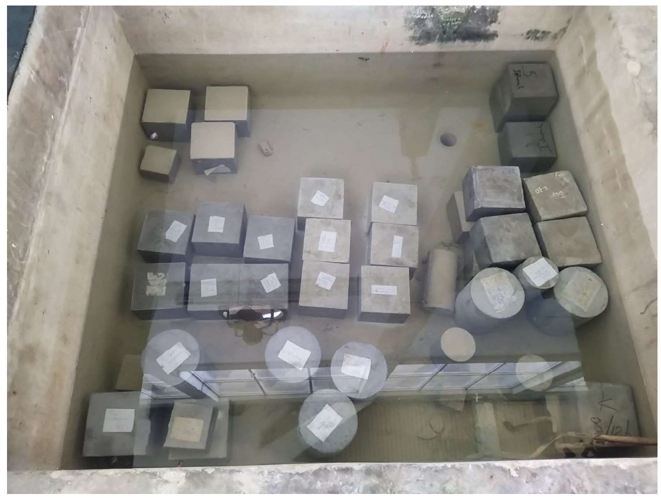
Ethimale Plantation (Pvt) Ltd stands as a leading sugar production establishment in Sri Lanka. To fulfill the characterization objectives, two SCBA samples were obtained, encompassing top ash and bottom ash, from each selected site, allowing for a comprehensive comparative investigation. It is essential to note that all these samples were generated on the same day as sugarcane crushing. Scanning Electron Microscopy (SEM) , particle size distribution, X-Ray Diffraction (XRD) , spectroscopy, Differential Scanning Calorimetry-Thermogravimetric Analysis (DSC-TGA) and X-Ray

TABLE 3.2: Mixture proportion for SCBA concrete

Mix Design	SCBA %	W/C	Quantities (kgm^{-3})				
			Water	Cement	SCBA	Fine	Coarse
Control / SB0	0	0.58	210.10	353.45	0.00	789.49	1046.96
SB5	5	0.58	210.10	335.78	17.67	789.49	1046.96
SB10	10	0.58	210.10	318.10	35.34	789.49	1046.96
SB15	15	0.58	210.10	300.43	53.02	789.49	1046.96
SB20	20	0.58	210.10	282.76	70.69	789.49	1046.96



(a) Concrete drum mixer



(b) Curing tank

Fig. 3.4: Concrete mixer and the curing tank

Fluorescence (XRF) were performed after sample preparation.

3.4.1 Scanning Electron Microscopy

The top and bottom ash samples underwent a drying process at 105 °C for 24 hours in an oven to eliminate moisture and get a stable weight. For SEM analysis of bottom ash samples, larger unburned particles were excluded using a 2.36 mm standard sieve. In contrast, top ash samples, naturally containing somewhat finer particles, were filtered using a 150 µm standard sieve. The examination of two SCBA samples and the assessment of grain morphology were conducted using a "Hitachi SU6600" SEM. Photos were captured at an acceleration voltage of 10 kV and an emission current of 2.3 A, focusing on secondary electron signals.

3.4.2 Distribution of Particle Size

The particle size distribution of SCBA was examined using the Fritsch-Analysette 22 Nano Tec particle size analyzer, vary with of 0.01 µm - 2100 µm. To assess the distribution of the original SCBA from industries, top ash samples underwent a 24-hour drying process in an oven at 105 °C. The samples weren't ground down at all. The test was conducted four times on each top ash sample, and the average results were calculated.

3.4.3 X-Ray Diffraction

The top ash from the Ethimale plantation was utilized for the XRD study. SCBA sample was dried for 24 hours at 105 °C to eliminate moisture. During that time, the sample's weight stayed constant. Crushing was then used to obtain powder samples with the finer particles. The XRD data were collected by a "Bruker D8Focus" diffractometer (Cu K radiation).

3.4.4 X-Ray Fluorescence Spectroscopy

XRF characterization was used to determine the composition of chemicals of top ash samples. Twin tapes were used to put appropriate samples from each source in the sampling stage. The analysis was performed at six separate places and an average was taken. A "HORIBA Scientific XGT-5200 X-Ray Analytical Microscope" was used for characterization, featuring a 100 µm XTG diameter, a 50 kV X-ray tube voltage.

3.4.5 Differential Scanning Calorimetry-Thermogravimetric Analysis

The Differential Scanning Calorimetry-Thermogravimetric Analysis (DSC-TGA) was performed using the "SDT Q600 V20.9 Build 20" thermal gravimetric instrument. The sample, weighing between 5 mg and 10 mg, was analyzed under a nitrogen (N_2) atmosphere at a heating rate of 19.8 °C/min.

3.5 Mechanical Characteristics of Bagasse Ash Blended Cement

The evaluation of mechanical properties in blended cement involves tests such as consistency and setting time. The consistency test measures the quantity of water need to make a cement paste with standard consistency, while the setting time test assesses the duration needed for the cement paste to sufficiently harden and conform to the shape of the mold in which it is cast.

3.5.1 Consistency

The consistency test for cement is a crucial laboratory procedure that determines the amount of water needed to achieve a standard consistency in a cement paste. The cement must be of a specified consistency for the Vicat plunger to penetrate to a point that is 5 mm to 7 mm above the bottom of the Vicat mold (Fig. 3.5a). The water consistency of SCBA-mixed cement was tested using the SLS Part 2-2002 requirements.

3.5.2 Setting Time

The initial and final setting time test is a crucial laboratory experiment that determines how long cement paste or concrete needs to harden up to take the shape of the mold into which it is cast. The initial setting time marks the point at which the paste starts to lose its plasticity, while the final setting time is reached when the paste has completely lost its plasticity and has gained adequate hardness to withstand a defined pressure. Following the instructions in SLS Part 2-2002, the pastes' initial and final setting times were calculated once they had reached their usual consistency. The Vicat plunger to measure the setting time is shown in 3.5b. The test is important in figuring out how long it will take the cement paste to reach its initial and ultimate setting times, which are needed for several operations such as transporting, placing, and compacting cement concrete. Additionally, an initial setting time is necessary to postpone the hydration or stiffening process.

3.6 Mechanical Properties of Bagasse Ash Blended Concrete

A comprehensive set of mechanical tests, encompassing slump, compressive strength, tensile test, UPV test, and bond strength, was conducted on the samples and the number of samples was given in Table 3.1. The aim was to scrutinize the mechanical behavior of the OPC-SCBA mixture concerning the hardened characteristics of concrete. The outcomes were meticulously analyzed and juxtaposed with those of a control concrete sample. The numerical data was graphically presented in the form of bar charts and aligned with the tabulated average results.

3.6.1 Slump Test

The slump test serves as a crucial assessment of the consistency and workability of freshly mixed concrete before it undergoes the hardening process. In this test, a sample of freshly mixed concrete is placed within a metal cone mold, and the measurement involves observing the settlement of the concrete after the removal of the mold. The slump is then quantified as the height, to which the concrete settles following the removal of the slump cone. The procedure for determining the slump, especially for cohesive concrete with medium to high workability, adhered to the guidelines outlined in BS 1881: Part 102: 1983. The test was conducted by this standard procedure.

(a) Vicat plunger to determine consistency (b) Vicat plunger to determine setting time

Fig. 3.5: Vicat plunger

3.6.2 Compressive Strength Test

The compressive strength test was performed on cubic block samples measuring 150 mm x 150 mm x 150 mm, specifically at intervals of 7, 28, and 90 days, followed by the guidelines outlined in BS 1881: Part 116: 1983. Ensuring adherence to the specified standards, Fig. 3.6 shows the cubic samples were accurately positioned onto the testing machine's plate designed for compressive strength evaluation. This arrangement ensured the uniform distribution of loads across two opposing surfaces of each cube. Uniform incremental loading was applied to the surface of the concrete cube. As the cube approached its failure point, deliberate reduction in the loading rate was implemented. Following this, the specimen was extracted and scrutinized for any atypical modes of failure. The load at the point of failure was then measured.

3.6.3 Split Tensile Strength Test

Tensile strength was determined through a split tensile test using a cylindrical sample measuring 150 mm x 300 mm cured in water for 28 days following the guidelines in BS 1881: Part 117: 1983. Fig. 3.7 depicts the split tensile testing apparatus and the split cylinder sample. The load was incrementally raised until the specimen reached its point of fracture, and the breaking load with the maximum value was taken into consideration.

Fig. 3.6: Compressive Strength Test

3.6.4 Flexural Strength Test

The assessment of flexural strength was carried out on beams measuring 150 mm x 150 mm x 750 mm, by the specifications outlined in BS 1881: Part 118: 1983. The flexural strength of the beams was assessed through a two-point loading test after a 28-day curing period. The beams were carefully positioned in the flexural strength apparatus, as depicted in Fig. 3.8a, ensuring the longitudinal axis of the sample was perpendicular to the rollers. A continuous and controlled loading process was initiated, marked by a gradual application of force until the cylinder reached its failure point. The breaking load with the highest value was considered for analysis.

3.6.5 Ultrasonic Pulse Velocity Test

The Ultrasonic Pulse Velocity (UPV) examination was conducted to examine the quality of concrete by transmitting an ultrasonic wave through a test cube. This test tries

(a) Split tensile testing machine

(b) Split sample

Fig. 3.7: Split Tensile Strength Test

to determine the material's porosity and find any potential cracks. The examination was done on concrete cubes that underwent curing of 7, 28, and 90 days, by BS 1881:

(a) Flexural strength testing machine

(b) Fractured sample

Fig. 3.8: Flexural Strength Test

Part 203: 1986 requirements. Before conducting the test, samples were extracted from the curing tank, and any surplus water on the surface was carefully wiped away. Fig. 3.9 illustrates a pair of transducers that were attached and properly calibrated for the testing procedure using a UPV device. This procedure's main objective was to evaluate the specimen's integrity and internal characteristics by analyzing the transmission of ultrasonic pulses.

3.6.6 Bond Strength

For the pull-out test, a 12 mm diameter bar was inserted in the centre of a concrete cylinder measuring 200 mm in height and 100 mm in diameter, as shown in Fig. 3.10a. The bonding strength was assessed using the pull-out force. The test was conducted using universal testing equipment, in line with ASTM C 234–91a (ASTM, 1999). The bond strength was determined using the corresponding Eq. 3.1:

$$F_{\text{bd}} = \frac{P_{\text{max}}}{\pi \Phi l_{\text{d}}} \tag{3.1}$$

where F_{bd} is the bond strength in (MPa), P_{max} is the maximum load (N), l_d is the embedded length of the bar (mm), and Φ is the diameter of the bar (mm).

Fig. 3.9: UPV testing apparatus

(a) Cylinders with 12 diameter bar (b) Pull out test setup

Fig. 3.10: Bond strength test

3.7 Durability of Concrete

3.7.1 Water Absorption

The experiment was done on cubes with the size of 150 mm × 150 mm × 150 mm. These cubes underwent 28 days and 90 days of water curing. Fig. 3.11a shows cores with a diameter of 50 mm were drilled from the cubes and subsequently subjected to a 72-hour drying process in an oven, followed by the guidelines specified in BS 1881: Part 122: 1983. After drying, the specimens were taken out and put in a sealed, dry container to cool. Following that, every single core was checked for weight and submerged for 30 minutes in a water tank, ensuring a water level of 25 mm above the top of the specimen, as illustrated in Fig. 3.11b. The cores were taken from the water tank after 30 minutes of immersion, dried with a towel, and reweighed. The percentage increase in mass caused by immersion, compared to the weight of the dry sample, was used to calculate the water absorption level for each specimen.

3.7.2 Rapid Chloride Permeability Test

According to ASTM C1202, RCPT gives a quick assessment of resistance against chloride ion penetration. New concrete materials were initially evaluated using this technique. However, this is currently employed in applications like acceptability testing and quality control. Cylindrical concrete specimens with a 100 mm diameter were

(a) Core drilling apparatus (b) Cores submerged in water

Fig. 3.11: Water absorption test

made. The side of the specimen was then coated with a rapid-setting coating using samples that were 50 mm thick (Fig. 3.12a). According to ASTM 1202, once the specimens are no longer sticky, they should be vacuum saturated using a vacuum desiccator (Fig. 3.12b) The concrete specimen with a 50mm thickness has a 60V potential differential as shown in Fig. 3.13a. One end is submerged in a NaOH (0.3N) solution, and the other end is submerged in a NaCl (3 %) solution for the concrete. The complete setup for the RCPT test is depicted in Fig. 3.13b. The current passing through the concrete sample is measured every 30 minutes while voltage is continually applied during 6 hours.

In this chapter, an in-depth exploration of the methodology and employed methods for conducting chemical tests on SCBA is presented. Additionally, the testing procedures applied to assess the mechanical and durability characteristics of concrete are thoroughly detailed. The experimental design involves replacing varying proportions of cement with SCBA, specifically at 5%, 10%, 15%, and 20%, along with a control group for comparison. The subsequent chapter will present the outcomes derived from the meticulous exploration outlined in this section. By examining the results, we aim to conclude the efficacy and implications of incorporating SCBA into concrete mixes at varying percentages. This sequential approach ensures a systematic and thorough investigation, contributing to a comprehensive understanding of the potential benefits and challenges related to the use of SCBA in concrete applications.

(a) Cylinders with coating (b) Vacum desiccator

Fig. 3.12: Pre setup for RCPT test

(a) Voltage supply to the RCPT test (b) Rapid chloride permeability test setup

Fig. 3.13: RCPT Test

CHAPTER 4

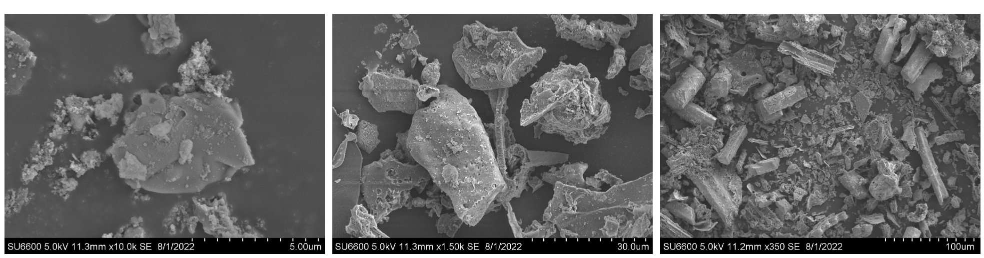
RESULTS

4.1 Chemical and Physical Examination of Sugar Cane Bagasse Ash

4.1.1 Scanning Electron Microscopy

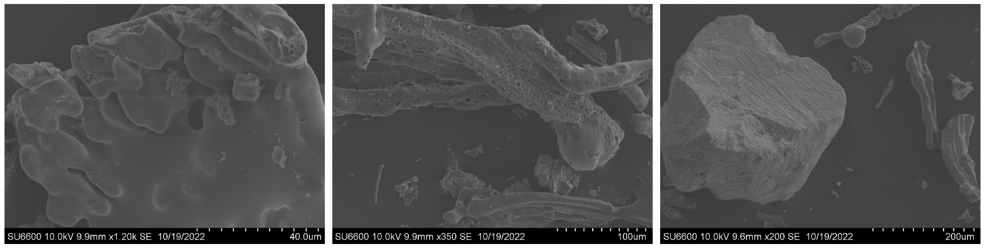
The SEM images of the top ash sample describe that the SCBA has elongated, prismatic, and tiny spherical particles, according to the SEM images shown in Fig. 4.1c with the scaled-down image of 100 µm. The prismatic particles are notable because they have sharp edges that imply the presence of crystalline minerals. The zoomed image at 30 µm, where burned substances with sharp edges are frequently seen as shown in Fig. 4.1b, further supports this result by demonstrating the existence of crystalline materials. Further details on the porous properties of SCBA samples are provided by scaled-down photos at 5 µm shown in Fig. 4.1a. These pictures demonstrate the porousness of the SCBA sample by showing the presence of pores with significant surface areas.

Fig. 4.2 shows SEM images of samples of bottom ash. According to Fig. 4.2c, it is possible to see big crystalline particles in the 200 µm range, which could mean that contamination happened when mud, sand, and soil particles were combined with SCBA. Fig. 4.2b depicts images at a scale of 100 µm that point out the existence of coarse, large, and porous substances. The shape of the particles might be considered highly irregular while the particle sizes vary widely. This might be because there is a lot of organic material that hasn't been burned present in the ash samples. At least some degree of crystallinity can be seen in photos taken at a 40 µm scale as shown in Fig. 4.2a. Typically, bottom ash samples showed a mixture of large foreign crystalline particles and coarse, porous particles. The bottom ash samples have poor pozzolanic characteristics, as evidenced by SEM pictures. Hence, the microstructures of the top ashes present positive characteristics for utilization as a pozzolanic substance in structural applications when compared to bottom ash samples.



(a) 5 µm (b) 30 µm (c) 100 µm

Fig. 4.1: Top ash samples (SEM images)



(a) 40 µm (b) 100 µm (c) 200 µm

Fig. 4.2: Bottom ash samples (SEM images)

4.1.2 Particle Size Distribution

The SCBA sample's microstructure is revealed to be primarily made up of small particles after being examined using a particle size analyzer and Fig. 4.3 illustrates the distribution of particle size of the SCBA sample. Table 4.1 reveals that the average particle size at 90% is 117.43 µm, signifying a notable presence of fine particles. This compound offers numerous advantages in augmenting the pozzolanic action of SCBA. The SCBA displays an average size distribution with a size of approximately 109.06 µm, ranging from the smallest to the biggest particles.

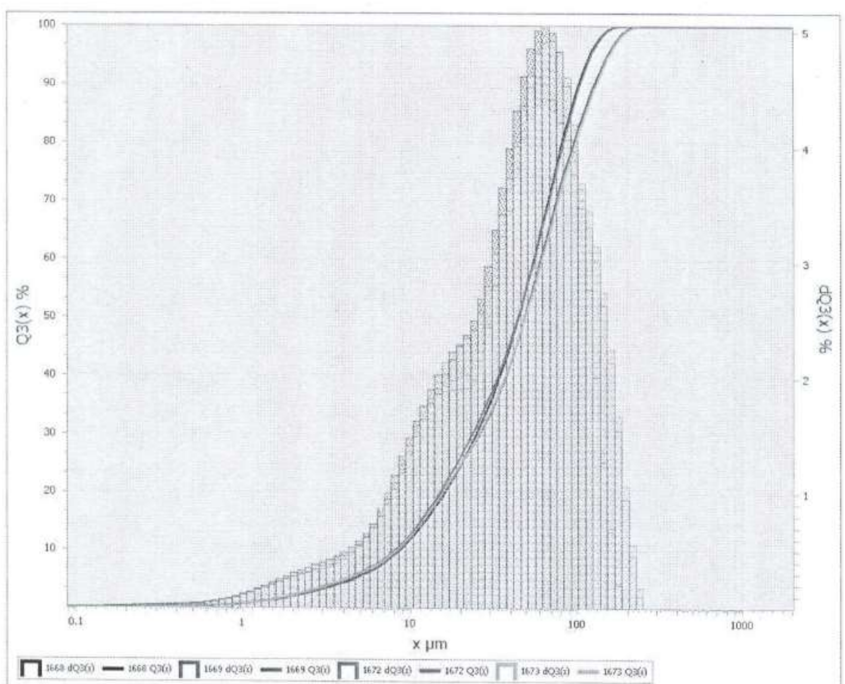


Fig. 4.3: Size distribution of SCBA particles

TABLE 4.1: Particle size distribution of SCBA

Sample	**10%**	**50%**	**90%**
SCBA (average µm)	8.36	46.72	117.43

4.1.3 X-Ray Diffraction

A qualitative X-ray diffraction (XRD) test was effectively employed to identify the crystalline mineralogical phases present in the SCBA sample. The result of plotting the representative diffraction pattern in the axis system is shown in Fig. 4.4. The labeled peak was used to identify and mark sharp peaks within a 2θ range of 20° – 70°. Iron oxide (Fe_2O_3), quartz (SiO_2), and cristobalite (SiO_2) all exhibit peaks in the ash sample's diffraction pattern. Various researchers have suggested that the existence of silica in the form of free quartz may be linked to multiple factors. These include contamination with sand and soil particles during harvesting of sugarcane, unregulated combustion, and silica absorption via the roots of sugarcane plants. [76, 77]. The sample's diffraction patterns reveal a small quantity of quartz as well as other strong peaks. There is a somewhat large hump that corresponds to amorphous materials in a 2° range between 26° and 55° [78, 79]. This shows that the crystalline characteristics that interfere with the pozzolanic capabilities of SCBA are at their lowest levels.

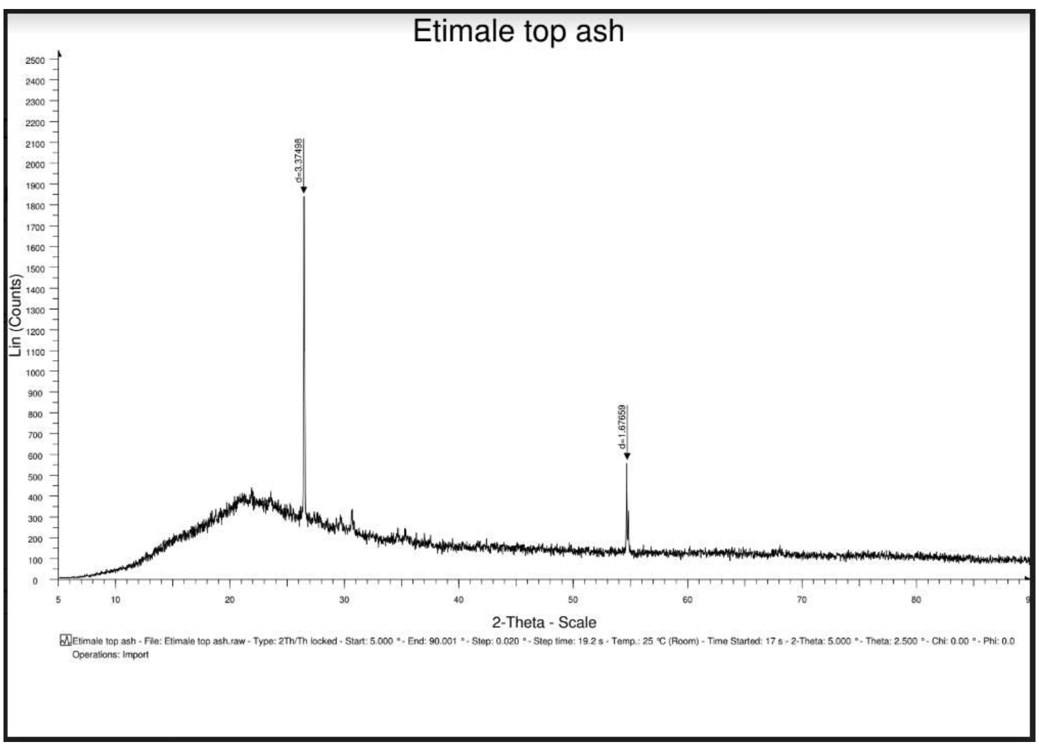


Fig. 4.4: XRD analysis of SCBA sample

4.1.4 X-Ray Fluorescence Spectroscopy

The outcomes of the chemical composition analysis are presented in Table 4.2, indicating the average derived from six independent measurements at six different locations within a sample. The values shown have been derived after correcting the XRF results for LOI. In SCBA samples, the cumulative weight percentage of Al_2O_3, SiO_2, and Fe_2O_3 is 64.87%, which is what gives pozzolanic qualities. Therefore, only class C of the ASTM C618 specification satisfies the requirements for the SCBA.

TABLE 4.2: Oxide composition of SCBA and Portland cement

w/w (%)	Fe_2O_3	Al_2O_3	SiO_2	P_2O_5	K_20	CaO	MnO	MgO	LOI
SCBA	1.9	0.56	62.41	2.08	7.14	4.25	0.42	1.4	19.61
OPC	4.1	4.76	21.9	0.1	1.15	65.45	0.16	0.2	0.98

4.1.5 Differential Scanning Calorimetry - Thermogravimetric Analysis

The thermal analysis of the top ash sample is shown in Fig. 4.5. The TGA characteristic is shown in the top curve, while the variations in the TGA curve's derivative and DSC are shown in the graph at the bottom of Fig. 4.5. The evaporation of moisture in the ash sample is the cause of the endothermic DSC peaks in the SCBA sample, which are localized at temperatures between 50 °C and 150 °C. Second endothermic peaks, again between 200 °C and 300 °C, are visible [80] in the ash sample and signify partial dihydroxylation of gibbsite. The variation of temperature between 200 °C and 950 °C is where the SCBA sample has lost the maximum weight, 19.11% of its starting weight. The thermal study was carried out in an inactive N_2 atmosphere, and therefore, the weight reduction observed may be attributed to the decomposition of various mineralogical phases and inert carbon components, rather than isolating carbon decomposition alone [38]. The exothermic peaks observed in ash samples between 600 and 650 °C are likely induced by the phase transition from P_{205} to P_{207}. Additionally, an endothermic peak associated with decomposition is observed above 1100 °C.

4.2 Mechanical Properties of Blended Cement

4.2.1 Consistency

The degree of wetness is defined as the consistency of a concrete mixture that determines whether it can be transported and finished without segregating or bleeding. As shown in Fig. 4.6, a rise in paste consistency was observed after OPC was replaced with SCBA. It could be according to SCBA's increased surface area, which allowed for greater water absorption than traditional cement. By including 20% SCBA, consistency increased from 33.75% to 66.25%.

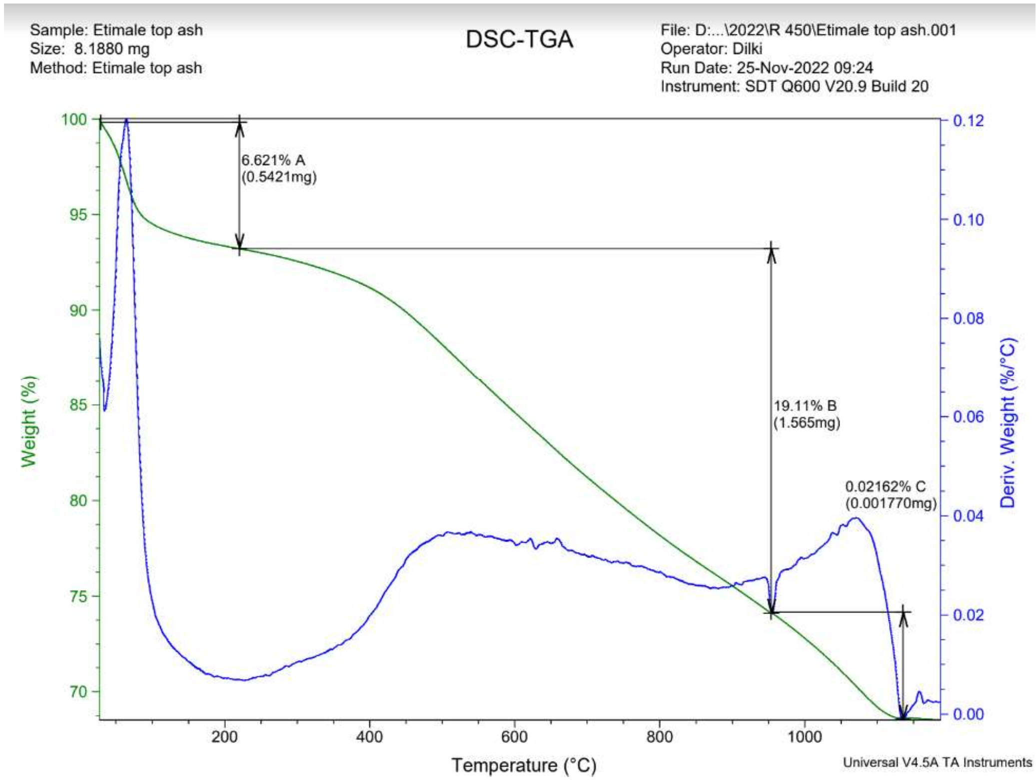


Fig. 4.5: DSC (below) and TGA (above) for SCBA sample

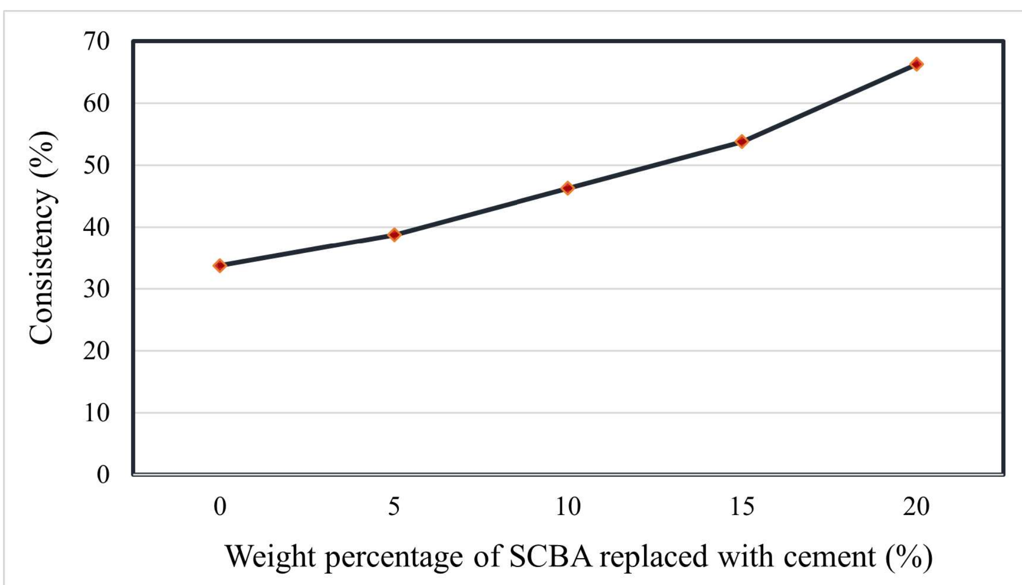


Fig. 4.6: Consistency of SCBA blended cement

4.2.2 Setting Time

The rate of strength development is intricately linked to the setting time, influencing the degree of hydration in concrete. Fig. 4.7 illustrates that increasing the percentage of SCBA replacement in cement leads to a notable rise in both initial and final setting times. Specifically, the initial setting time increases from 105 minutes for 0% SCBA replacement to 240 minutes for 20% SCBA replacement, while the final setting times for 0% and 20% SCBA are 390 minutes and 525 minutes, respectively. All these values remain within the permissible limits defined by SLS Part 2-2002. Longer setting times can be linked to reasons such as a higher ratio of water to cement, lower cement concentration, and the presence of SCBA in different coatings surrounding cement substances, which may impede hydration [81].

4.3 Mechanical Properties of Concrete

4.3.1 Slump Test

The influence of SCBA on the workability of concrete is depicted in Fig. 4.8. Throughout this test, the water-cement ratio was held constant to provide a clearer understanding of how ash affects concrete. The results indicate a reduction in slump values as the amount of ash increases in the concrete mixtures. However, it may be determined that mixes containing SCBA will require more water than control mixtures to reach the necessary workability. The amount of SCBA in the combination enhances this need.

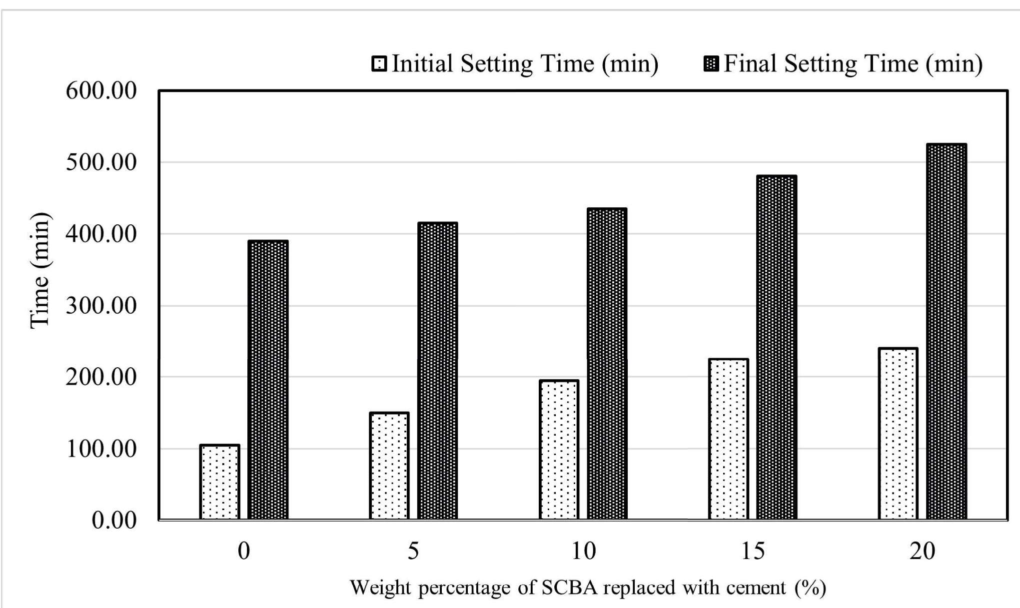


Fig. 4.7: Setting time of SCBA replaced cement

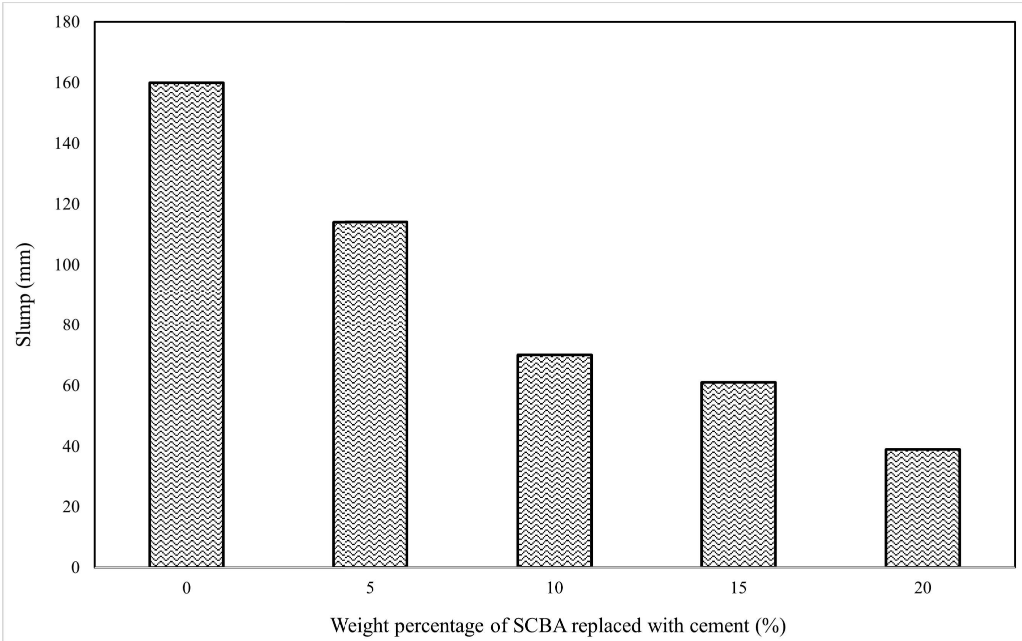


Fig. 4.8: Slump of SCBA replaced concrete

The larger SSA and the porous nature of bagasse ash particles are what causes this increase in water requirement [30].

4.3.2 Compressive Strength Test

Fig. 4.9 shows the compressive strength average values of concrete cubes containing SCBA at various concentrations and curing times. The concrete mixes blended with SCBA were compared with the control concrete, which included 100% OPC. The early strength of bagasse ash replaced concrete after 7 days was evaluated. The strength of the reference concrete was 24.70 MPa. With the addition of 5% and 10% SCBA, the compressive strength increased to 27.63 MPa and 25.93 MPa, respectively. The improvement in strength can be due to the microscopic particles of bagasse ash filling the air spaces or voids in the concrete structure, resulting in denser concrete and exhibiting a packing effect [82]. However, a decrease in strength was seen for 15% and 20% SCBA-replaced concrete, with strengths of 19.55 MPa and 15.87 MPa, respectively. Reduction of calcium oxide (CaO) contents, the delayed hydration response, and the low reactivity of silicon dioxide (SiO_2) could all be factored in the decline in strength [75].

Following the BRE mix design, the targeted compressive strength for concrete cubes is 25 MPa at 28 days. The control concrete achieved a compressive strength of 30.8 MPa after 28 days of curing, which increased to 33.03 MPa after 90 days. Interestingly, the strength containing until 15% SCBA was found to be higher com-

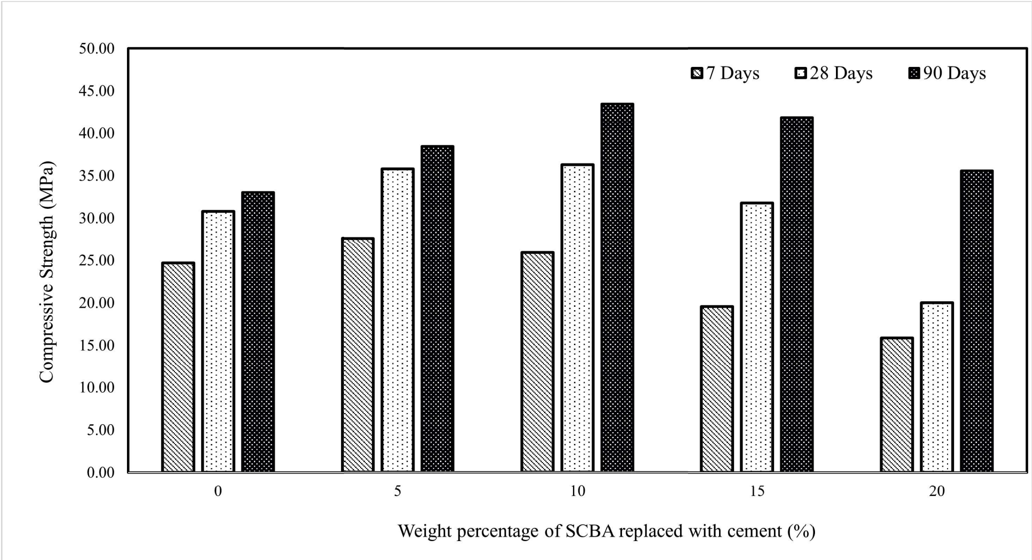


Fig. 4.9: Compressive strength results of SCBA replaced concrete

pared to the control concrete at 28 days. The strengths of concretes containing 5%, 10%, and 15% SCBA by weight of binder were 35.8, 36.3, and 31.7 MPa at 28 days, where 116%, 118%, and 103% of the control concrete, respectively. The increment of strength results from the pozzolanic activity that transforms calcium hydrate into C-S-H gel [83]. These values increased to 38.47, 43.5, and 41.87 MPa at 90 days or 125%, 141%, and 136% of the control concrete. Concrete with 20% SCBA has a lower compressive strength compared to control concrete at 28 days. With a compressive strength of 20.03 MPa, the concrete with the 20% SCBA exhibits a 65% reduction compared to the reference concrete. Implosion, the bursting of spherical bubbles with uniform size, and the irregular bubble formation can all be ascribed to this decrease in strength. These phenomena give an idea of the loss of mechanical properties in the concrete, explaining the reduction in strength with higher SCBA content.

In the meantime, the SCBA mix from 5% to 20% revealed several interesting characteristics, particularly during 90 days of curing. According to the results, there was an increasing pattern in strength relative to the curing time. At 90 days, nearly all of the SCBA blended concrete mix has greater compressive strengths than the control concrete. The compressive strength of concrete containing 20% SCBA has increased to 35.57 MPa at 90 days, marking a significant improvement from the 20.03 MPa strength observed at 28 days. This represents a remarkable 115% increase over the control concrete. The enhanced strength over the 90 days suggests progressive pozzolanic hydration of SCBA, showcasing its ability to contribute to strength development over time. The characteristic of low early strength followed by substantial later strength development aligns with typical pozzolan behavior. These results highlight the pozzolanic potential of SCBA, suggesting that a about 15% replacement of cement with SCBA can be recommended as a better choice, particularly with regard to compressive strength considerations.

4.3.3 Tensile Strength

According to Neville [84], it is beneficial to analyze the tensile strength to determine the load at which cracking will take place. The tensile stress in reinforced concrete members leads to the development and propagation of fractures. Traditional methods of measuring tensile strength can be challenging to apply due to difficulties in maintaining a purely axial load. Consequently, the split tensile strength and flexural strength tests are commonly employed to assess tensile behavior in concrete [85]. Fig. 4.10 shows the splitting tensile strength results of the SCBA blended concrete after 28 days of curing. As can be seen, the splitting tensile strength values have their highest value than the control concrete at 15% of SCBA, and then they start decreasing. The ongoing reaction of cement composites with high silica content, leading to the formation of additional C - S - H gel, has been suggested as a contributing factor to increased tensile strength [86]. Conversely, the decrease in strength in SCBA-replaced concrete may be attributed to its SSA, potentially causing increased porosity [62].

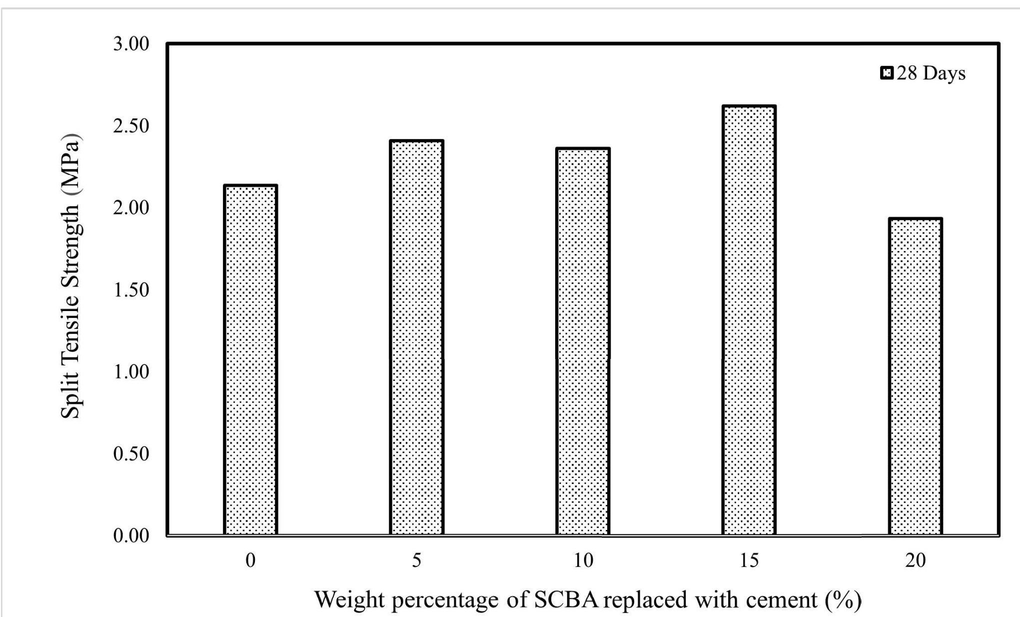


Fig. 4.10: Split tensile strength of SCBA blended concrete

4.3.4 Flexural Strength

In Fig. 4.11, the effect of bagasse ash on the flexural strength of concrete composites is depicted. Except for mixtures containing 20% SCBA, it is evident that the inclusion of SCBA enhances flexural strength beyond that of the control concrete. The high porosity content of SCBA might contribute to the observed drop in strength [62]. Notably, mixtures containing 5% SCBA had the highest value, followed by a decreasing trend. This suggests that 15% bagasse ash might be a suitable substitution while still meeting optimum flexural strength requirements, as it surpasses the strength of the control sample. Furthermore, it has been proposed that cement with a significant silica concentration continues to interact with lime, forming additional C-S-H gel and enhancing flexural strength [86].

4.3.5 Ultrasonic Pulse Velocity

It was proved that concrete with a greater UPV can be linked to a higher compressive strength, and vice versa, though not always in the same proportion [29]. In Fig. 4.12, the results for UPV with varying SCBA content are presented. According to the findings of this study, the velocity through the specimens began to decrease at the age of early stages, and this decline became more pronounced with the replacement of SCBA to the concrete over time. The velocity reduced when the SCBA percentage was in-

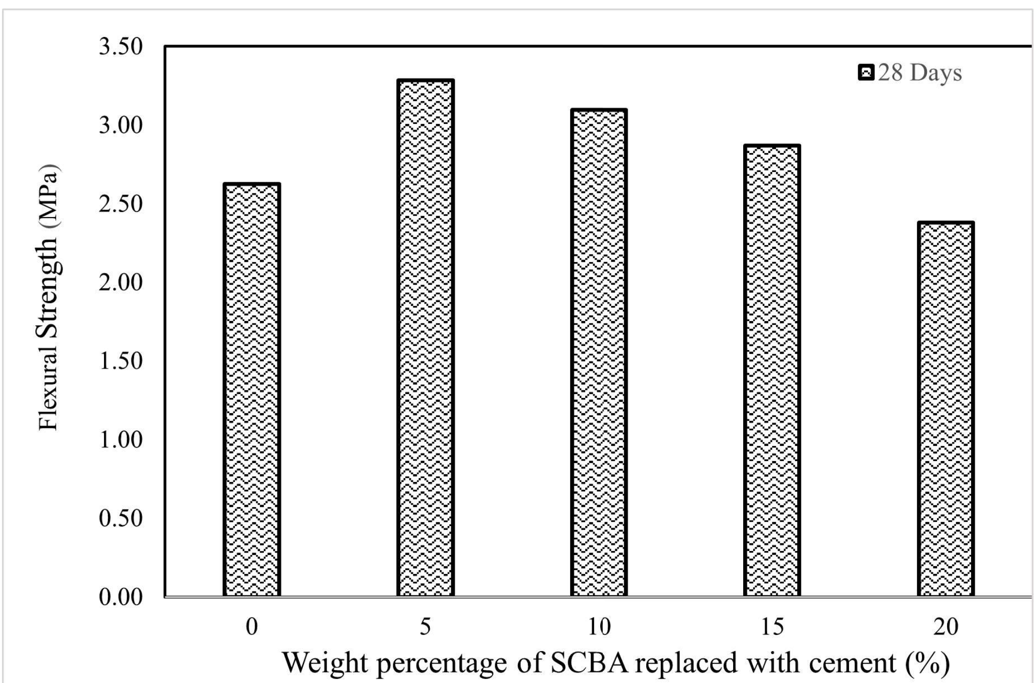


Fig. 4.11: Flexural strength of SCBA blended concrete

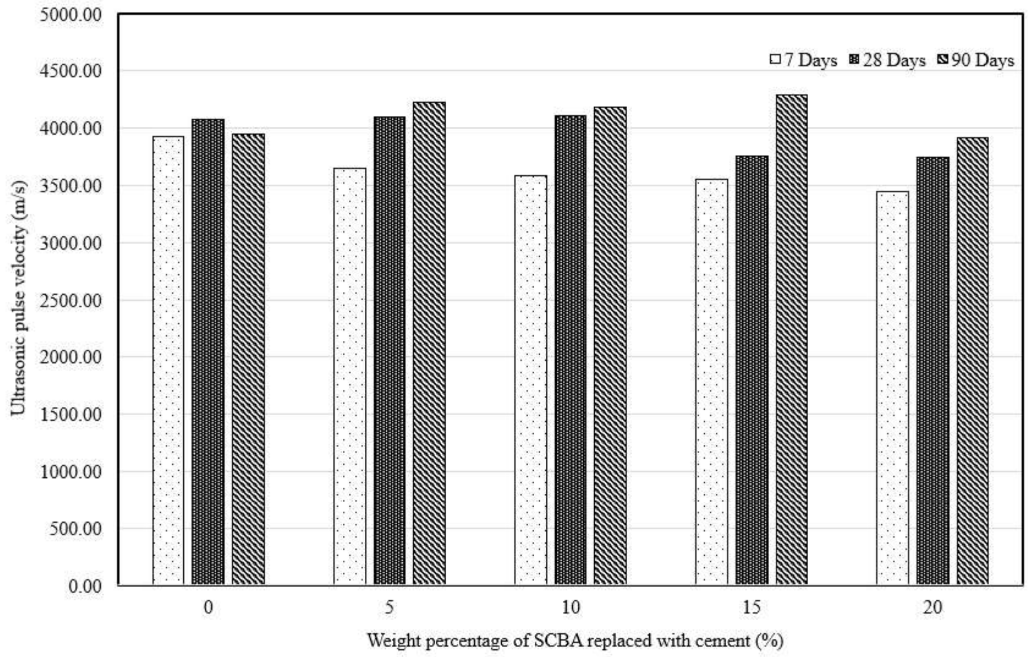


Fig. 4.12: UPV of SCBA blended concrete

creased at 7 days of cure. In comparison to the control concrete, the velocity changed by 7.04% after a 5% SCBA substitution. The drop was 8.67%, 9.33%, and 12.17% accordingly with 10%, 15%, and 20% SCBA replacement. The SCBA's low density and high porosity were attributed to this reduction. According to Mulay et al. [87], pores were the main contributing factor to the OPC-SCBA blended mix's low velocity.

As the SCBA level in the mixture was raised, up to a 10% replacement, the pulse velocity increased before decreasing for 28 days. At 28 days, the pulse velocity increases for replacing SCBA by 5% and 10% were 4.37% and 4.75%, respectively, and the velocity decreases for replacing SCBA by 15% and 20% were 4.17% and 4.41%, respectively. The velocity across the specimens increased by 7.61%, 6.53%, and 9.45% for SCBA replacements of 5%, 10%, and 15%, and the velocity decreased by 0.23% for SCBA replacements of 20% for 90 days of curing. The OPC-SCBA specimens' total pulse velocities have increased over time. This proved that the concrete has become more compact with increasing concrete age, which is why the high pulse velocity.

4.3.6 Bond Strength

Table 4.3 represents the outcomes and failure mode of the pullout experiment. The ultimate bond strength was calculated using the ultimate load. The findings indicate that 5% SCBA improved the strength by approximately 7.2% contrasted to the control concrete. Breaking and necking of the steel bar were seen in both the control concrete and the 5% SCBA blended concrete, suggesting a robust interaction between the concrete

TABLE 4.3: Pullout test results

SCBA (%)	P_{max} (kN)	Bond strength (MPa)	Failure mode
0	52.33	6.94	Steel Rupture
5	53.48	7.44	Steel Rupture
10	54.43	6.98	Splitting + Pull out
15	56.09	6.92	Splitting + Pull out
20	55.26	5.61	Splitting + Pull out

and the bar. In specimens containing 10% to 20% SCBA, the failure occurred due to steel bar slippage succeeding the split of the concrete cylinder. The bond strengths of the 10% SCBA mix were 0.6% higher compared to the control specimen. The failures of the cylinders are shown in Fig. 4.13.

Fig. 4.13: Tested specimens of pullout test

4.4 Durability of Concrete

4.4.1 Water Absorption

Fig. 4.14 illustrates the results of SCBA blended concrete's water absorption. It was observed that replacing SCBA with cement for up to 10% showed a decreasing pattern while replacing it with cement for 15% and 20% showed an increasing trend over 28 days. For 5% SCBA replacement, the water absorption was reduced by 8.5% compared to the control and increased by 28% for 20% SCBA replacement. The declining trend was attributed to the concrete samples' compaction and dense structure [87]. The increasing trend is seen because the high absorption of SCBA due to the pores, as suggested by previous studies [62]. However, at the 90-day curing period, this increasing pattern was observed to decline, especially up to 15% of SCBA replacement. Additionally, it is noteworthy that water absorption for each mix decreases as the curing period for the same mix increases. This reduction in water absorption over time is attributed to the absorption with SCBA, which steadily reduces permeable voids during the curing process [6].

4.4.2 Rapid Chloride Permeability Test

The charge penetrating through the concrete specimen was determined by continually measuring amperage values over 6 hours. This total charge (Q) was computed to calculate the concrete specimen's resistance to chloride permeability. Eq. 4.1 governs that value.

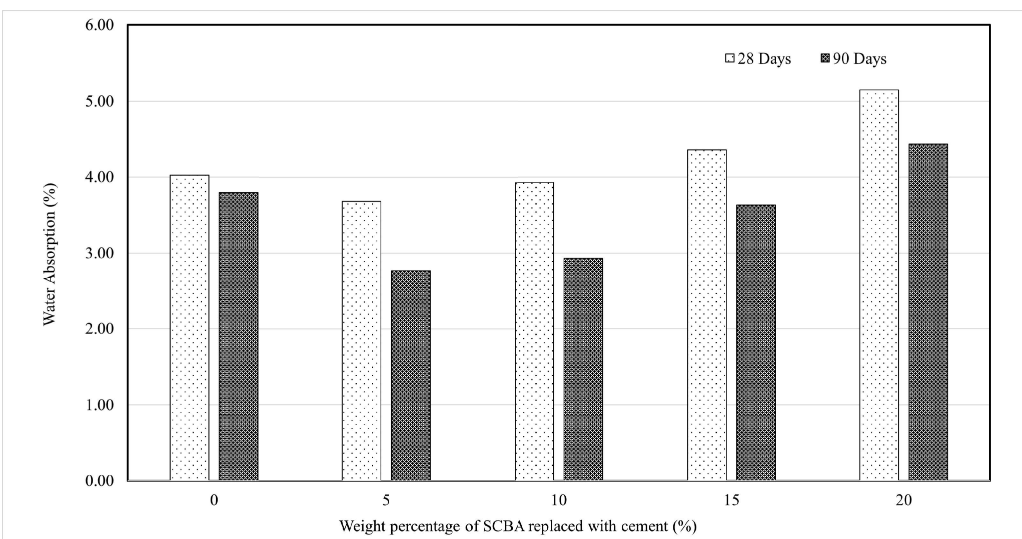


Fig. 4.14: Water absorption of SCBA blended concrete

$$Q = 900(I_0 + 2I_{30} + 2I_{60} + 2I_{90} + ... + 2I_{360}) \tag{4.1}$$

Based on the charge passed through specimens, the ASTM standard offers a qualitative assessment of the chloride ion penetrability as shown in Table. 4.4. The chloride ion penetrability level for all samples, including the control and those with 5%, 10%, 15%, and 20% SCBA replacement, is categorized as 'high' for 28 days of curing. The chloride ion penetration is influenced by three main factors. Those are pores and the quantity in the concrete, the interconnection between those pores, and the free chloride ions in the pore solution. The chloride ion passed within the specimen is lower compared to the control concrete up to 10% of SCBA replaced with cement as shown in Fig. 4.15. It is due to the high compaction of concrete which may lower the interconnection of pores. This might reduce the penetration of chloride irons through concrete specimens. The increase in the electrical charge passing through the concrete is notable when 15% and 20% of SCBA is used as a replacement for cement. The increase in charge passing through SCBA-replaced concrete in the RCPT test is linked to the substantial SSA of SCBA. The presence of a greater number of pores within the SCBA-replaced concrete creates a more intricate network of pathways. When a voltage is applied, this complexity results in an improvement in the passage of charge through the substance.

TABLE 4.4: Qualitative identification RCPT

Charge passed (Coulomb)	Penetrability of chloride ion
>4000	High
4000-2000	Moderate
2000-1000	Little
100-1000	Very little
<100	Negligible

4.5 Discussion

In the presented research, the microstructural analysis of top ash and bottom ash samples through SEM images provides valuable insights into their potential as pozzolanic substances for structural applications. The SEM images of the top ash sample show the presence of elongated, prismatic, and tiny spherical particles, with prismatic particles exhibiting sharp edges indicative of crystalline minerals. The porous nature of the top ash is highlighted, suggesting favorable characteristics for pozzolanic action. Conversely, SEM images of bottom ash particles show the existence of large crystalline particles, potentially indicating contamination during combustion. The bottom ash

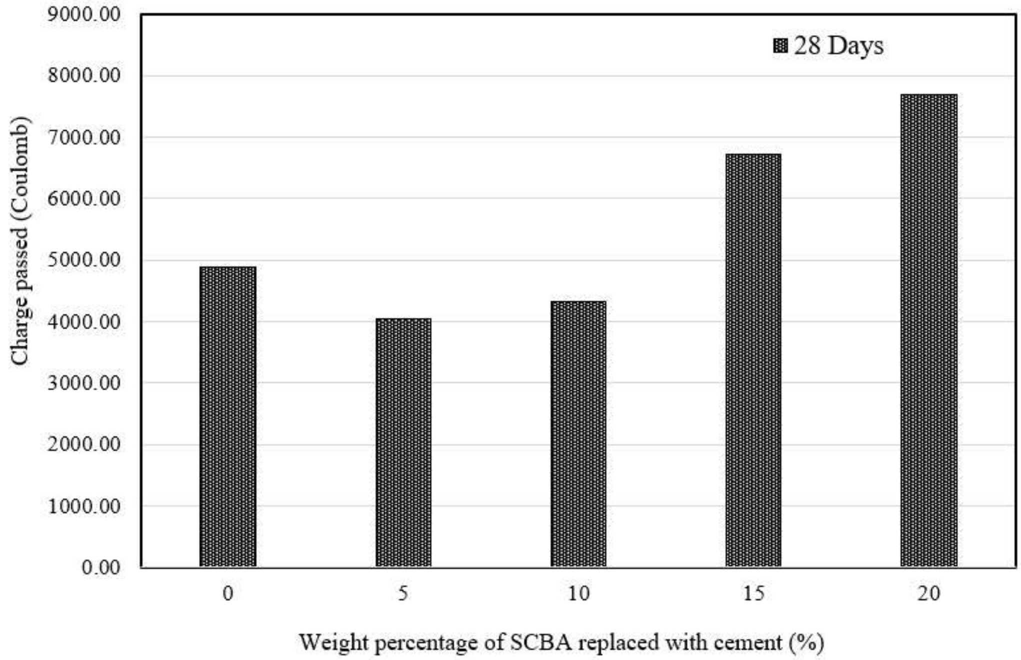


Fig. 4.15: Charge passed through the SCBA blended concrete

samples exhibit poor pozzolanic characteristics, as evidenced by their microstructures. Moving beyond microstructure, further analysis of the top ash sample's particle size distribution, XRD patterns, and chemical composition enhances our understanding of its potential pozzolanic qualities. The top ash sample demonstrates a notable presence of fine particles, advantageous for enhancing pozzolanic action. XRD analysis reveals the presence of crystalline mineralogical phases, including iron oxide, quartz, and cristobalite, with the potential influence of silica attributed to various factors. Chemical composition analysis aligns with ASTM C618 specifications, emphasizing the pozzolanic potential of the top ash.

The subsequent part of the study delves into the mechanical properties of blended cement, focusing on consistency, setting times, and various strength parameters. The inclusion of SCBA affects consistency, with an observed rise attributed to increased surface area allowing greater water absorption. Setting times and compressive strength values indicate a complex relationship between SCBA content and concrete properties. Notably, a concentration of 0 to 15% SCBA in the cement blend appears better percentage for achieving enhanced strength in terms of compression and tension, while the study underscores the progressive hydration of bagasse ash over time. The exploration of mechanical properties extends to additional parameters such as UPV and bond strength. UPV results indicate a decrease with increasing SCBA content, emphasizing the impact of SCBA's high porosity on the velocity of sound waves through concrete. The bond strength evaluations provide valuable insights into the interaction between concrete and steel reinforcement, showcasing a potential enhancement in bond strength at lower SCBA concentrations. However, at higher replacement percentages, the observed failure modes suggest a shift from a robust interaction to steel bar slippage, possibly linked to increased porosity. Continuing the analysis, the study extends its focus to the durability aspects of concrete incorporating SCBA. Water absorption tests reveal a nuanced relationship, with up to 10% SCBA replacement leading to decreased water absorption due to improved compaction and denser structure. However, at higher replacement percentages, the increasing trend in water absorption suggests the potential influence of SCBA's high porosity. The rapid chloride permeability test provides insights into the penetration of chloride ions, a crucial factor influencing concrete durability. While up to 10% SCBA replacement shows a reduction in charge passed through the specimens compared to the control concrete, indicating potentially lower chloride permeability, higher SCBA percentages exhibit an increase, likely attributed to the intricate network of pores within SCBA-replaced concrete.

In summary, the extensive examination of mechanical and durability parameters provides a nuanced understanding of the interplay between SCBA content and diverse concrete properties. The findings underscore the complexity inherent in incorporating SCBA into concrete mixtures, necessitating a thoughtful and sophisticated approach to harness its full potential for sustainable and durable formulations. The observed intricate relationships between SCBA content and properties such as compressive strength, water absorption, chloride permeability, ultrasonic pulse velocity, and bond strength highlight the multifaceted impact of SCBA on the overall performance of concrete. This comprehensive analysis not only deepens our comprehension of the material characteristics but also emphasizes the importance of tailored concrete mix designs. Furthermore, the study underscores the need for ongoing research and development to refine concrete formulations with SCBA, ensuring that sustainability objectives are met without compromising the structural integrity and durability of the resulting concrete. In navigating this intricate relationship, the integration of SCBA emerges as a promising avenue for the construction industry, provided that innovative strategies are employed in its incorporation into concrete production processes.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The findings of this investigation explored the feasibility of Sugar Cane Bagasse Ash (SCBA) production in Sri Lanka as a pozzolan and its potential to replace cement in concrete production. Based on the results of this study, the following conclusions can be drawn:

- Locally available Bagasse ash satisfies all criteria for pozzolanic characteristics. Therefore, it can be used as a supplementary cementing component.
- The top ash produced from the Etimale plantation was chosen as a replacement for cement due to its smaller particle size and amorphous nature.
- The dominant oxide identified in the ash composition was SiO_2, accounting for over 60% of the total composition. XRD results further confirmed the presence of amorphous phases. SEM images revealed various particle shapes, including irregular, prismatic, fibrous, and spherical forms.
- The introduction of SCBA results in an increase in both consistency and setting time due to SCBA's increased surface area, which allowed for greater water absorption than traditional cement. This increment falls within the acceptable limits defined by the SLS standard.
- The inclusion of SCBA results in a reduction in the workability, with a notable difference of approximately 60% reported in a slump as the SCBA increases from 0% to 20%. The larger SSA and porous nature of SCBA contribute to this decrease in workability.
- Replacing cement with 10% to 15% SCBA in concrete mixtures appears to be a better choice for enhancing hardened properties. The strength increment is attributed to the pozzolanic activity, transforming calcium hydrate into the C-S-H gel. However, it's noteworthy that all SCBA replacement samples displayed an increase in compressive strength at 90 days, indicating the gradual progression of the pozzolanic hydration process.
- Replacing about 10% of cement with SCBA resulted in lower values for water absorption and RCPT compared to the control concrete due to the compaction of concrete. However, beyond this point, the values began to increase due to the porous characteristics of SCBA.

Overall, a 15% replacement of cement with SCBA produced from the Etimale plantation can be recommended for concrete mixtures, considering the improvement in mechanical and durability properties.

5.2 Recommendation for Future Research

In completion, a few suggestions and direct further improvement for additional research are provided below.

- It is recommended to conduct further experiments on the mechanical and durability characteristics of concrete by replacing the cement with SCBA in the range of 10%-20%. This will provide a better understanding of selecting an optimum SCBA percentage for concrete.

- It was evident that there is a noticeable enhancement in the mechanical strength parameters of SCBA-replaced concrete after 90 days compared to those observed at 7 and 28 days. Further testing is required to investigate the change in these strength parameters over time, such as 6 months, 1 year, etc.

- Testing on reinforced concrete elements, such as beams and slabs, is essential to comprehensively understand the characteristics of SCBA for structural use. This involves examining properties under different cracked states, stress-strain features, shear and flexural performance, as well as torsion behavior. These tests provide valuable insights into how SCBA impacts the structural performance of concrete elements in diverse conditions. Future research is advised because these structural characteristics have not been widely reported.

- Researchers have recently become interested in Ultra High-Performance Concrete (UHPC) . Since it hasn't been well studied, the possible use of SCBA in UHPC is an interesting study area.

- The viability of SCBA in geopolymer concrete must be investigated given its recent increase in popularity. Additionally, this research can be expanded to identify the coordination of mechanisms and optimum mix.

- The characteristics of SCBA in blended concrete must be understood in the context of studies on long-term durability qualities. Consequently, an in-depth investigation of characteristics like shrinkage, creep, carbonation, etc. must be carried out.

- Periodic examinations are crucial for SCBA-composite concrete structures, especially in the face of natural disasters and after prolonged exposure to the typical environment. A thorough investigation of both structural and material aspects of SCBA durability is essential. Comprehensive research into the structural properties of SCBA-blended concrete is necessary before it is widely used in construction.

- Research must be done on the life cycle assessment of cementitious composites based on SCBA, including its benefits to the environment and economy to make SCBA viable in the industry of cement.

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