STRUCTURAL PERFORMANCE OF GLASS CONCRETE MADE FROM SUGAR CANE BAGASSE ASH CEMENT

BRIAN MWENDWA MUTUA

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DECLARATION

This thesis is my original work and it has not been submitted to any other university for examination.

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

Brian Mwendwa Mutua

This thesis has been submitted for examination with our approval as the university supervisors.

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

Dr. Eng. T. Nyomboi

PAUISTI, Kenya

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

Prof. Eng. R. N. MUTUKU

Technical University of Mombasa, Kenya

DEDICATION

I dedicate this work to Almighty God, my wife Imelda Ndinda, my sons Randy and Reagan, my parents Mr and Mrs. Joseph M. Ngewa and my sisters Jennifer, Mercy and Mary.

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LIST OF ACRONYMS

ASR	Acid Silicate Reaction
BS	British Standard
EN	Eurocode Standard
IS	Indian Standard
KS	Kenya Standard
KSB	Kenya Sugar Board
SCB	Sugar Cane Bagasse
SCBA	Sugar Cane Bagasse Ash
SCBAC	Sugar Cane Bagasse Ash Cement
GCSCBAC XX-YY	Glass Concrete Made Using Sugar Cane Bagasse Ash Cement
XX	Percentage Replacement of Sand by Crushed Glass
YY	Percentage Replacement of Cement by Sugar Cane Bagasse Ash

ABSTRACT

Due to the increasing price, demand, consumption of cement, and environmental impacts of solid waste build up, researchers and scientists are in search of developing alternatives to aggregates and binders, which are cheaper, eco-friendly and contribute towards waste management. This research presents findings of sugar cane bagasse ash cement properties and its effects when used in making glass concrete in terms of strength and structural responses. Sugar cane bagasse ash was used to replace cement in the proportions of 0, 5, 10, 15 and 20% by mass and crushed glass used to replace sand in the proportion of 30% in concrete mix of 1:2:4 (class 20) at varying water cement ratios.

From the consistency, setting times and chemical composition tests, results of the findings showed that sugar cane bagasse ash can replace cement up to a maximum of 10%, providing allowable consistency, initial and final setting and cement with required chemical compositions according to the required standards. Good workability can be achieved if sugar cane bagasse is used to replace cement at 10% and glass used to replace fine aggregates at 30%, maintaining a water cement ratio of 0.6.

The compressive, flexural and tensile split tests showed that the strengths of the various mixes were lower as compared to the control mix. Also, significant increase up to 10% replacement of cement with sugar cane bagasse ash and 30% replacement of fine aggregates with crushed glass was noted achieving a 70% 28-days strength at 7 days.

The structural behavior of glass concrete beams made using sugar cane bagasse ash cement showed that deflections were within the allowable limit of 20mm as per BS 8110-1 (1997) for replacement of cement with SCBA up to 15% and replacement of sand with crushed glass up to 30%. The general behavior of the beams was that the higher the proportions of sugar cane bagasse ash in the mix at 30% glass composition, the less the strains induced in the beam produced. Also, at initial loads, the strains were seen to increase then remain constant over the loading time.

In conclusion, it was recommended that, for best results, cement could be replaced with sugar cane bagasse ash at 10% and fine aggregates replaced with crushed glass at 30% and a good workability achieved. This mix containing sugar cane bagasse ash and crushed glass can be used for lightly loaded beams in buildings provided the engineers design mix for the members is 1:2:4 or class 20.

CHAPTER ONE

1. INTRODUCTION

1.1 Background to the study

Concrete is a construction material composed of cement as well as other cementitious materials such as fly ash and slag cement, aggregate (generally, course aggregate, e.g. gravel, limestone, or granite plus fine aggregate, e.g. sand), water and may be chemical admixtures. Due to the increasing price, demand and consumption of cement, researchers and scientists are in search of developing alternatives to aggregates and binders, which are eco-friendly and contribute towards waste management.

One of these alternatives to cement is the fibrous waste product obtained from sugar mills, sugar cane bagasse (SCB), once burnt, called sugar cane bagasse ash (SCBA). Over the past ten years, bagasse production in the country has increased by nearly thirty percent. In 2008, the sugar factories in the Kenya crushed over five million tonnes of sugarcane thereby producing just above two million tonnes of bagasse (KSB, 2009). In previous studies, SCBA has been used as a partial replacement of cement and the resulting concrete has shown experimentally to have higher compressive strength as compared to that of the concrete without SCBA. SCBA also has been found that at 30% replacement with cement, it increases workability of fresh concrete hence use of super plasticizer is not essential (Kawade et al. 2013).

Glass being non-biodegradable is one such material that is not suitable for addition to landfill. Fortunately, glass can be recycled indefinitely without any loss in quality, but first needs to be sorted by colour. This is an expensive process, and subsequently waste glass is increasingly being used in applications where mixed colour is not an issue, such as an aggregate in civil construction.

When glass is crushed to a particle size finer than 75µm, concrete specimens are found to achieve prolonged compressive strength development, which can be attributed to the pozzolanic nature of very fine glass powder (Lee et al. 2008). Also, Taha et al. (2008) found out that the addition of waste glass to the concrete mix has been found to decrease concrete slump, yet workability was still deemed sufficient adequate without the need for admixtures at for replacement levels up to 50% Adaway et al. (2015), found that the optimum percentage replacement of sand with fine glass aggregate was thirty percent. Compressive strength was found to increase with the addition of waste glass to the mix up until the optimum level of replacement. This was attributed to the angular nature of the glass particles facilitating increased bonding with the cement paste. In proportions exceeding the optimum level, waste glass was found to negatively impact the development of compressive strength.

1.2 Problem Statement

In Kenya, the challenge of Solid Waste Management is real (Gakungu et al. 2011). Collection systems are inefficient and disposal systems are not environmentally friendly. 30 to 40 per cent of all solid waste generated in urban areas is uncollected and less than 50 per cent of the population is served with waste collections by relevant waste disposers (Otieno, 2010). Also, in the same research by Otieno (2010); up to 80 per cent of collection transport is out of service or in need of repair and argues that if the issue of sustainable solid waste management in Kenya is not considered urgently, all the towns in Kenya will be engulfed in waste.

Glass, being non-biodegradable solid waste, is not suitable for addition to landfill, and as such recycling opportunities need to be investigated. Due to the high material consumption of the construction industry, the utilization of waste glass as a partial replacement for fine aggregate in structural concrete is necessitated. Previous studies by Adaway et al. (2015); showed that concrete mixes containing glass exhibited lower slumps than that of the control mixes attributing the reduction in slump solely due to the angular geometry of glass particles, which reduces the availability of cement paste and hence the fluidity of the mix. Also in the same findings, no excessive bleeding or segregation of concrete specimens was encountered during preparation, supporting another earlier research that indicated fine aggregate replacements less than 50% had minimal negative effects on properties of fresh concrete.

According to Taha et al. (2009); compressive strengths were also found to increase with increase in glass replacement of fine aggregates to an optimum, for substantial results indicating that glass is a good replacement of fine aggregate but the only problem which needs to be dealt with is the workability issue. Hence, this presents a research area where this issue of workability can be improved while investigating other properties, thus, the introduction of SCBA in the glass concrete.

Sugar cane bagasse is another industrial and agricultural waste which is fibrous in nature obtained from industrial processes of sugar mills as by product after the juice is extracted from the sugarcane. The utilization of this by product has been the focus from waste reduction point of view. Ordinary Portland cement is the most extensively used construction material in the world. Since the early 1980’s, there has been an enormous demand for the mineral admixture and in future this demand is expected to increase even more. Also in this modern age, every structure has its own intended purpose and hence to meet this purpose modification in traditional cement concrete has become essential. This situation has led to the extensive research on concrete resulting in mineral admixture to be partly used as cement replacement to increase workability in most structural application.

For this reason, SCBA is one of the main by-product that can be used as mineral admixture due to its high content in silica (SiO_2) with the aim of replacing cement by weight, in concrete, then bringing the cost of concrete and subsequently cost of construction down without compromising on the concrete quality. Test results indicated that the strength of concrete increase up to 15% SCBA replacement with cement. Hence, from the above studies, there was necessity to carry out research on the effects of SCBA on cement and subsequently investigate the effects of SCBAC on glass concrete. The outcome of the research was to provide information on characteristics of cement partially replaced with SCBA. In addition, the effects of using SCBAC on glass concrete was also be investigated.

1.3 Justification of the study

Cement is becoming too expensive day after day. Also, to make industrial and agricultural wastes to useful construction materials, a lot of research needs to be carried out on how best these wastes can be made useful construction materials. These researched materials replace concrete ingredients with aim of making the concrete cheaper but of adequate quality as required by the standards. Also, the environmental management issue would be solved by using the waste generated from industries and agricultural sector e.g. Sugar cane bagasse and waste glass.

1.4 Objectives

1.4.1 General objective

To investigate the physical and mechanical properties of glass concrete made from sugar cane bagasse ash cement.

1.4.2 Specific objectives

1) To determine the effects of sugar cane bagasse ash on the properties of cement.
2) To establish the effects of sugar cane bagasse ash cement on the rheological properties of glass concrete.
3) To assess the influence of sugar cane bagasse ash cement on the structural performance of glass concrete.

1.5 Research questions

i. Does sugar cane bagasse ash affect positively or negatively, the performance of cement?

ii. What are the effects of sugar cane bagasse ash on the rheological properties of glass concrete?

iii. Once the effects of sugar cane bagasse ash on fresh glass concrete are known, what about the effects on the hardened concrete?

1.6 Scope and limitations of the study

The research was aimed at achieving the above-mentioned objectives whereby the main area of investigation was the effect of SCBA on cement and the effect of SCBAC on glass concrete. This entailed experiments on cement with SCBA, and SCBAC in glass concrete. Due to complexity of the research, only variation of SCBA on cement was done but the composition of glass in glass concrete was held constant. The composition of glass was held constant at 30% of the fine aggregates, as per results from previous studies by Adaway et al. (2015).

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Glass and bagasse waste generation rates

Waste generation rates are dependent on several factors. The basic factor is population, which is the number of people generating the waste in the area in question i.e. the greater the number of people generating the waste, the greater the rate of waste generation. However, waste generation rates are dependent on other factors. Malhotra (2004); argues that the composition of waste is determined by various factors which include population, level of income, sources, social behavior, climate, industrial production and the market for waste materials. Also, the same argument is supported by Ngoc et al. (2007); arguing that waste generation rates are affected by socio-economic development, degree of industrialization and climate. These arguments are true for public places like municipalities but for technical training institutions, the waste generation rate is dependent on factors like the institution type. For example, institutions with boarding students generate more waste than institutions without boarding facilities. The courses offered also affect the waste generation rates. Institutions with technical courses including wood work and metal work produce more waste than institutions with business courses. Total technical waste generation rate for public technical training institution in Kenya is 23 tonnes in a week. Organic materials continue to be the largest component of institutional solid waste. Vegetable remains account for 82% of the waste, paper account for 4%, metal 4% and glass 1% according to Gakungu et al (2012).

Also, in findings conducted by Siam (2011); Solid waste in Gaza Strip mainly consists of household wastes, building debris, agricultural wastes, industrial wastes, medical wastes, workshops wastes, and other waste materials. Out of the solid waste, it is estimated that 79.81%, of the household solid waste consist of organic material, sand 7.21%, plastic and rubber 5.02%, cloth 1,9%, glass 0.85%, metals 2.22% and carton 2.02%. The two researchers confirm to us that in approximate, 1% of every waste generated in a particular place contains waste glass.

The current municipal solid waste generated on daily basis in Nairobi is 4,016 tonnes as predicted by Allison (2010). The composition of waste generated has been evolving with years. Table 2.1 shows a summary of the evolving solid waste composition in Nairobi indicating that 2% of the waste, i.e. on average 80 tonnes of this waste produced daily is glass in Nairobi region.

Table 2.1: Nairobi evolving solid waste composition

Waste Type	Percentage Composition			
	MoLG &FARID 1985 (Kibwage, 1996)	JICA, 1998	ITDG, 2004 (Bahri, 2005)	UNEP/CCN/NTT, 2009
Organic	78	58	61.4	50.9
Paper	10.2	17	11.8	17.5
Plastic	4.1	12	20.6	16.1
Glass	3.8	2	0.7	2.0
Metals	1.9	3	0.6	2.0
Other	2	8	4.9	11.4

Source: Solid waste Management in Nairobi: A situation analysis. Report for City Council of Nairobi, 2010

Bagasse is obtained from crushing of sugar cane in sugarcane factories. For instance, according to research done by clean development mechanism (CDM)-Executive Board, (2006), in providing alternative to the more fossil-fuel based electricity component of the Kenyan national grid, Mumias Sugar Company Limited crushed 2,400,000 tonnes of cane in 2005 and was expected to crush similar quantities in 2006 based on the quantities which had been crushed so far and the projections for the remaining months of the year. From the total cane crushed, existing data indicated that 37% was bagasse, which translated to 888,000 tonnes of bagasse. The same data showed that for each tonne of sugarcane crushed, 0.27 tonnes of bagasse was used to produce process energy (steam and electricity). This leaves a surplus of 240,000 tonnes of bagasse (10% of total cane crushed), and it is this amount which is transported by company trucks and dumped in the plantations to decompose with significant methane emissions.

2.2 Portland cement

Cement is produced by either a wet or dry process. In the wet process, raw materials are blended and ground in a slurry condition while in dry process operations are carried out with the materials in dry state. Portland cement is obtained from finely pulverizing clinker produced by calcining to incipient fusion properly proportioned argillaceous and calcareous materials while carefully controlling final constituents and properties (Rajput, 2010). Portland cement comes in five basic types and a number of specialty varieties to fulfil different physical and chemical requirements as indicated in Table 2.2.

Table 2.2: General features of the main types of Portland cement (Rajput, 2010)

	Classification	Characteristics	Applications
Type I	General purpose	Fairly high C_3S content for good early strength development	General construction (most buildings, bridges, pavements, precast units, etc.)
Type II	Moderate sulphate resistance	Low C_3A content (<8%)	Structures exposed to soil or water containing sulphate ions
Type III	High early strength	Ground more finely, may have slightly more C_3S	Rapid construction, cold weather concreting
Type IV	Low heat of hydration	Low content of C_3S (<50%) and C_3A	Massive structures such as dams. Now rare.
Type V	High sulphate resistance	Very Low C_3A content (<5%)	Structures exposed to high levels of sulphate ions

The Portland cement is further classified in to rapid hardening portland cement which has high lime content and can be obtained by increasing the C_3S content. It can also be obtained from ordinary Portland cement by finer gauging. The basis of application of rapid hardening cement is its hardening properties and heat emission rather than setting rate. It is however subjected to large shrinkage and water requirement for workability is more. Concrete made from rapid hardening Portland cement can be safely exposed to frost since it matures quickly. It is resistant to action of fire, sea water, acidic water and sulphates and is used as refractory concrete in industries and also in pre-casting.

Another type of cement is ordinary portland cement which is the most common cement used in general concrete construction when there is no exposure to sulphates in the soil or ground water. It is manufactured using dry process technology. This cement manages to balance between high heat development and strength properties. It is classified into two types (42.5N and 52.5N).

Further, super sulphated portland cement is manufactured by inter-grinding or intimately blending a mixture of granulated blast furnace slag not less than 70 percent calcium sulphate and a small quantity of 33 grade Portland cement. Water resistance of concretes from super-sulphated Portland cements is higher than that of common Portland cements because of absence of free calcium oxide hydrate. It has low heat of hydration and it is resistant to chemical attacks in particular sulphates.

For sulphate resisting portland cement, the amount of tri-calcium aluminate is restricted to an acceptably low value (<5). It is manufactured by grinding and intimately mixing together calcareous and argillaceous and or other silica alumina and iron oxide bearing materials. This cement can be used as an alternative to ordinary Portland cement, Portland pozzolana cement and Portland slag cement under normal conditions.

Portland slag cement is manufactured by inter-grinding a mixture of portland cement clinker and granulated slag with addition of gypsum or calcium sulphate or by an intimate and uniform blending of portland cement and finely ground granulated clay.

Low heat portland cement to limit the heat of hydration of low heat portland cement the tri-calcium aluminate component in cement is minimized and a high percentage of di-calcium silicate and tetra-calcium aluminoferite is added. The rate of strength development is slow but ultimate strength is same as that of ordinary portland cement.

Portland pozzolana cement it is manufactured by grinding portland cement clinker and pozzolana (usually fly ash10- 25% by mass of portland pozzolana cement) or by uniformly blending portland cement and fine pozzolana. pozzolana (burnt clay, shale or fly ash) has no cementing value itself but has the property of combining with lime to produce a stable lime- pozzolana compound that has definite cementitious properties. Free lime present in the cement is thus removed and consequently the resistance to chemical attack increases making it suitable for marine works.

Among the cements produced locally is Nguvu CEM IV/B (P) 32,5N. It is a pozzolanic cement with wide range of applications from domestic concrete to large building projects. Its good strength performance makes it suitable for both general purpose and structural concrete applications. These applications require good technical ability, quality control and experience to design concrete mixes. Its structural applications in reinforced concrete include: suspended slabs, beams, columns, foundations, water retaining structures and pre-cast concrete members.

2.3 Recycled glass as a partial replacement for fine aggregate in structural concrete

Concrete is a combination of several ingredients including water, aggregates and binder as the main constituents. Researchers have from time to time replaced the ingredients and reinforcement with different alternatives to achieve some desired results. Recycled materials like waste glass is increasingly being used as partial replacement of natural aggregates in order to preserve natural resources (Padney et al., 2003).

Waste management is becoming a major issue for communities worldwide. Glass, being non-biodegradable, is not suitable for addition to landfill, and as such recycling opportunities need to be investigated. Due to the high material consumption of the construction industry, the utilization of waste glass as a partial replacement for fine aggregate in structural concrete is particularly attractive.

The construction industry presents an attractive market for the use of waste glass. One of the principal components of construction is concrete, due to its high compressive strength, durability and ease of construction. However, concrete production is highly resource and energy intensive, with the industry responsible for approximately 5 – 8% of worldwide greenhouse gas emissions (Scrivener et al.;

2008). As such, opportunities to reduce the environmental impacts of the concrete industry are required (Malhotra, 2004). The total carbon dioxide (CO_2) emissions worldwide were 21 billion tons in 2002 as shown in Table 2.3 below.

Table 2.3: Carbon dioxide (CO_2) emissions by industrialized countries in 2002 (Malhotra, 2004)

Country	Percentage of carbon dioxide (CO_2)
USA	25
EU	20
Russia	17
Japan	8
China	>15
India	>10

Early studies into the effects of incorporating waste glass into concrete focused on its suitability as a replacement for fine aggregate. The results from these tests demonstrated that the presence of larger glass particles caused excessive expansion and cracking of the concrete specimens, resulting in compromised structural integrity. These effects can be attributed to the strong reaction between the alkali in cement and the reactive silica in glass (Johnson, 1974). In order to minimize alkali-silica reactions (ASR), the partial replacement of fine aggregate and/or cement in concrete has been investigated. Research has concluded that the increasing proportions of crushed glass as a replacement for fine aggregate results in an increase in ASR expansion (Oliveira *et al.*, 2013) and (Serpa et al., 2013). Saccani et al. (2008) found that mixes containing up to 30% fine glass aggregate displayed levels of expansion that were below the deleterious limit set in ASTM C1260 (American Society for Testing and Materials, 2007).

Furthermore, Zhu et al. (2004) identified that glass particles finer than 1.18 mm exhibited lower expansion than natural fine aggregate, even after extended testing. When glass was crushed to a particle size finer than 75μm, concrete specimens were found to achieve prolonged compressive strength development, which was attributed to the pozzolanic nature of very fine glass powder (Chen et al., 2006).

A study undertaken by Shayan et al., (2006) demonstrated that concrete specimens containing glass as a fine aggregate achieved higher levels of compressive strength than those containing glass as a cement replacement. Similar results were obtained by Taha et al. (2009), who found that concrete containing glass as a partial replacement for cement exhibited lower levels of compressive strength than the control mix. Due to the importance of compressive strength development in structural concrete, it is concluded from these findings that the greatest benefits may be derived from incorporating waste glass as a replacement for fine aggregate, with particle size limited to ensure detrimental ASR effects are mitigated.

2.4 Effect of use of bagasse ash as a partial replacement of cement in concrete

Concrete is a globally accepted construction material in all types of civil engineering structures. Different types of mix-designs are used in order to obtain proper concrete to satisfy appropriate purposes. The increase in construction has brought heavy demand for ingredients of concrete such as cement and sand, and these materials are becoming costly and scarce. With ever increasing environmental problems because of industrial waste products comes a great need to use these products in an appropriate manner to reduce health and environmental problems. Concrete being a versatile material the ingredients mainly the cement replacements have taken a step ahead for the better alternative by means of naturally available sources. One such alternative is by the effective utilization of sugar cane bagasse ash, of varying percentages as a partial replacement for ordinary Portland cement in concrete.

Sugar cane bagasse largely possess two polysaccharide fractions namely cellulose and a polyphenol macromolecule called lignin, the larger component being cellulose (33-36%), a polysaccharide containing a linear chain of a number of glucose links that produces crystalline regions and subsequent rises resistance to the hydrolytic process. The second principal component of sugar cane bagasse is the hemicellulose contributing 28-30% and possesses hetero polysaccharide that varies according to the source of sugar cane (Sun & Cheng, 2002) and (Ververis et al., 2007).

Also, according to Kawade et al., (2013) in Table 2.4, sugar cane bagasse consists of approximately 50% of cellulose, 25% of hemicelluloses and 25% of lignin. Each ton of sugarcane generates approximately 26% of bagasse (at a moisture content of 50%) and 0.62% of residual ash. The residue after combustion presents a chemical composition dominates by silicon dioxide (SiO_2) as shown it Table 2.4 below.

Table 2.4: Chemical composition of sugar cane bagasse ash (U.R. Kawae, et al 2013)

Sr. No.	Chemical Composition	Percentage of carbon dioxide (CO_2)
1	Silica (SiO_2)	66.89
2	Alumina(Al_2O_3) & Ferric Oxide (Fe_2O_3)	29.18
3	Calcium Oxide (CaO)	1.92
4	Magnesium Oxide (MgO)	0.83
5	Sulphur Trioxide (SO_3)	0.56
6	Loss of Ignition	0.72
7	Chloride	-

Calcium hydroxide, traditionally called slaked lime, is an inorganic compound with the chemical formula $Ca(OH)_2$ which is a colourless crystal or white powder. It is one of the hydration products of Portland cement, that greatly contributes towards the deterioration of cement composites. However, when a pozzolana is blended with Portland cement, it reacts with lime to produce additional calcium-silicate-hydrate, which is the main cementing material. The pozzolanic material therefore reduces the quantity of lime and increases the quantity of calcium-silicate-hydrate which enhances the cementing quality when Pozzolana is blended in a suitable quantity with Portland cement, (Padney et al., 2003). Currently, blended cements are used in many parts of the world to give the desired mix properties (Bakar et al., 2010)

U.R. Kawade, et al., (2013) found out in their study; on effect of use of bagasse ash on strength of concrete; that the strength of concrete increases when sugar cane bagasse ash is used to partially replace cement by 15% of weight.

2.5 Utilization of bagasse ash as a partial replacement of fine aggregate in concrete

In the current world, researchers are focusing on different ways of utilizing wastes including agricultural and industrial wastes as a source of raw materials for the construction industry.

These wastes utilization would not only be economical, but may also help to create a sustainable and pollution free environment. Sugar-cane bagasse is one such fibrous waste-product of the sugar refining industry, along with ethanol vapour. Sugar Cane Bagasse Ash contains high amounts of un-burnt matter, silicon, aluminium and calcium oxides. These ashes are obtained directly from the mill and are not reactive because they are burnt under uncontrolled conditions and at very high temperatures. The ash, therefore, becomes an industrial waste and poses disposal problems. A few studies have been carried out in the past on the utilization of bagasse ash obtained directly from the industries to study pozzolanic activity and their suitability as binders by partially replacing cement. Modani, et al, (2012) in their study on the use of bagasse ash as a partial replacement of fine aggregates in concrete found out that, bagasse ash had lower specific gravity, bulk density and fineness modulus than the normal fine aggregates as shown in Table 2.5.

Table 2.5: Physical properties of coarse aggregates, fine aggregates and bagasse ash (P.O. Modani, et al., 2012)

Physical tests	Coarse Aggregates	Fine aggregates	
		River sand	Bagasse ash
Specific gravity	2.83	2.64	1.25
Fineness modulus	3.08	3.08	2.12
Bulk density (Kg/m^3)	1428	1428	837

The same study found out that 10 to 20% fine aggregates replacement by sugar cane bagasse ash in concrete gave good results without a considerable loss of workability and strength properties i.e. the compressive strength results showed that, the strength of the mixes with 10 and 20% bagasse ash increased at later days (28 days) as compared to 7 days that may be due to pozzolanic properties of bagasse ash. Also, sorptivity test result showed that the sorptivity coefficient increased with increase in percentage of bagasse ash which indicates more permeable concrete that is due to porous nature of SCBA and the impurities in it.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Introduction

The various research materials including sugar cane bagasse ash and waste glass were collected and prepared by drying of the sugar cane bagasse ash and hand crushing of the waste glass. These materials and the different mixes were subjected to various tests as the research was purely experimental and was based on the standard applicable codes. The various tests were conducted in the structural and materials laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya.

3.2 Material preparation

The materials that were used in this research entailed the following:

i. Aggregates (fine and coarse).
ii. Ordinary Portland cement (Binder).
iii. Waste Glass aggregates (Part of fine aggregates).
iv. Sugar Cane bagasse ash (Part of binder replacement).

3.2.1 Pozzolanic cement

Nguvu CEM IV/B(P) 32,5N cement is formulated from cement clinker and inter-ground with other constituents, mainly natural pozzolana, in accordance with the requirements of the harmonized East African Standard KS EAS 18-1:2001, Composition, specifications and conformity criteria for common cements. KS EAS 18-1 is an adoption of the European Norm EN 197 cement standard. As per the manufacturers specifications, Nguvu 32,5 is a CEM IV/ B-P pozzolanic cement in the strength class 32,5 N/mm as per the cement standard KS EAS 18-1:2001 for common cements. It is characterized by high early and 28 day strengths, fast setting and improved sulphate resistance.

3.2.2 Sugar cane bagasse ash

The partial replacement material to cement, i.e. sugar cane bagasse ash was gotten from Muhoroni sugar company, Western Province in Kenya. This was because of the availability of ready sugar cane bagasse ash for research and easiness of acquisition logistics. According to Fernandez et al, (1996), any sample heated at between 350 to 490^{0}C all organic matter disappears at this temperature range. Hence, the sugar cane bagasse had no organic matter present as it was heated at 350^{0}C as per research done by Anjum Munir et al., (2004). The sugar cane bagasse which is a waste from boiler chimney of their co- generating plant is obtained in the process of burning sugar cane bagasse to produce steam during electricity generation process. The ash was sieved through 0.075mm sieve to remove finer materials for using is the study. Once the Sugar cane bagasse ash finer material was obtained, cement was partially replaced with it in 0, 5, 10, 15 and 20% proportions. Tests which were conducted for each set of partial replacement for sugar cane bagasse ash cement were consistency test, initial and final setting times and chemical composition of the mixes using X-ray florescence spectral analysis method. The results were compared with the control experiment (0% sugar cane bagasse ash cement-SCBAC) in order to get the actual physical properties of the sugar cane bagasse ash. The results were used to explain the outcomes of fresh and hardened glass concrete with sugar cane bagasse ash cement.

3.2.3 Aggregates

Waste glass was obtained from Juja town, Kenya at selected collection points. Baseline investigations had showed that up to 1,300 kilograms of glass from was available in form of broken bottles which were non-recyclable and non-reusable. Once the waste glass was obtained, it underwent manual crushing so as to reduce it to sand size and used as an alternate material for natural sand (as partial replacement in different percentages or full replacement) in the concrete.

The natural aggregates included both fine aggregates, river sand less than 5 mm in size, and coarse aggregates from crushed stones of 5 mm or larger in size. These materials were collected from a local supplier of building materials at Juja. The coarse aggregates were subjected to various laboratory tests including sieve analysis tests and specific gravity tests to ensure that they conformed to BS EN 1097 (2013). Generally, the aggregates should be free from any organic contamination and coatings of clay, which impair bonding of the material with cement leading to poor concrete.

Also, the aggregates should be chemically inert, clean, hard and durable. Organic impurities can affect the hydration of cement and the bond between the cement and the aggregate. Some aggregates containing silica may react with alkali in the cement causing the concrete to disintegrate. This is alkali-silica reaction (ASR), commonly known as "concrete cancer", which is a reaction which occurs over time in concrete between the highly alkaline cement paste and the reactive non-crystalline (amorphous) silica found in many common aggregates, given sufficient moisture. The presence of chlorides in aggregates also causes corrosion of the steel reinforcement in reinforced concrete.

Particle size distribution test was carried out according to set out in BS 882: 1983 for coarse aggregates, fine aggregates and the waste glass aggregates. This was achieved by taking 1000g of each aggregate, dividing up and separating the aggregates by means of series of test sieves; as shown in Figure 3.1; so as to get several particle size classifications of decreasing sizes. This was to help in determining the particle size distribution of the aggregates and drawing of the grading curves for the various aggregates so as to select the portion which only lied within the acceptable limits.

The objectives of the test were to:

i. To determine the particle size distribution of specified fine, glass and coarse aggregates.
ii. Plot grading curves of the various specified aggregates.

Figure 3.1: Test sieves

The bigger the size of the aggregate, the less the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste, bigger size of aggregates gives higher workability.

3.2.4 Sugar cane bagasse ash cement properties

The sugar cane bagasse obtained from Muhoroni sugar factory in Kenya was dried and sieved to ensure that only particles passing 0.075mm were collected for this study so as to conform with the maximum size of cement and eliminate the constituents of fine aggregates. Cement replacement with sugar cane bagasse ash was done at 0, 5, 10, 15 and 20% intervals per given sample. For each replacement, the following tests was carried out:

3.2.4.1 Consistency test of sugar cane bagasse ash cement

The standard consistency of a cement paste is defined as that consistency which permits the Vicat plunger to penetrate to a point 5 to 7mm from the bottom of the Vicat mould. The standard procedure as stipulated in IS:4031 (Part 4) 1988 was followed. The apparatus required were; Vicat apparatus conforming to IS: 5513:1976, weighing balance and a trowel. 1200g of cement and 300g of sugar cane bagasse ash was also required to enable four runs of the experiment. The sugar cane bagasse ash cement (SCBAC) was prepared by partially replacing cement (Nguvu CEM IV/B (P) 32,5N) with sugar cane bagasse ash (SCBA) by 0%, 5%, 10%, 25%

and 20% by weight. A total of five samples were prepared and four runs per sample were done to get the amount of water which made the paste per mix to resist the 10mm needle of the Vicat apparatus to penetrate to the bottom of the mould base. The consistency cement paste was expressed as a percentage by weight of dry cement and is usually this percentage varies from 26% to 33% for ordinary portland cement.

3.2.4.2 Initial and final setting time tests of sugar cane bagasse ash cement

Once the consistency tests of the various replacements are obtained, the results were used to determine the initial and final setting times of the sugar cane bagasse ash cement as per the standard procedure as stipulated in IS: 4031 (Part 5) 1988 and as shown in Plate 3.2 and Plate 3.3 where by the initial setting time was that time period between the time water was added to cement and time at which 1 mm square section needle failed to penetrate the cement paste, placed in the Vicat's mould 5 mm to 7 mm from the bottom of the mould. Final setting time was that time period between the time water was added to cement and the time at which 1 mm needle made an impression on the paste in the mould but 5 mm attachment did not make any impression.

The required apparatus were weighing balance, Vicat apparatus, stop watch and measuring cylinder.

a)Consistency test b) Setting time test

Figure 3.2: Consistency and setting times tests

3.2.4.3 Chemical analysis of sugar cane bagasse ash cement

This was done to determine the chemical composition of the different samples of SCBAC (Sugarcane Bagasse Ash Cement) based on BS 812: 1992 for chemical analysis of Portland cement. The exercise was conducted using XRF technology (X-Ray Florescence Spectral Analysis) in the Ministry of Mining, Mines and Geological Department, Nairobi and the results are shown in Table 4.3.

3.3 Rheological properties of glass concrete using sugar cane bagasse ash cement

3.3.1 Introduction

Concrete is considered by most researchers in most circumstances to behave like a Bingham fluid. A Bingham fluid flow is characterized by two entities: the yield stress and the plastic viscosity. The yield stress is the stress needed to start moving the concrete, while the plastic viscosity is a characterization of the flow of the concrete once the stress is higher than the yield stress. (Chiara Ferraris, 2005)

The rheological test methods for concrete tend to fall into one of four general categories as confined flow, free flow, vibration or rotational rheometers. The free flow method was selected to describe the mode by which the concrete was forced to flow.

Free flow, the material either flows under its own weight, without any confinement, or an object penetrates the material by gravitational settling. Free flow methods include slump, modified slump, penetrating rod and turning tube viscometer. Table 3.1 shows the recommended slumps for different works.

Table 3.1: Recommended slumps (R. K. Rajput, 2000)

Concrete type	Recommended slump(mm)
Vibrated concrete	10 – 25
Mass Concrete	25 – 50
Road Works Concrete	25 – 50
Ordinary beams and slabs	50 – 100
Columns, retaining walls and thin vertical sections	75 – 125

3.3.2 Effect of sugar cane bagasse ash on workability of glass concrete

Workability may be defined as the amount of useful work necessary to produce full compaction of concrete. Workability implies the ease with which a concrete mix can be handled from the mixer to its finally compacted shape. The provision of adequate workability is critical to enable the transportation, placing and compaction of the concrete with the available equipment. It has been proposed that the workability should be defined by at least 3 separate properties: -

a) Compactibilty or the ease with which the concrete can be compacted. A fully compacted mix contains minimal voids and hence will produce higher strength concrete of less permeability.
b) Mobility or the ease with which concrete can flow into moulds around steel and be remoulded.
c) Stability or the ability of concrete to remain a stable coherent homogeneous mass during handling and vibration without the constituents segregating.

In determination of the flexural, compressive and tensile strength effects of bagasse ash cement on glass concrete, concrete mix of the ratio 1:2:4 was used where the batching was done by weight. The slump test was performed according to BS EN: 12350: 2009 whereby the standard slump cone was filled with concrete in four layers, rodding 25 times per layer, then lifting the cone and measuring the extend to which the concrete collapsed. This concrete collapse (slump) was maintained between 10 – 25 mm as required for vibrated concrete shown in Table 3.1. This was done for each sugar cane bagasse ash replacement at 0, 5, 10, 15 and 20% for cement in glass concrete production. The results, as shown in Table 4.5 were used to explain the effect sugar cane bagasse ash cement on glass concrete in terms of workability.

3.3.3 Compressive strength of glass concrete with sugar cane bagasse ash cement

The main objective of this experiment was to determine the strength of the hardened glass concrete containing bagasse ash cement. It was done in accordance to BS EN: 12390: 2000, whereby samples containing different proportions of bagasse ash cement were prepared and casted in moulds of internal dimensions of 150x150x150mm. Then the compressive strengths at 7, 14, 21, and 28 days were determined by crushing the samples in a universal testing machine as shown in Figure 3.3. For each proportion, three cubes were casted and the average taken, hence a total of 60 cubes were prepared.

a) Cube placing before testing b) Cube after testing

Figure 3.3: Compressive strength test

3.3.4 Cylinder split test of glass concrete with sugar cane bagasse ash cement

Cylinder split test was carried out to determine the tensile strength of concrete in an indirect way. A standard test cylinder of concrete specimen of 300 mm X 150mm was prepared for the various percentages of replacements of cement with bagasse ash in glass concrete at 0, 5, 10, 15, and 20%. For each replacement, three cylinders will be casted, cured and tested according to BS EN: 12390: 2009. The average tensile strength was taken for 7 and 28 days; hence a total of 30 cylinders will be prepared. To allow the uniform distribution of the applied load and to reduce the magnitude of the high compressive stresses near the points of application of the load, strips of plywood were placed between the specimen and loading platens of the testing machine. Concrete cylinders split into two halves along vertical plane due to indirect tensile stress generated by Poisson's effect.

3.3.5 Flexural strength test of glass concrete with sugar cane bagasse ash cement

This was test carried out to determine the tensile strength of concrete according to BS EN: 12390: 2009. The samples were prepared for the various percentages of replacement of sugar cane bagasse ash with cement in glass concrete and conducting three runs per replacement, then testing at 28 days after curing, hence 15 samples of dimensions 150x150x560mm were prepared and tested as shown in Figure 3.4 according to BS EN: 12390: 2009 using three point flexural test method where by the beam specimen was placed between two supports and load applied at the centre until failure using a universal testing machine and the results as shown in Table 4.4.

Figure 3.4: Flexural strength test

3.4 Accessing the influence of sugar cane bagasse ash on the structural performance of glass concrete

Concrete mix of the ratio 1:2:4 of class 20 was used for the research work as stated in Clause 3.3.2. This was because of its wide applications for general structures. Batching of the ingredients was done by weight; mixing was done manually and vibrated using electric vibrator. Portable water was used conforming to BS EN: 3148: 1980 for all mixes. After mixing, the concrete was placed in formwork made of block boards. Removal of form work took place after 24 hours and curing proceeded for 28 days while covered with membrane to retain water. The three-point load test was conducted as shown in Figure 3.5. The following beam elements were studied in investigating the structural performance of glass concrete with sugarcane bagasse ash cement as shown in Figure 3.6;

i. Variation of load using hydraulic load cell against deflection using the linear variable displacement transducers (LVDT). The LVDT was placed at the mid span of the beams to measure the deflection of the beam due to applied loads from the load cell.

ii. Shear strain gauges- The strain gauges were placed on concrete surface within the shear region in form of strain rosette to measure the beams shear strains and compare with the shear stresses of the beams. Also, some were attached to the stirrups to determine the strains induced on the shear reinforcements.

iii. Flexural strain gauges on bottom steel- These strain gauges were attached to centre of longitudinal reinforcement to measure induced flexural strains in the reinforcements, and at bottom of the beams to measure the flexural strains induced in the beams. All the above devices were connected to a data logger where the output data was captured and recorded. For the reinforcement, which was used, design was done for residential use, and reinforcement was determined.

To determine the structural behaviour of beams made using various proportions of sugar cane bagasse ash cement and 30% glass proportion of fine aggregates, a total of 15 beams were casted and tested at 28days. The sizes of the beams were 300 mm X 200 mm in cross section and 1.2m length simply supported over an effective span of 1.0m. The slump was maintained at 25mm for the whole exercise. Re-bars used as longitudinal reinforcement were Y12 bottom bars and Y8 top bars and R6 as shear re bars at 150mm centre to centre, arrived at after carrying out simple ultimate designs. The re bars were checked for tensile strength according to BS 4449 (1997). The results gave a factored strength of 537 N/mm^2 which was within the acceptable upper and the lower yield strengths of 648 N/mm^2 and 261 N/mm^2.

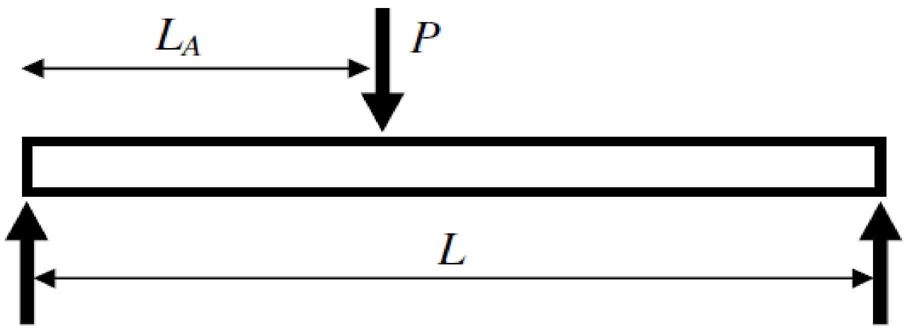

Figure 3.5: Sketch of three-point load test

Figure 3.6: Sample beam testing for load versus deflection, shear stresses, flexural stresses and shear strains

CHAPTER FOUR

4. RESULTS, ANALYSIS AND DISCUSSIONS

4.1 Properties of sugar cane bagasse ash cement

The exercise was carried out to investigate the consistency, setting times and chemical composition of sugar cane bagasse ash cement (SCBAC) and the following observations were made.

4.1.1 Consistency of sugar cane bagasse ash cement

Table 4.1 shows the consistency of sugar cane bagasse ash cement. The consistency was calculated as a percentage of the dry weight of the cement and the results are presented in Table 4.1.

Table 4.1: Consistency of sugar cane bagasse ash cement

S/No.	% of SCBA in cement	Weight of cement (g)	Weight of SCBA (g)	Water content (ml)	Plunger resistance (mm)	Consistency (mm)
1	0	400	0	153	6	38.25
2	5	380	20	155	5	38.75
3	10	360	40	158	5	39.5
4	15	340	60	158	5	39.5
5	20	320	80	160	5	40.0

The consistency results show that the consistency increased as the amount of sugar cane bagasse ash (SCBA) content increased in the mix sample. Even though, the required consistency varies from 26 to 33% for ordinary portland cement (IS 1489-1: 1991), the samples never fell within the range as shown in Figure 4.1. This is explained by the fact that Nguvu CEM IV/B(P) 32,5N is a blended cement and in addition, by adding sugar cane bagasse ash to Nguvu CEM IV/B(P) 32,5N cement has the effect of increasing the amount of water required to achieve the required consistency. Hence the more the amount of SCBA in cement, the higher the amount of water required to achieve a certain consistency. For the research done, the consistency of the SCBAC can be limited to 40% for up to 20% cement (Nguvu CEM IV/B(P) 32,5N) replacement as compared to pure ordinary portland cement.

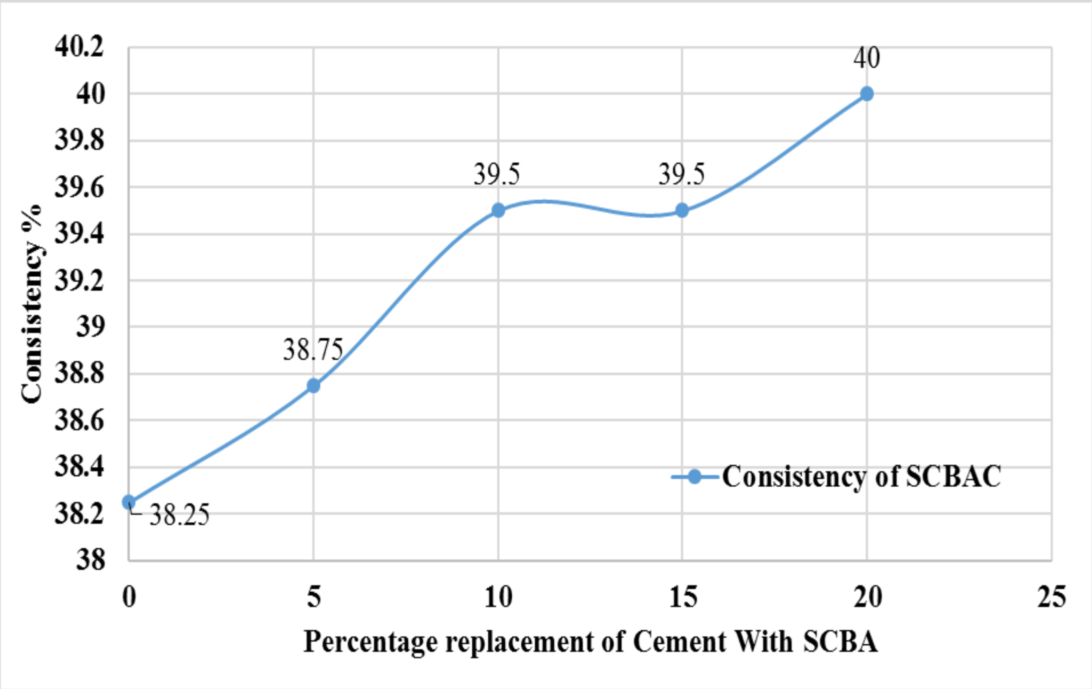

Figure 4.1: Consistency of sugar cane bagasse ash cement

4.1.2 Initial and final setting time of sugar cane bagasse ash cement

Table 4.2 shows the average initial and final setting times for sugar cane bagasse ash cement. This was done after the consistency test had been done to determine the amount of water to give the required consistency per mix of SCBAC.

For the initial setting time, four runs in two separate sets of Vicat apparatus of the experiment were carried out to determine the initial setting time of each mix of SCBAC. The observed initial setting time for the four runs per Vicat apparatus was recorded and the mean initial setting time for the two Vicat apparatus was calculated and tabulated in Table 4.2.

Table 4.2: Initial and final setting time for sugar cane bagasse ash cement

% of bagasse in cement	Average initial ietting iime (Hours)	Average final setting time (Hours)
0	2.25	8.33
5	2.67	7.92
10	2.83	7.83
15	3.08	7.58
20	3.42	7.5

From Table 4.2, the initial setting time increased as the amount of SCBA proportion increased in cement but was still within the acceptable limit of not less than 30 minutes as required by the standards. Also, the final setting time decreased as the SCBA content in the cement increased but was still within the acceptable limit of not more than 10 hours as shown in Figure 4.2. Hence, in the initial stages, SCBA can be seen as a retarder due to the sufficient amount of water it holds, as indicated by the consistency tests. In the long run, it may be seen as an accelerator, as the more the content in cement, the less the time it takes before it finally sets. This can be explained by the fact that most of the water had been used in the initial strength development stages, hence finally, the setting was speeded up by less water available.

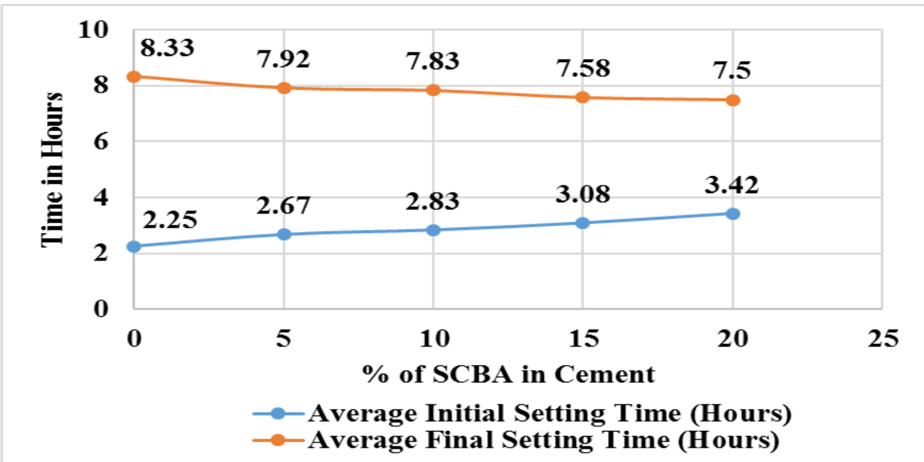

Figure 4.2: Initial and final setting time for sugar cane bagasse ash cement

4.1.3 Chemical analysis of sugar cane bagasse ash cement

This was done to determine the chemical composition of the different samples of SCBAC (Sugarcane Bagasse Ash Cement) and the results are as shown in Table 4.3.

Table 4.3: Chemical composition of sugar cane bagasse ash cement

% of Bagasse in cement	0	5	10	15	20	100
Sample name	C-100 SCBA-0	C-95 SCBA-5	C-90 SCBA-10	C-85 SCBA-15	C-80 SCBA-20	C-0 SCBA-100
Aluminum oxide (Alumina)-Al_2O_3	4.8	4.5	4.65	4.59	4.38	3.53
Silicon dioxide (Silica)-SiO_2	32	32.68	33.38	34.57	35.29	69.33
Phosphorus oxide-P_2O_5	0.76	0.85	0.85	0.93	1.08	2.66
Potassium oxide- K_2O	2.31	2.66	2.82	2.98	3.32	10.09
Calcium oxide -CaO	52.16	51.02	49.72	48.32	47.07	5.15
Titaniun- Ti	0.38	0.42	0.51	0.58	0.7	1.21
Iron- Fe	4.39	4.63	4.89	4.98	5.17	6.6
Sulphur- S	2.88	2.89	2.79	2.67	2.61	0.73
Others	<1	<1	<1	<1	<1	<1

From Table 4.3, aluminum oxide (Al_2O_3), calcium oxide (CaO) and sulphur elements generally decreased with increase in the sugar cane bagasse ash proportion in the SCBAC, but all the other elements increase with increase in the SCBA content. Generally, the pattern of the element proportion per mix sample as seen in Figure 4.3 is seen to be maintained. Also, the range of mineral composition of pure cement and the SCBAC is within the acceptable limit of 5%.

The results showed that, in the pure sugar cane bagasse ash, all the components of the pure cement were present having the oxides of silicon, potassium, iron and calcium being the most being the most prominent by 69.3% (SiO_2), 10.1% (K_2O), 6.6% (Fe), and 5.2% (CaO), respectively. But, for the pure cement, the most prominent oxides were calcium, silicon, aluminium and iron by 52.2% (CaO), 32% (SiO2), 4.8% (Al_2O_3) and 4.4% (Fe), respectively. Graphically, the variations of the proportions are as shown in Figure 4.3.

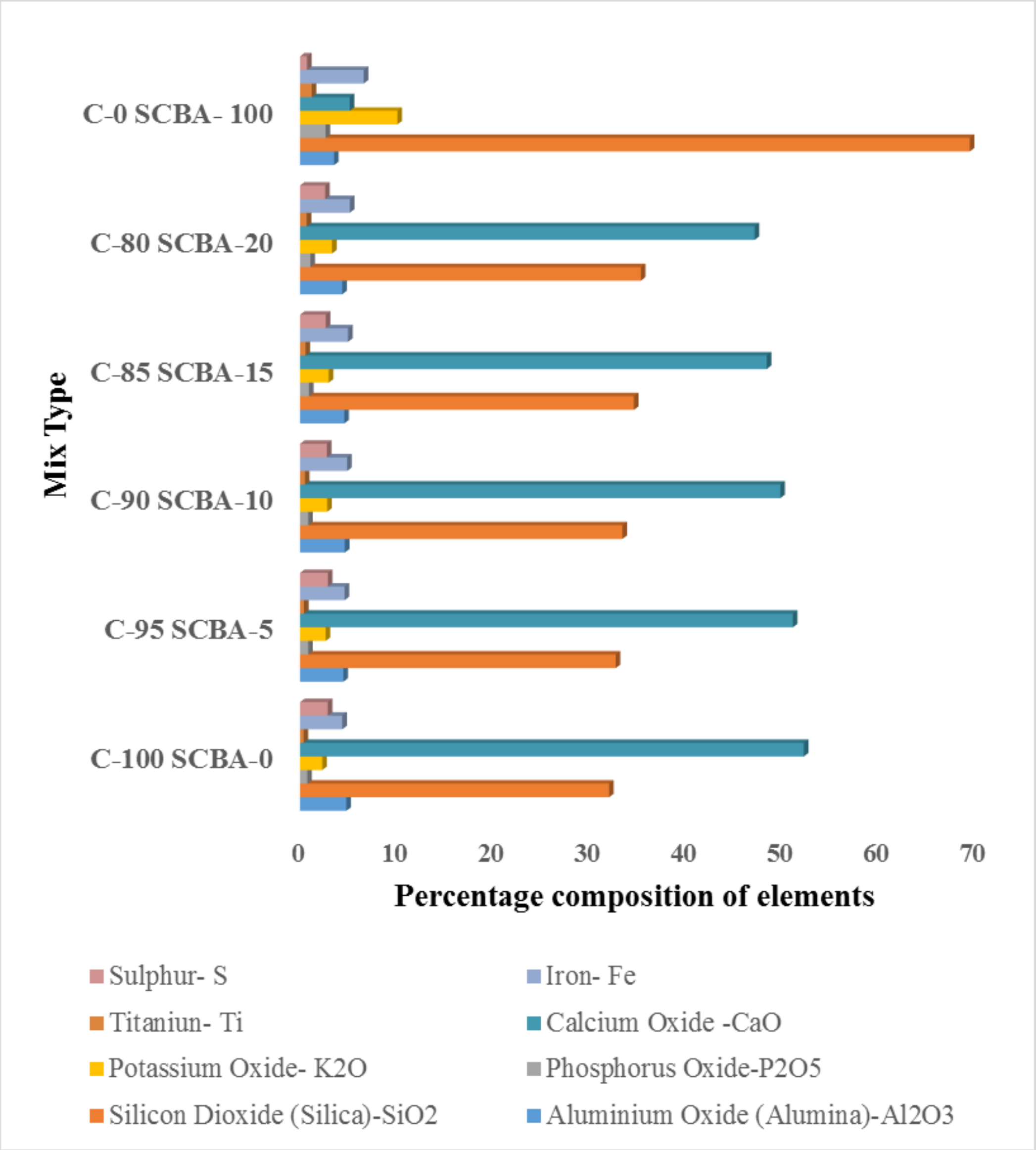

Figure 4.3: Chemical composition of sugar cane bagasse ash cement

4.2 Aggregate properties

4.2.1 Grading, specific gravity and unit weight of aggregates

The grading of aggregates was done in accordance to BS812(1985) and all the aggregates fell within the grading envelope indicating that they were within the acceptable limits as shown in Figures 4.4 to 4.6.

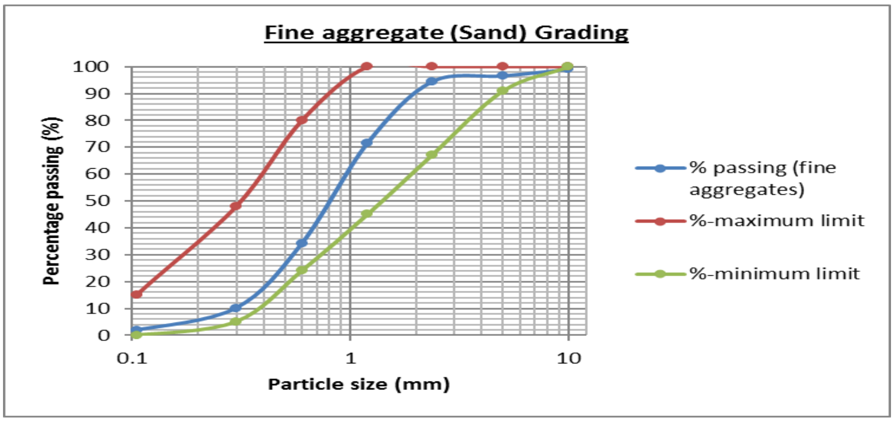

Figure 4.4: Fine aggregate grading

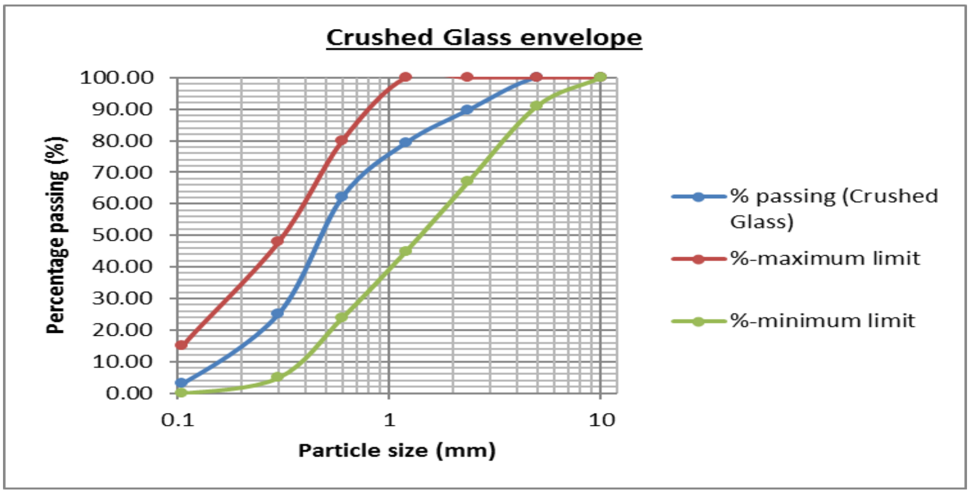

Figure 4.5: Crushed glass grading

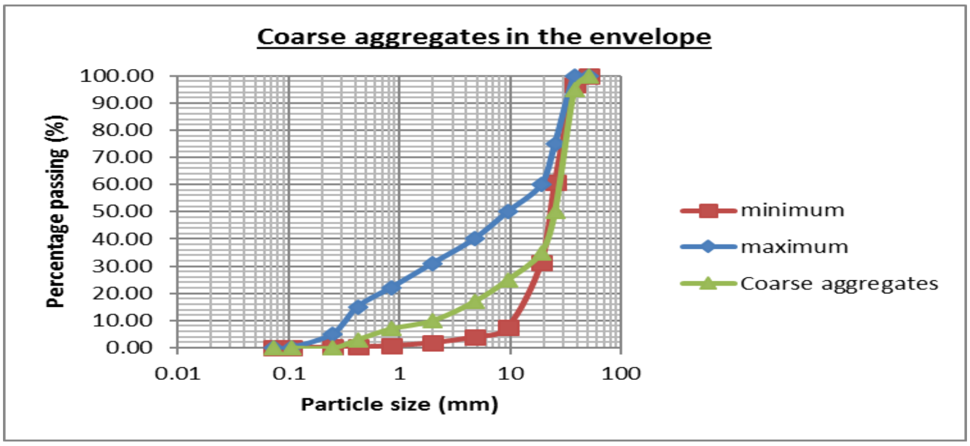

Figure 4.6: Coarse aggregate grading

The Specific gravity, water absorption and moisture content were determined in accordance to BSEN1097-6(2013) and the results showed in Table 4.4.

Table 4.4: Material properties of sand, crushed glass and ballast

Material	Bulk density (Kg/m^3)	Moisture content (%)	Specific gravity	Silt content (%)
Sand	1410	1.52	2.79	0.78
Crushed glass	1374	0.1	2.64	-
Ballast	1612	0.92	2.81	-

For the bulk densities, aggregates weighing less than 1120 Kg/m^3 were classified as light weight aggregates and more than 2080 Kg/m^3 were classified as heavy weight aggregates. For anything in between were natural mineral aggregates used for producing normal weight concrete (NWC), hence the aggregates fell within normal mineral aggregates. On the specific gravity, most natural aggregates have specific gravities between 2.4 and 3.0 hence the aggregates fell within this range. Hence, from these properties, the aggregates were found to be suitable for use in the research as they possessed the required engineering properties.

4.3 Properties of glass concrete made using sugar cane bagasse ash cement

After determining the workability of the various trial mixes to get the right amount of water for each mixture of glass concrete made of sugar cane bagasse ash cement (SCBAC), compressive strength, density, tensile split test, flexural strength tests were carried out to determine the properties of the hardened glass concrete made of sugar cane bagasse ash cement.

4.3.1 Effects of sugar cane bagasse ash cement on rheological properties of glass concrete

The variations in the water content to get the targeted slump of between 10-25mm for the various mixes was done in accordance to BS12350(2009). Concrete mix of 1:2:4 representing binder: fine aggregate: coarse aggregate. In this mix, 30% of the coarse aggregates was crushed glass. For the fine aggregate, only river sand was used and for the binder, cement was partially replaced with sugar cane bagasse ash at 0, 5, 10, 15 and 20% proportions. Table 4.5 shows the various percentages of material combination and the resulting water cement content and slump obtained. GCSCBAC XX-YY in Table 4.5 means glass concrete made using sugar cane bagasse ash cement, XX the proportion of glass in the fine aggregate (F.A) and YY is the proportion of sugar cane bagasse ash in the binder. C.A means coarse aggregate proportion, W/C means water- cement ratio and SCBA means sugar cane bagasse ash. These descriptions of concrete were used throughout the study of the behaviour of glass concrete made using sugar cane bagasse ash cement.

Table 4.5: Water cement ratio variations of glass concrete made using SCBAC

	Binder		**F. A**		**C.A**		
Specimen type	Cement	SCBA	Sand	Glass	Ballast	Slump	W/C ratio
GCSCBAC 00-00	100	0	100	0	100	24	0.55
GCSCBAC 30-05	95	5	70	30	100	25	0.58
GCSCBAC 30-10	90	10	70	30	100	24	0.61
GCSCBAC 30-15	85	15	70	30	100	24	0.62
GCSCBAC 30-20	80	20	70	30	100	25	0.65

From Table 4.5, it was observed that the water cement ratio increased with increase of SCBA content in cement for the slump level maintained within the margin of 25mm. Hence, for the allowed workability to be maintained in the mixes, the higher the SCBA content in cement, the higher water content. This is because SCBA was seen to absorb a lot of water hence more water was required for the hydration process to take place. The variation graphically is explained by Figure 4.7.

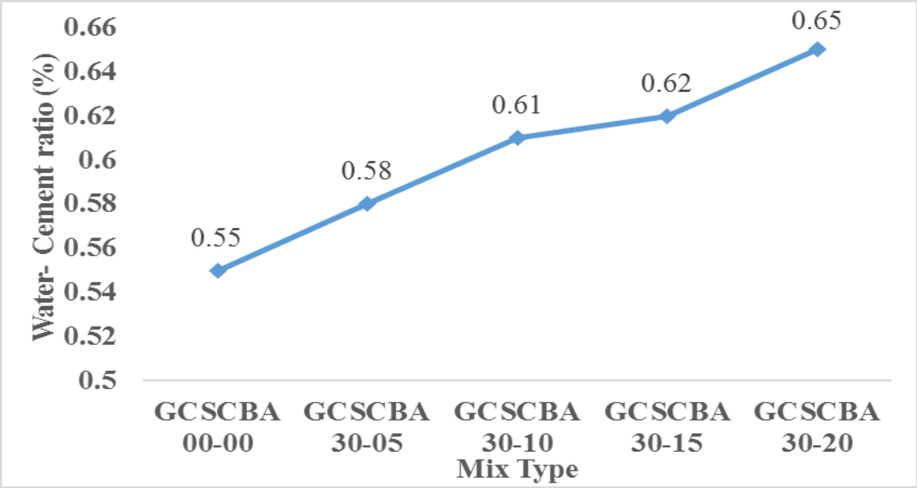

Figure 4.7: Water cement ratio variations of glass concrete made using SCBAC

From the results, in order to achieve good workability, the best water cement ratio can be maintained at 0.6 where by the percentage content of sugar cane bagasse ash is 10% and glass content is maintained at 30%.

4.3.2 Effects of sugar cane bagasse ash cement on compressive strength and density of glass concrete

A total of 60 cubes measuring 150mm were tested at a slump maintained at 25mm to explain the compressive strength behaviour of glass concrete made using sugar cane bagasse ash cement. Table 4.6 shows the compressive strengths of each mix proportion and each value is the mean of triplicate results per test.

Table 4.6: Compressive strength variations of glass concrete made using SCBAC

	7 Day Strength (N/mm^2)	14 Day Strength (N/mm^2)	21 Day Strength (N/mm^2)	28 Day Strength (N/mm^2)	F_{cu7}/F_{cu28} (%)
GCSCBAC 00-00	14.652	17.829	21.723	23.602	69.994
GCSCBAC 30-05	11.068	12.510	18.550	21.390	51.745
GCSCBAC 30-10	11.456	12.991	20.213	22.203	51.597
GCSCBAC 30-15	11.065	12.177	16.588	20.719	53.406
GCSCBAC 30-20	9.501	10.377	13.539	17.787	53.415

Comparatively, the strength of the glass concrete made using sugar cane bagasse ash cement was lower than the control experiment. Also, it is observed that, for the concrete containing both sugar cane bagasse ash and glass, the strength initially increased up to 10% SCBA replacement in cement at 30% glass replacement in fine aggregates, but there after the strength dropped as the proportion of SCBA increased in the mix. This explains that, up to 10% SCBA replacement in cement increases the compressive strength glass concrete due to the increased amount of water cement ratio required for hydration process, but above 10% replacement of the cement with SCBA, the strength goes down as the content becomes saturated and the water is not useful in hydration process as it is being held between the SCBA pores. Graphically, the results are shown below.

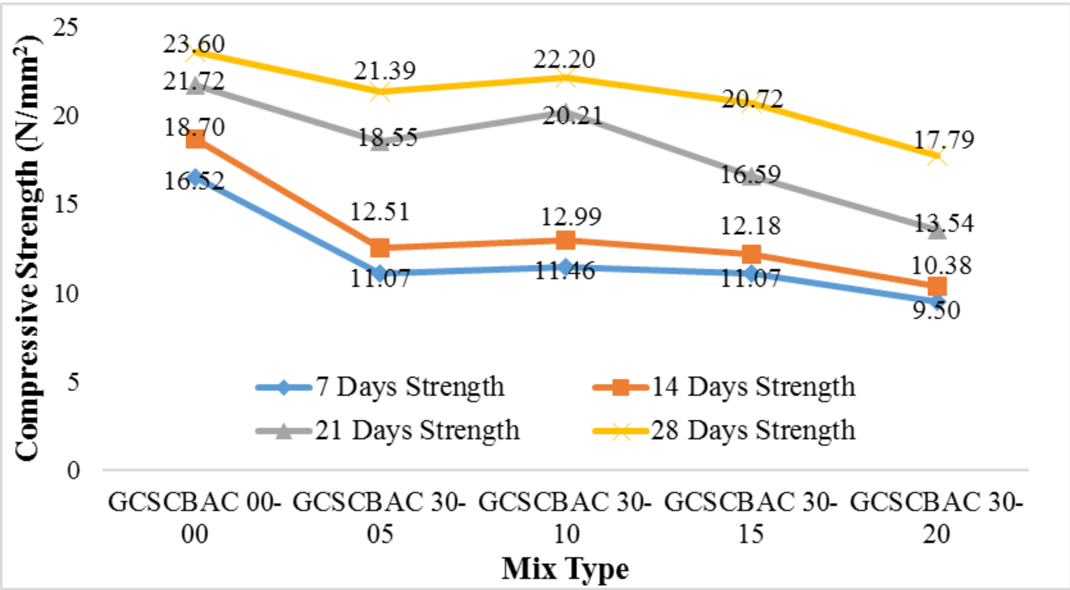

Figure 4.8: Compressive strength variations of glass concrete made using SCBAC

Figure 4.9 shows the percentage of 28 days' compressive strengths achieved at 7 days for the various mixes.

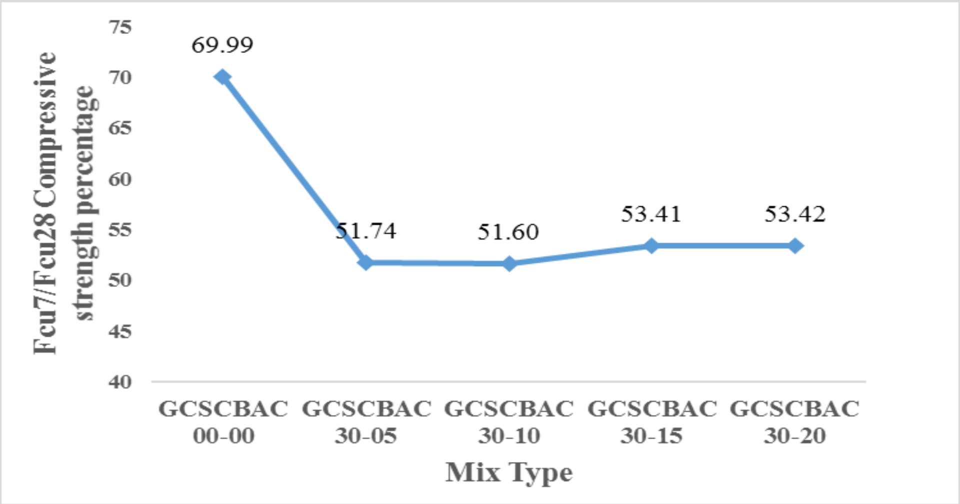

Figure 4.9: Percentage of 28 days' compressive strength achieved at 7 days of glass concrete made using SCBAC

From Table 4.6, it can be seen that the control mix achieved the required 70% compressive strength at 7 days but for the rest of the mixes, the compressive strength was lower than the required (between 50 to 55%). Also, there is increase in compressive strength as the age of curing increases. From Figure 4.9, the ratio of 7 days to 28 days' compressive strength shows that there is general increase in the rate of strength development as the replacement level increased. Also, the ratio of strength of the mixes to the control mix at the same age is as shown in the Table 4.7.

Table 4.7: Compressive strength percentages of various GCSCBAC mixes to that of control mix of the same age.

	7 Days	14 Days	21 Days	28 Days
GCSCBAC 00-00	100.00	100.00	100.00	100.00
GCSCBAC 30-05	67.00	66.90	85.40	90.63
GCSCBAC 30-10	69.35	69.47	93.05	94.07
GCSCBAC 30-15	66.98	65.12	76.36	87.78
GCSCBAC 30-20	57.51	55.49	62.33	75.36

From Table 4.7, it can be seen that the compressive strength of the various mixes was lower as compared to the control mix, but significant increase up to 10% replacement is noted then general drop for all mixes as shown in Figure 4.10.

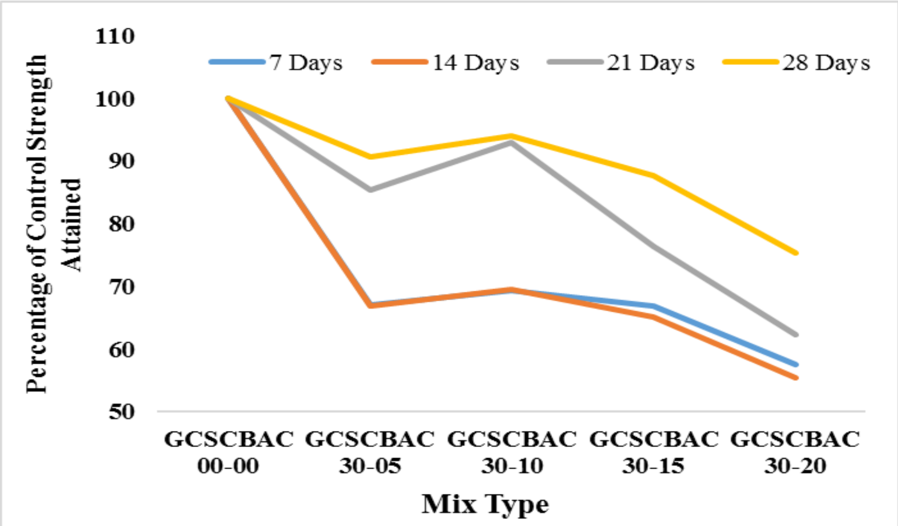

Figure 4.10: Percentage of control compressive strength achieved at same ages

From Table 4.8, the density was not very consistency but generally not expected to vary so much, that is why they ranged between 2283 to 2406 Kg/m^3.

Table 4.8: Density variations of glass concrete made using SCBAC

	7 Days (Kg/m^3)	14 Days (Kg/m^3)	21 Days (Kg/m^3)	28 Days (Kg/m^3)
GCSCBAC 00-00	2283	2285	2302	2376
GCSCBAC 30-05	2319	2321	2350	2362
GCSCBAC 30-10	2280	2406	2352	2355
GCSCBAC 30-15	2354	2347	2366	2329
GCSCBAC 30-20	2362	2343	2336	2365

This can be explained by the fact that batching of the concrete ingredients and the various replacements were done by weight and not by volume. The graphical representation is as shown in Figure 4.11.

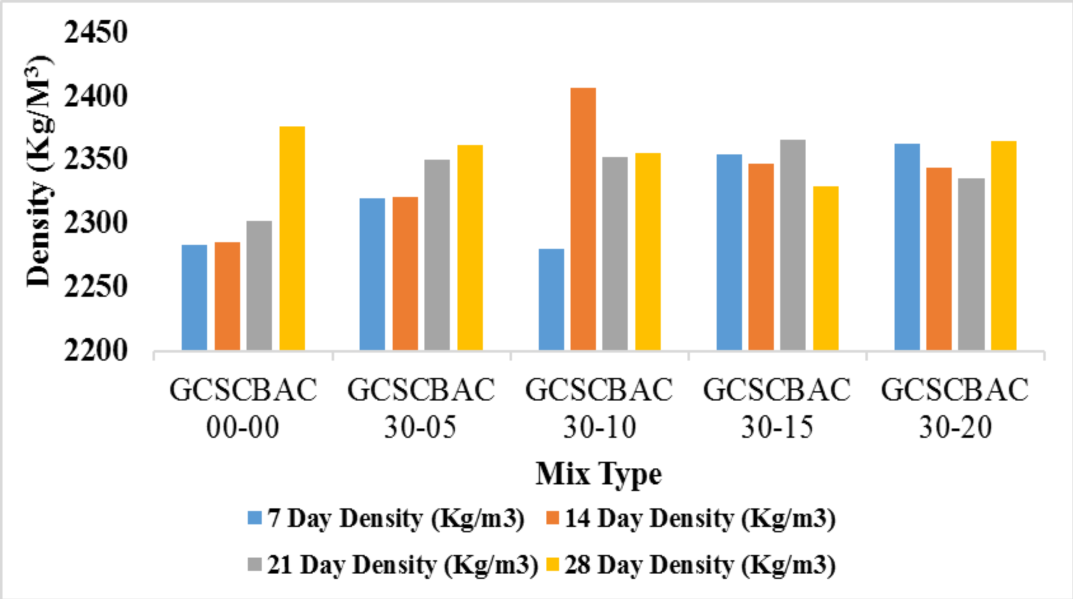

Figure 4.11: Density variations of glass concrete made using sugar cane bagasse ash cement

4.3.3 Effects of sugar cane bagasse ash cement on split tensile strength of glass concrete

For this investigation, an average of three cylinders were tested for 7 and 28 days split tensile strength, making a total of tested specimens to be 30 cylinders for 5 mixes. Table 4.9 shows the results of the 7 and 28 days split tensile strength of glass concrete made using sugar cane bagasse ash cement, each value being a mean of three-cylinder test results.

Table 4.9: Split tensile strength of glass concrete made using sugar cane bagasse ash cement

	Tensile strength, Ft (N/mm^2)		
	7 Days	28 Days	F_{cu7}/F_{cu28} (%)
GCSCBAC 00-00	1.917	2.763	0.693607
GCSCBAC 30-05	1.837	2.557	0.718383
GCSCBAC 30-10	1.733	2.473	0.700809
GCSCBAC 30-15	1.590	2.390	0.665272
GCSCBAC 30-20	1.483	2.217	0.669173

The results show that the tensile split test, even though lower that control experiment, increased with increase in the concrete curing age but decreased with increase sugar cane bagasse ash content in the mix. Also notable is that for 5 and 10% replacement of cement with sugar cane bagasse ash and at 30% replacement of the fine aggregates with glass for both mixes. The concrete had achieved higher strength than the control experiment at 7 days reaching at 71.8 and 70% respectively as compared to the control experiment at 69.4%. But generally, there was a decrease in strength ratio of 7 to 28 days from GCSCBAC 30-05 to GCSCBAC 30-20 mixes as shown in Figure 4.12.

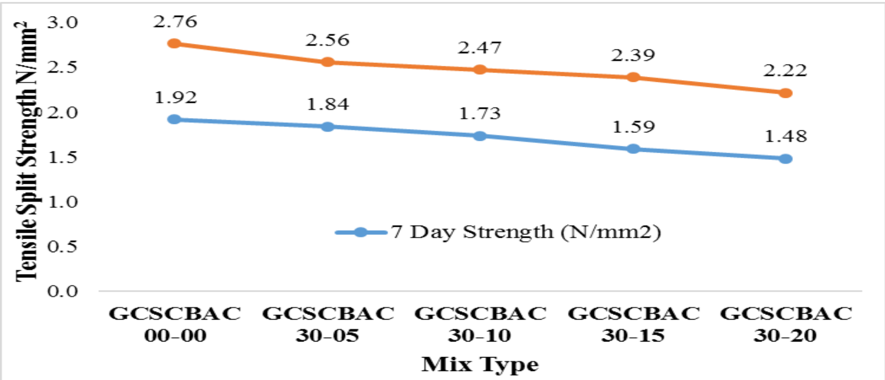

Figure 4.12: Tensile split strength of glass concrete made using sugar cane bagasse ash cement

Figure 4.13 shows the tensile split strength of glass concrete made using sugar cane bagasse ash cement as a ratio of control concrete of the same age.

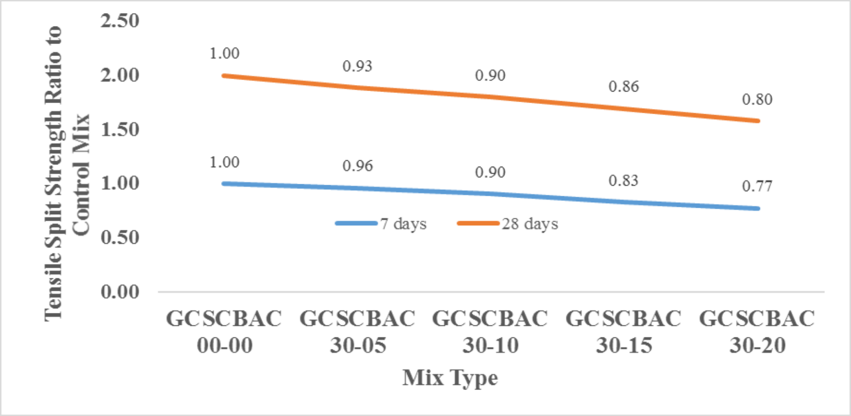

Figure 4.13: Percentage of control tensile split strength achieved at same ages

In establishing the relationship between the compressive strength and tensile strength of glass concrete made using sugar cane bagasse ash cement at 28 days, Figure 4.14 was used to explain the relationship based on the strengths at 28 days. The mathematical relationship between the compressive strength (Fcu_{28}) at 28 days and the corresponding split tensile strength (Ft_{28}) at 28 days is represented in the Equation 4.1 with R^2 value of 0.93.

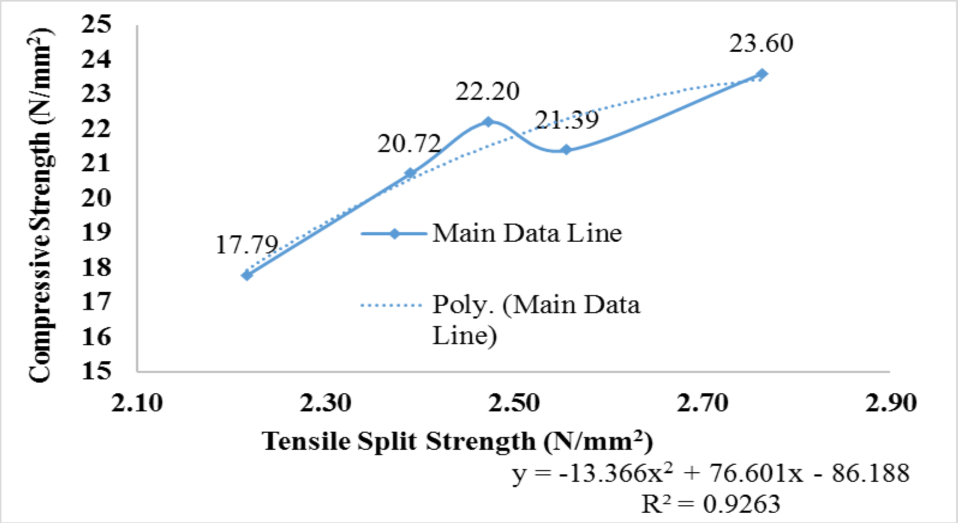

Figure 4.14: Relationship between compressive strength and tensile split strength of glass concrete made using sugar cane bagasse ash cement

$$Fcu28 = -13.366Ft28^2 + 76.601Ft28 - 86.188 \text{ -------------(4.1)}$$

The values of tensile strength of concrete are usually 10-15% of compressive strength but not more than 20%. From the equation, the estimated values were within the range of 10-15%.

4.3.4 Effects of sugar cane bagasse ash cement on flexural strength of glass concrete

Flexural strength test was done using a 1500kN universal testing machine and the results are shown in Table 4.10. Each value of the flexural strength represents the mean of triplicate results and tests were done at 28 days only. From the results, the flexural strength was lower than the control mix.

Table 4.10: Flexural strength of glass concrete made using sugar cane bagasse ash cement

	28 Days Flexural Strength (N/mm^2)	28 Days Compressive Strength (N/mm^2)
GCSCBAC 00-00	3.80	23.60
GCSCBAC 30-05	3.61	21.39
GCSCBAC 30-10	3.49	22.20
GCSCBAC 30-15	3.33	20.72
GCSCBAC 30-20	3.15	17.79

Generally, from Figure 4.15, it can be observed that the higher the replacement of sugar cane bagasse ash in the mix while holding the proportion of glass to 30% of the fine aggregates, the lesser the flexural.

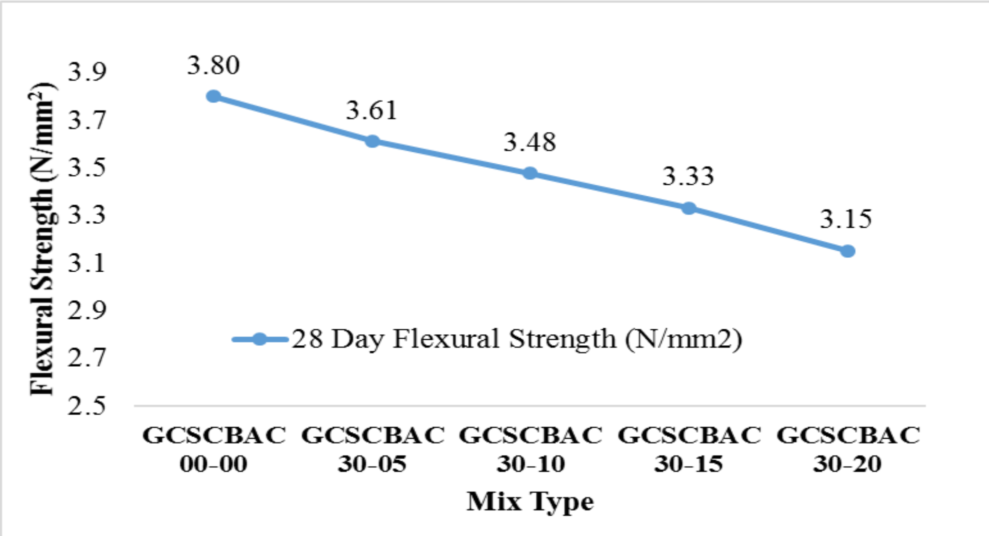

Figure 4.15: Flexural strength of glass concrete made using sugar cane bagasse ash cement

To establish the mathematical relationship between the flexural strength and the compressive strength of glass concrete made using sugar cane bagasse ash cement, Figure 4.16 shows graphically the relationships between these two strengths.

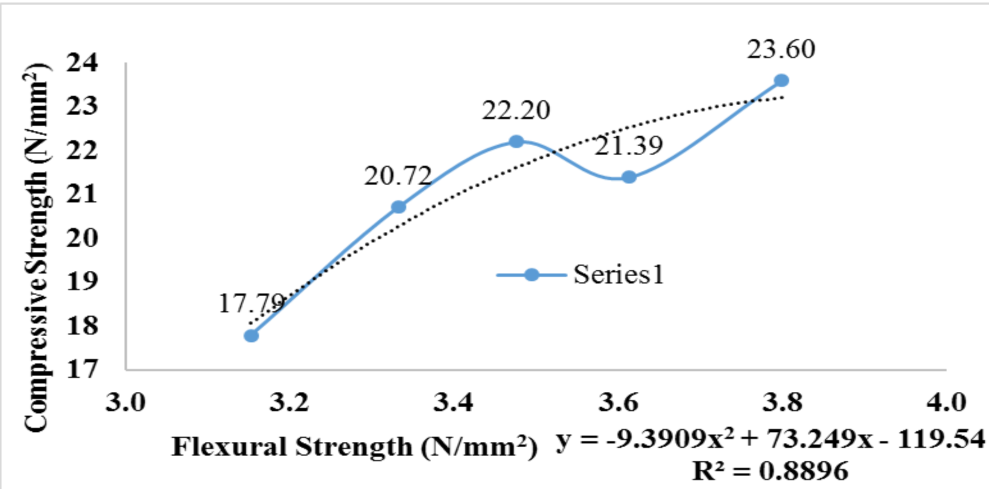

Figure 4.16: Relationship between compressive strength and flexural strength of glass concrete made using sugar cane bagasse ash cement

$Fcu28 = -9.39Ff28^2 + 73.251Ff28 - 119.54$ -------------(4.2)

From the trend observed in Figure 4.16, a mathematical relationship between the compressive strength ($Fcu28$) and flexural strength ($Ff28$) of glass concrete made

using sugar cane bagasse ash cement can be represented by a polynomial equation 4.2 with R^2 values of 0.89. The usual relationship between compressive strength and flexural strength of concrete is that the compressive strength is approximately 8-10 times the flexural strength, hence the estimated values of equation 4.2 were within the required range.

4.4 Structural behavior of glass concrete beams made using sugar cane bagasse ash cement

4.4.1 Load- deflection behavior of glass concrete beams made using sugar cane bagasse ash cement

For this treatment, load deflection behaviour of glass concrete beams made using sugar cane bagasse ash cement was determined by taking the average deflection of the three beams for all types of mixes of concrete under investigation and the results plotted as shown in the Figure 4.17 in page 46.

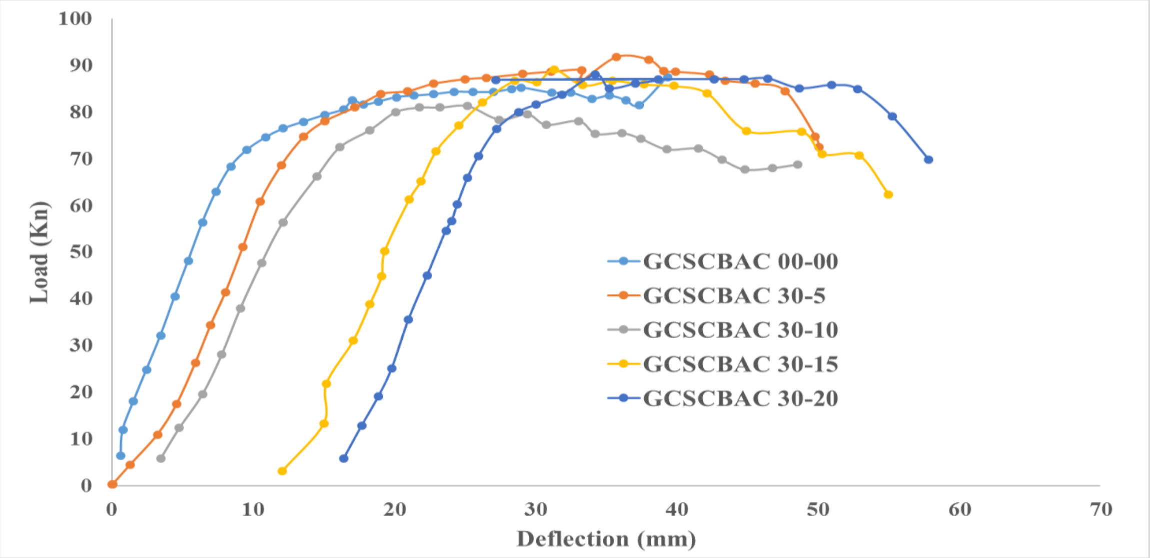

Figure 4.17: Load- deflection curves of glass concrete beams made using sugar cane bagasse ash cement

From Figure 4.17, all the beams for the various mix types exhibited similar load deflection characteristics but attained their ultimate at different points with a rapid decrease in the initial stiffness at the appearance of major diagonal cracks. The control beam attained the least ultimate load than beams containing sugar cane bagasse ash as part of the cement and 30% waste glass as part of fine aggregates. Generally, deflections were found to increase with increase in replacement levels of cement with sugar cane bagasse ash and replacement of fine aggregates with glass at 30%. Also, the reason why the deflections did not start at zero for all the mixes was the fact that, the jerk from the load cell might have been positioned firmly hence applying some load at set up stage before load application.

4.4.2 Deflection at different loading stages of glass concrete beams made using sugar cane bagasse ash cement

Table 4.11 in page 48 shows the summary of deflection of each beam at service and ultimate load. The service load was calculated by dividing the ultimate load by 1.5 according to BS 6399-1 1996. The results from Table 4.11 shows that for all the beams with sugar cane bagasse ash took higher service loads than the control beam. GCSCBAC 30-10 took highest service and ultimate loads. Deflections at service loads and ultimate loads were smallest for the control beam and increased as the replacement percentages increased. For the deflections at ultimate loads, only GCSCBAC 00-00, GCSCBAC 30-5 and GCSCBAC 30-10 met the deflection requirements of less than 20mm for BS 8110-1 (1997) and for deflections at service loads, all the beams with mix proportions at service loads plus GCSCBAC 30-15 met the deflection requirements of less than 20mm for BS 8110-1 (1997) of rectangular beams. Generally, all the mix proportions had their deflections increasing with increase in the replacement percentages.

Table 4.11: Deflection at different stages of glass concrete beams made using sugar cane bagasse ash cement

Mix type	Ultimate Load (kN)	Service Load (kN)	Deflection at Ultimate Load (mm)	Deflection at Service Load (mm)
GCSCBAC 00-0	68.32	45.55	8.41	5.2
GCSCBAC 30-5	68.4	45.6	12.0	8.6
GCSCBAC 30-10	77.48	51.65	16.41	11.2
GCSCBAC 30-15	77.12	51.41	24.56	19.3
GCSCBAC 30-20	76.32	50.88	27.24	22.8

4.4.3 Shear behavior of glass concrete beams made using sugar cane bagasse ash cement

The shear stress shear strain curves of beams were plotted to visualize the behaviour of glass concrete beams made using sugar cane bagasse ash cement and the results compared with control beams. Shear stress was calculated by the relationship shown in the equation 4.3 in page 49 and the data plotted in Figure 4.18 in page 49.

$$\mathbf{v} = \frac{p}{2bh} \text{----------------------(4.3)}$$

Where: - v is the shear stress

p is the applied load

b is the breath of the beam

h is the depth of the beam

Shear strain was calculated from the strain rosette arrangement using the relation in equation 4.4

$$\gamma_{xy} = \varepsilon_{45}{}^{0} - (\varepsilon_{90}{}^{0} + \varepsilon_{0}{}^{0}) \text{----------------------(4.4)}$$

Where: -

γ_{xy} is shear strain

$\varepsilon_{45}{}^0$ is the strain at 45^0 inclined to the horizontal

$\varepsilon_0{}^0$ is the strain at 0^0, $\varepsilon_{90}{}^0$ is the strain at 90^0

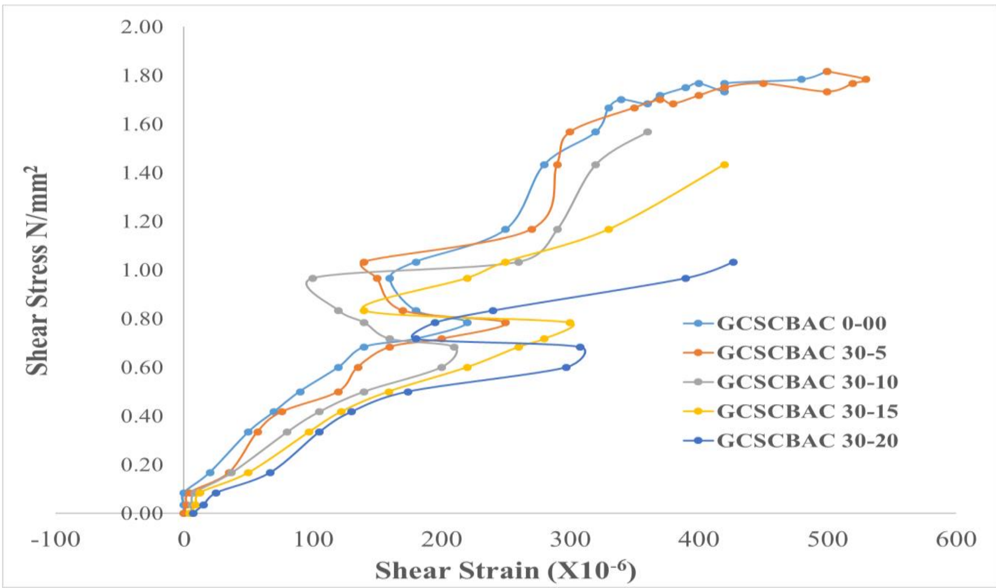

Figure 4.18: Shear stress- shear strain curves of glass concrete beams made using sugar cane bagasse ash cement

From the shear stress- shear strain curves in Figure 4.18, negative strain relaxation was observed between 0.6 to 0.8N/mm^2 for all the beams after the ultimate shear stress was attained. For beams containing sugar cane bagasse ash proportion of cement and 30% waste glass content, the relaxation mas more pronounced as compared to the beams without these waste materials. Also, strain increase was more pronounced for beams containing sugar cane bagasse ash of 0 and 5% by proportion of cement with 30% glass by proportion of fine aggregates, and less for beams containing 30% waste glass by proportion of fine aggregates and 10, 15 and 20% sugar cane bagasse ash proportion of cement. Generally, for all the beams, the shear stress- shear strain curves behaved the same.

4.4.4 Flexural strain behavior of glass concrete beams made using sugar cane bagasse ash cement

Figure 4.19 shows the relationship between loads applied and induced flexural strains at the bottom of all concrete beams containing various mix proportions of sugar cane bagasse ash as part of cement and glass as part of fine aggregates.

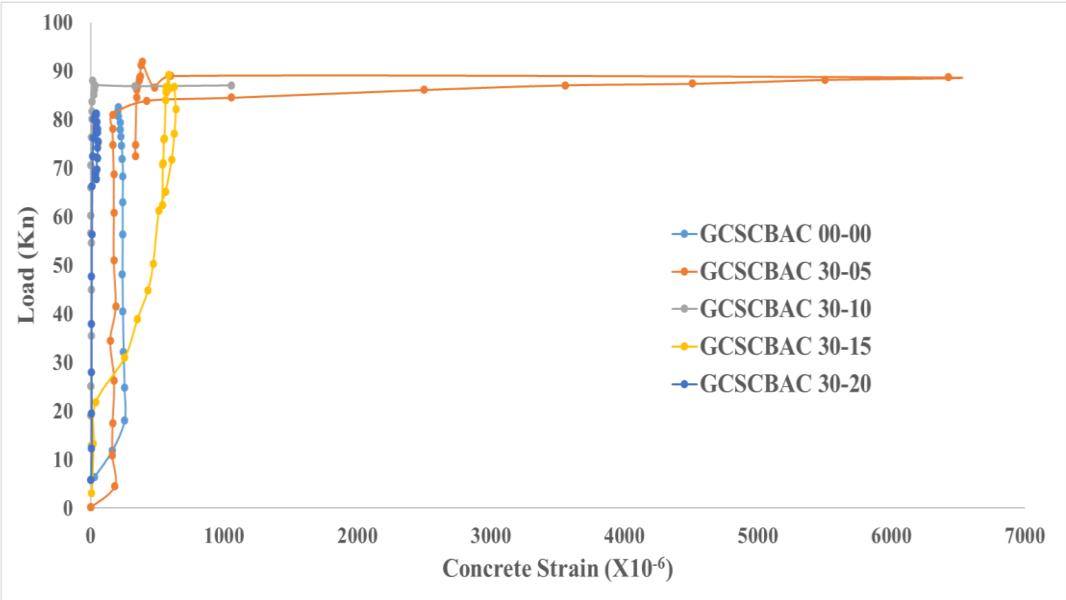

Figure 4.19: Concrete strain curves of glass concrete beams made using sugar cane bagasse ash cement

From Figure 4.19, it was observed that for the control, its strain increased during initial stages up to 469×10^{-6} for 50kN, then thereafter, there was no much increase in the strain with increase in the loading. Same case was depicted by mix type GCSCBAC 30-05 but the strain went up to 183×10^{-6} for 18kN then same behaviour as the control mix was depicted. For the other mixes, initially, the induced strains were initially negligible up to between 80 to 90kN where by the strains exponentially increased. The general behaviour of the beams was the higher the proportions of sugar cane bagasse ash in the mix at 30% glass composition, the less the strains induced in the beam produced. Also, at initial loads, the strains were seen to increase then remain constant over the loading time. Figure 4.20 shows the flexural strains induced at the centres of the longitudinal reinforcements embedded in the beams in response to load applications.

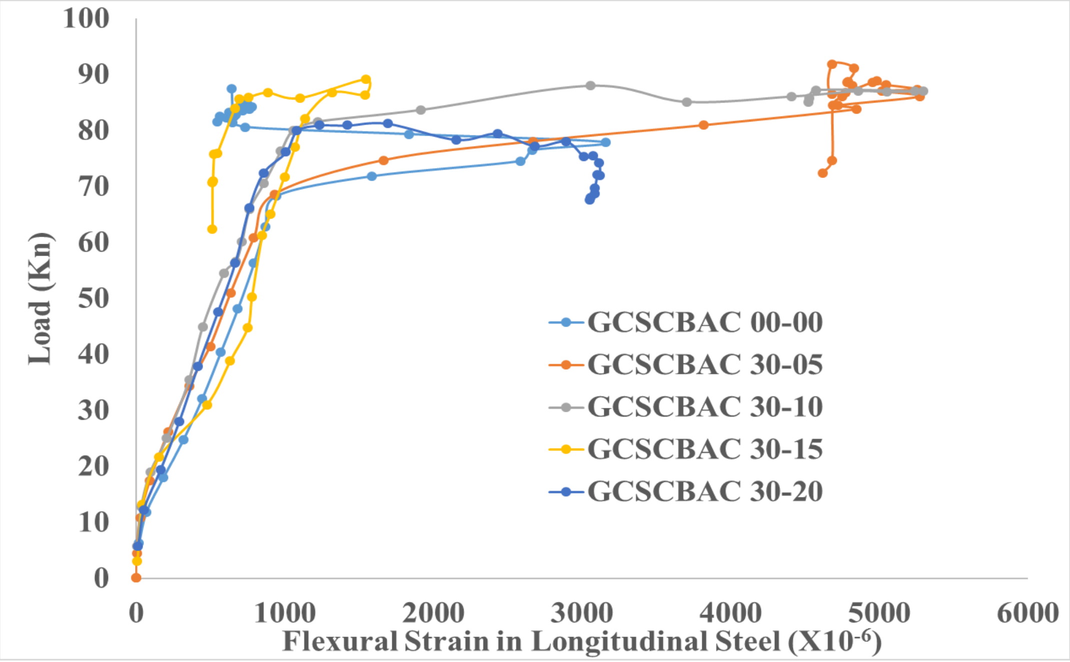

Figure 4.20: Flexural strain curves induced at centre of longitudinal reinforcements of glass concrete beams made using sugar cane bagasse ash cement

For all the beams, they initially behave alike inducing zero strains until the load reached 10kN. For GCSCBAC 00-00 and GCSCBAC 30-05, the linear elastic response is up to 70kN but for the rest, the linear elastic stretched up to 80kN but all the mixes generally exhibited similar trends during the linear elastic region. Figure 4.21 shows the stirrup strains induced at the centres of the shear reinforcements embedded in the beams in response to load applications.

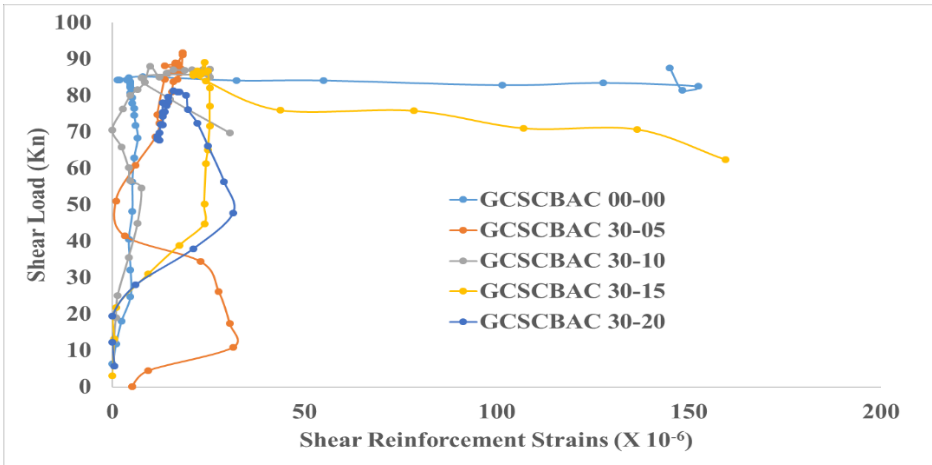

Figure 4.21: Stirrups strain curves of glass concrete beams made using sugar cane bagasse ash cement

It can be seen that for all mix types, the beams had a relaxation of the strains. Before the relaxation, GCSCBAC 30-20 had the highest strains of $48x10^{-6}$ but immediately after yield point which occurred at 80kN, it failed. For GCSCBAC 00-00 and SCBAC 30-15 sustained some load after 85kN until they failed. There was no remarkable comparison for the behaviours of the strains in the stirrups for the different mixes.

4.4.5 Cost and environmental benefits of glass concrete made using sugar cane bagasse ash cement

Glass concrete made using sugar cane bagasse ash cement has several benefits including cost and environmental benefits. Based on the materials used, a brief cost analysis was carried out to bring out the cost benefits of using sugar cane bagasse ash and waste glass in concrete over the normal concrete without these materials. The basis of the analysis was market buying price. Both sugar cane bagasse ash and waste glass were bought at zero shillings. Also, water was got from the laboratory for free hence its cost was not considered. Also, the mixture to produce one cubic metre of concrete containing these waste materials at different proportions was used. The cost of the materials were Kshs. 2500, 2000 and 800 for 1000 Kg of sand, 1000kg of ballast and 50 kg of cement respectively. The density of concrete was taken as 2400 Kg/m^3. Table 12 shows the cost components of all the constituents used in the mix and the savings made excluding the cost of mixing.

Table 4.12: Cost analysis of glass concrete beams made using sugar cane bagasse ash cement

Mix Type	GCSCBAC 00-00	GCSCBAC 30-05	GCSCBAC 30-10	GCSCBAC 30-15	GCSCBAC 30-20
Cement (Kshs)	5487.36	5212.99	4938.62	4664.26	4389.89
SCBA (Kshs)	0.00	0.00	0.00	0.00	0.00
Sand (Kshs)	1714.20	514.26	514.26	514.26	514.26
Waste glass (Kshs)	0.00	0.00	0.00	0.00	0.00
Coarse aggregates (Kshs)	2742.72	2742.72	2742.72	2742.72	2742.72
Total (Kshs)	9944.28	8469.97	8165.60	7921.24	7646.87
Savings (%)	0	14.83	17.58	20.34	23.1

It can be seen from Table 4.12 above that as the mix proportions increased, the saving increased up to 23.1% for concrete containing sugar cane bagasse ash of 20% of cement and 30% crushed glass of fine aggregates. In addition, apart from cost saving, there are environmental advantages of using sugar cane bagasse ash and waste glass. These include: -

a) Reduction of carbon dioxide ($C0_2$) emissions to the atmosphere by using less cement as a lot of $C0_2$ is produced during cement production whose net effect results to reduced global warming.
b) Reduction in sugar cane bagasse waste from sugar mills, and waste glass which sometimes is not disposed well as these poses health hazard effects on surrounding communities and also environmental degradation.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS AND AREAS OF FURTHER RESEARCH

5.1 Conclusions

The structural performance of concrete containing 30% of fine aggregates as crushed waste glass and cement replacement by sugar cane bagasse ash of up to 20% was studied experimentally. From this research work, the following conclusions may be drawn;

i. Sugar cane bagasse ash (SCBA) is hygroscopic, as the higher the content in cement, the higher the amount of water required for standard consistency to be achieved.

ii. For sugar cane bagasse ash cement (SCBAC), the consistency has been found to cap at 40% for up to 20% SCBA replacement in Nguvu CEM IV/B(P) 32,5N.

iii. SCBAC is a retarder at initial setting time with up to 3.42 hours for 20% replacement in Nguvu CEM IV/B(P) 32,5N cement, but an accelerator with up to 7.5 hours final setting time at 20% Nguvu CEM IV/B(P) 32,5N cement replacement.

iv. The highest component of SCBA is SiO_2 at 69.3% as compared to pure Nguvu CEM IV/B(P) 32,5N cement with 32.0 % of the same compound mineral.

v. The highest component of pure Nguvu CEM IV/B(P) 32,5N cement is CaO at 52.16% as compared to pure SCBA with 5.2% of the same compound mineral.

vi. All the mineral components of the SCBAC did not vary with more than 5% from the composition of pure cement, and are within the acceptable limits as per BS12-1996 hence, the replacement up to 20% is generally acceptable.

vii. In order to achieve good workability, the best water cement ratio can be maintained at 0.6 where by the percentage content of sugar cane bagasse ash is 10% and glass content is maintained at 30%.

viii. The compressive, flexural and tensile split tests showed that the strengths of the various mixes were lower as compared to the control mix, but significant increase up to 10% replacement of cement with sugar cane bagasse ash and 30% replacement of fine aggregates with crushed glass was noted achieving a 70% 28-days strength at 7 days.

ix. The usual relationship between compressive strength and flexural strength of concrete was that the compressive strength was approximately 8-10 times the flexural strength, hence the estimated values of were within the required range.

x. For the deflections at ultimate loads, only GCSCBAC 00-00, GCSCBAC 30-5 and GCSCBAC 30-10 met the deflection requirements of less than 20mm for BS 8110-1 (1997) and for deflections at service loads, all the beams with mix proportions at service loads plus GCSCBAC 30-15 met the deflection requirements of less than 20mm for BS 8110-1 (1997) of rectangular beams. Generally, all the mix proportions had their deflections increasing with increase in the replacement percentages.

xi. Strain increase was more pronounced for beams containing sugar cane bagasse ash of 0 and 5% by proportion of cement with 30% glass by proportion of fine aggregates, and less for beams containing 30% waste glass by proportion of fine aggregates and 10, 15 and 20% sugar cane bagasse ash proportion of cement. Generally, for all the beams, the shear stress- shear strain curves were behaving the same.

xii. The general behaviour of the beams was that the higher the proportions of sugar cane bagasse ash in the mix at 30% glass composition, the less the strains induced in the beam produced. Also, at initial loads, the strains were seen to increase then remain constant over the loading time.

5.2 Recommendations

From the results, the following recommendations were made;

a) In order to recycle and make our wastes useful especially in civil engineering, there is need to start up funded research courses on these wastes to determine their engineering properties and where they can be used best. E.g. Recycled waste use in Civil Engineering.

b) Once cement is replaced with sugar cane bagasse ash at 10% and fine aggregates replaced with crushed glass at 30%, good workability is achieved and early strength developments of concrete class 20 of the ratio 1:2:4 are achieved of up to 70% in 7 days. This is possible at water cement ratio of 0.6. This mix can be used for lightly loaded beams and slabs in buildings.

c) There is also need to develop codes or guiding standards on the use of various wastes like sugar cane bagasse ash and glass in concrete. Once developed, there will be reduced cost of construction due to use of readily available wastes and solve the problem of environmental degradation.

5.3 Further research areas

The following research areas are recommended for further research pertaining the use of sugar cane bagasse ash and crushed glass on concrete;

a) Combined effects of sugar cane bagasse ash and crushed glass on concrete permeability and cracking effects.

b) Effect of sugar cane bagasse ash and crushed glass concrete on other mix ratios of concrete.

c) Effects of plasticizers on glass concrete made using sugar cane bagasse ash cement

d) Investigation of columns and slabs behaviour using glass concrete made using sugar cane bagasse ash cement.

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APPENDICES

APPENDIX 1: List of publications

Brian Mwendwa Mutua, Dr. Timothy Nyomboi, Prof. Raphael Ndisya Mutuku, " Consistency, Setting Times and Chemical Properties of Sugar Cane Bagasse Ash Cement", International Journal of Science and Research (IJSR), https://www.ijsr.net/archive/v5i10.php, Volume 5 Issue 10, October 2016, 520 - 524, DOI: 10.21275/ART20162079

APPENDIX 2: Grading of aggregates

Table A-1: Grading of sand from Meru

Test sieve size (mm)	Weight retained (g)	Weight passing (g)	% Passing	% Maximum limit	% Minimum limit
0	4.5	0	0	0	0
0.074	18.5	4.5	0.4	0	0
0.105	100.5	23	1.9	15	0
0.3	296.5	123.5	10.1	48	5
0.6	460.5	420	34.2	80	24
1.2	280	880.5	71.6	100	45
2.36	26.5	1160.5	94.4	100	67
5	30.5	1187	96.6	100	91
10	8	1217.5	99	100	100

Table A-2: Grading of crushed glass

Test sieve size (mm)	Weight retained (g)	Weight passing (g)	% Passing	% Maximum limit	% Minimum limit
0	16	0	0.00	0	0
0.074	25	16	1.17	0	0
0.105	86	41	2.99	15	0
0.3	304	345	25.18	48	5
0.6	506	851	62.12	80	24
1.2	235	1086	79.27	100	45
2.36	142	1228	89.64	100	67
5	0	1370	100.00	100	91
10	0	1370	100.00	100	100

Table A-3: Grading of ballast

Test sieve size (mm)	Weight retained (g)	Weight passing (g)	% Retained	% Passing	% Maximum limit	% Minimum limit
0	5.2		0.07	0.00	0	0
0.074	2.1	5.2	0.03	0.07	0	0
0.105	9.1	7.3	0.12	0.09	0	0
0.25	11.1	16.4	0.14	0.21	5	0
0.42	30.8	27.5	0.39	0.35	15	3
0.84	85.5	58.3	1.09	0.75	22	7
2	170.5	143.8	2.18	1.84	31	10
4.76	278.8	314.3	3.57	4.02	40	17
9.52	1853	593.1	23.71	7.59	50	25
19.1	2293.3	2446.1	29.35	31.30	60	35
25.4	2810.8	4739.4	35.97	60.65	75	50
38.1	264.7	7550.2	3.39	96.61	100	95
50.8	0	7814.9	0.00	100.00	100	100
totals	7814.9		100.00			