# Structural Performance of Sugarcane Bagasse Ash Laterized Concrete

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CE300-0011/12

A thesis submitted to Pan African University, Institute for Basic Sciences Technology and Innovation in partial fulfilment of the requirement for the degree of

Master of Science in Civil Engineering (Structural Option)

November, 2014

# DECLARATION

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

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# ACKNOWLEDGEMENT

I will like to thank God almighty for helping me throughout the thesis period and African Union through the Pan African University for their scholarship and funding of this research work.

My sincere gratitude go to my two supervisors, Prof. Raphael N. Mutuku and Dr. T. Nyomboi for their comments, contributions and assistance rendered during the laboratory work and thesis writing. I also want to thank the Director and the entire administration of PAUISTI for their warmth hospitality throughout the programme.

A special thanks to my wife and son for their patience and love during my laboratory work and the period of writing my thesis, my sincere appreciation to my parents, in-laws, siblings and Maina’s family for their continuous care, prayers and support during this programme. I want also to specially appreciate the contribution of my late sister, Bose L. Shuaibu, towards my education pursuit, even in death, your impact in our life as a family will never be forgotten.

Finally, I want to appreciate my fellowship members, the PAU students’ fellowship and all my class mates. Thank you and God bless you all.

# DEDICATION

This work is dedicated to God almighty, my wife Mosunmola Shuaibu, Son David Shuaibu and parents Mr. and Mrs Shuaibu Aroge.

# ABSTRACT

The need to provide cheaper housing and find alternative to ordinary Portland cement in most part of the world has necessitated research in blending and replacing the constituent materials of concrete. Although many studies have been carried out to assess the suitability of blending cement with sugarcane bagasse ash and sand with laterite soil, however, no work have been done on the combine effect of the two materials on the properties of concrete. This research present the findings on strengths, permeability and structural behavior of concrete beams containing sugarcane bagasse ash and laterite soil to blend traditional concrete and produce sugarcane bagasse ash laterised concrete for low cost housing construction purposes.

Sugarcane bagasse ash and lateritic soil were used as blenders and mixed with normal concrete ingredients by replacing partially (a) cement with sugarcane bagasse ash and (b) sand with laterite soil in the proportions 0, 5,10,15 and 20 and 0, 5, 10, 15, 20 and 25% by mass respectively. Concrete mix of 1:2:4 (cement: sand: aggregate) with a water-cement ratio of 0.55 was used to determine the effect of material replacement levels on workability and compressive strength of concrete. The same mix but with a constant slump of 30mm±3mm was used to determine effect of combine material replacement levels on concrete properties and behavior of structural beams.

Results of the investigation showed that (a) sugarcane bagasse ash and laterite soil reduces workability of concrete, therefore sugarcane bagasse ash laterised concrete required higher water contents to produce a workable concrete (b) the strengths of concrete was observed to decrease with increase in combine material replacement levels of cement and sand (c) replacement of 20% of cement and 25% of sand by sugarcane bagasse ash and laterite soil respectively, SB-LA-20-25C gave a little higher than the design strength of 20MPa at 28 days, thus indicating the possibility of using laterite soil and sugarcane bagasse ash as replacement for sand and cement respectively in concrete and (d) the permeability of hardened sugarcane bagasse ash laterised concrete was observed to improve as the replacement level of cement and sand increases.

Structural performance of 12 reinforced beam specimens SB-LAB-00-00ns1.8-00, SB-LAB-15-20ns1.8-01 and 02, SB-LAB-00-00ns1.2-00, SB-LAB-00-00ns1.2-01 and 02, SB-LAB-05-05ys1.2-01, SB-LAB-10-15ys1.2-01, SB-LAB-10-15ys1.2-02, SB-LAB-15-20ys1.2-01 and SB-LAB-15-20ys1.2-02 with a shear span/effective depth ratio of 1.5 for 1.2m beams and 2.0 for 1.8m beams showed that (a) the presence of the sugarcane bagasse ash and laterite soil improves the deflection at ultimate applied load and shows a superior post cracking behaviour in comparison with the control specimen (b) the ultimate cracking load reduces as the material replacement levels increases and the presence of shear reinforcement also increases the ultimate cracking load (c) the mode of failure of a beam is affected by the material replacement levels and the presence of shear reinforcement and finally (d) the ultimate shearing stress reduces as the material replacement levels increases and was also observed that the presence of shear reinforcement increases the shear stress, however, all the beams satisfied the preliminary shear requirement by BS8110-1:1990.

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| | |
|---|---|
| BRE | Building Research Establishment |
| BS | British Standard |
| BSI | British Standard Institute |
| EN | Euro code Standard |
| ASTM | American Society for Testing and Materials |
| CP | Code of Practice |
| SB-LA-XX-YYC | Sugarcane Bagasse Ash Laterised Concrete |
| XX | Percentage Replacement of Cement by Sugarcane Bagasse Ash |
| YY | Percentage Replacement of Sand by Laterite Soil |
| C | Concrete |
| SB-LAB-XX-YYys | Sugarcane Bagasse Ash Laterised Concrete Beam with Shear Reinforcement |
| SB-LAB-XX-YYns | Sugarcane Bagasse Ash Laterised Concrete Beam without Shear Reinforcement |
| ZZ | Beam Serial Number |

# CHAPTER 1

## 1.0 Introduction

## 1.1 Background

Concrete is the most commonly used construction material in the world. This material contains the mixture of aggregates and ordinary Portland cement as the conventional binding material. The production of Ordinary Portland cement has been found to be responsible for about 5%–8% of global carbon (IV) oxide ($CO_2$) emissions and cement industry has also been found to be the second largest $CO_2$ emitting industry behind the power generation (Worrell, Price, Martin, Hendriks, & Meida, 2001). It was further found that each tonne of cement production produces approximately one tonne of $CO_2$ emission (Ogbeide, 2010). Concrete as a construction material have been on a high demand in most part of the world due to need to undertake mega projects and built infrastructure in order to expand development and productive capacity of the economy (MIDA, 2009). The partial replacement of ordinary Portland cement however by agricultural waste or agro-waste has been seen as an alternative solution for decreasing $CO_2$ emission due to less cement consumption for construction industry (Utsev & Taku, 2012; Sada, Amartey, & Bako, 2013; Ettu, Arimanwa, Nwachukwu, Awodiji, & Amanze, 2013). On the other hand, sand has been the major material used as fine aggregate in civil engineering construction, and had made this material to be of high demand and had led to the continuous increase in the cost of sand which translated to increase in the cost of construction.

Therefore increasing cost of housing and other construction have necessitated researchers to continue to seek ways of reducing the cost of building projects by exploring other alternative eco-friendly materials. Research around the world has shown that industrial and agricultural by-products regarded as wastes such as sugarcane bagasse ash, fly ash, grand granulated bottom ash and rice husk ash could be used as partial replacement of ordinary Portland cement to achieve this purpose (Ganesan, Rajagopal, & Thangavel, 2007). Currently, there have been attempts to utilize the large amount of bagasse, the residue from an in-line sugar industry and the bagasse-biomass fuel in electric generation industry (Sugar, 2004). When this waste is burned, it gives ash having amorphous silica, which has pozzolanic properties (Baguant, 1995). Some studies have been carried out on the ashes obtained directly from the industries to study the pozzolanic activity and their suitability as binders, particularly as partial replacement of cement (Payá, 2002). The utilization of agricultural by-products as cement replacement material may impact on the cost of production of concrete and other construction materials such as mortar, concrete pavers, concrete roof tiles and soil cement interlocking block since most of these waste especially in Africa are not been sold but dumped on lands and into water bodies.

Pozzolanic materials are defined as siliceous or aluminum-siliceous compounds that separately possess little or no cementitious properties. These materials can react with calcium hydroxide in the presence of water at ambient temperature to form compounds with agglomerative properties when finely grounded (Malhotra & Mehta, 1996). Several study therefore have shown that some of these pozzolanic materials can be used as admixtures in concrete or other construction materials in order to replace some of the constituent materials which in some cases improve the strength and durability, while achieving an environmental benefits from the use of the described materials (Massa zza, 1988; Sabir, Wild, & Bai, 2001; Mehta, 2002).

For many years, sand has been predominantly used as fine aggregate in civil engineering construction. More recently, the cost of sand have been continuously increasing resulting in ever increasing cost of construction. Research into the utilization of laterite as partial replacement for fine aggregate in concrete production for building purposes have been carried out in attempts to using locally available materials accumulating on our construction sites as waste (Olawuyi & Olusola, 2010). Laterite soil is used to describe all the reddish residual and non-residual tropically weathered soils, which genetically form a chain of materials ranging from decomposed rock through clays to sesquioxide-rich crusts. The term does not imply any compositional, textural or morphological definition or properties of laterite soils as such; all distinctions useful for engineering purposes are based on the differences in geotechnical characteristics (Gidigasu, 1976).

Slump test is a measure of flow of fresh concrete. It is used to measure the consistency of fresh concrete mix; and it is the most commonly used method to determine the workability of fresh concrete all over the world. This test is performed to check the consistency of freshly made concrete. Consistency is a term very closely related to workability. Workability of concrete is mainly affected by its consistency, that is, wetter mixes will be more workable than drier mixes, but concrete of the same consistency may vary in workability. It is also used to determine consistency between individual batches. Slump test is one of the simple and important tests which help us to get a homogenous fresh concrete mix before casting.

Concrete mix can be designed to provide a wide range of mechanical and durability properties to meet the design requirements of a structure. The compressive strength of concrete unlike tensile and flexural strengths, is the most common strength performance measure used by the engineer in designing buildings and other structures. Unlike tensile strength and flexural strength, compressive strength test results are primarily used to determine if a concrete mixture as delivered meets the requirements of the specified strength in the job specification. Therefore, it is more important to a design engineer for designing structural elements in structural engineering.

Permeability of concrete is also an important property of concrete. It measures the resistance of concrete to water permeation. When concrete make contact with water, the calcium hydroxide in the hydrated cement paste becomes leached out (Carde & François, 1999) which may lead to decomposition and leaching of the main hydrates in concrete, leading to increase porosity of the concrete (Yang, Jiang, Zhang, Du, & Zhou, 2011). In structural applications, the permeability of concrete is a very important property of concrete in order to protect the life of the embedded reinforcement in the concrete.

## 1.2 Structural Performance of Reinforced Concrete Beams

Load carrying capacity is the extent to which a member or a member material behave when subjected to load. This refers to deflection, shear and bending behaviour and its failure pattern. Deflection is the distance a beam or structure deforms under loading, typically due to bending in a beam. This load carrying capacity of a structural member is a function of the stiffness of that member. The aim of design of a structural member is to achieve an acceptable probability that the structure will perform satisfactorily during its intended life time, with an appropriate degree of safety. It should sustain all the loads and deformations of normal construction and use, and have adequate resistance to the effect of misuse and fire. In other words, the essence of design of a member is to fulfil its serviceability requirements and also withstand the ultimate loads which the member can be subjected to in its life time. Bending and shear behaviour of a structural beam are concern to civil and structural engineers as the latter is known to result in sudden and catastrophic failure. In addition, structural performance of sugarcane bagasse ash laterised concrete beams was also investigated. A sugarcane bagasse ash laterised concrete in this context is a concrete with simultaneous partial replacement of cement by sugarcane bagasse ash and sand by laterite soil.

## 1.3 Statement of Problem

In most developing countries, several attempts to provide housing for the populace has failed because of limited resources. The production of ordinary Portland cement is characterised by emission of ($CO_2$) which is one of the greenhouse gases that cause global warming. The dependence on sand as the sole material for fine aggregate in concrete had also led to continuous increase in the cost of concrete production. The use of sugarcane bagasse ash therefore as partial replacement of cement may minimise consumption of ordinary Portland cement in concrete since low income earners will prefer blending their cement with bagasse ash in concrete production. Utilising sugarcane bagasse ash as partial replacement of ordinary Portland cement in concrete production will also save the environment from dumping this waste into open lands which poses serious threat to the society by polluting the air and waste bodies (Kinuthia, Mofor, Melo, & Djialli, 2006).

The fact that concrete is the most commonly used construction material in the world for all kinds of structures have continued to place a high demand for the constituent concrete materials which have led to high cost of concrete production (Aho & Utsev, 2008). Laterite has the advantage of been readily available in most communities in most parts of the world. It can be obtained through excavation of substructure works including excavations for foundations. The utilisations of laterite therefore, can also save the cost of disposing the excavated laterite on site and take advantage of its availability in concrete production.

## 1.4 Research Objectives

### 1.4.1 Main Objective

The main Objective of this study is to assess the structural performance of sugarcane bagasse ash-laterised concrete (SB-LA-XX-YYC).

### 1.4.2 Specific Objectives

The specific objectives are as follows;

i. To determine the effect of material replacement levels on workability and compressive strength of concrete.
ii. To determine the effect of combined material replacement levels on compressive strength, tensile strength and flexural strength of concrete with slump of 30mm.
iii. To determine the effect of combined material replacement levels on permeability of hardened concrete.
iv. To compare the shear and bending behaviour of sugarcane bagasse ash laterised concrete with or without shear reinforcement with that of a normal concrete.
v. To determine the effect of sugarcane bagasse ash and laterite soil on crack load, ultimate Load and physical failure pattern of reinforced beams.

## 1.5 Research Hypothesis

The hypothesis tested in this research are;

i. Sugarcane bagasse ash and laterite content has significant influence on properties of concrete.
ii. Sugarcane bagasse ash and laterite soil content enhance the performance of structural concrete.

## 1.6 Justification

Global warming has continued to attract so much attention and has become a challenge to the international community, therefore any avenue to reduce $CO_2$ foot print has become a welcome development throughout the world. An alternative to the use of different binder in concrete therefore will help to this fact since each tonne of cement production produces approximately one tonne of $CO_2$ emission (Ogbeide, 2010). The per capita consumption of cement is increasing and the major reason behind cement demand growth is increasing urbanization. Utilising sugarcane bagasse ash will also save the environment from dumping this waste on open land and water bodies which poses serious threat to the society by polluting the air and rivers.

Secondly, in most developing countries, several attempts to provide housing for the populace has failed because of limited resources. The of laterite soil as partial replacement of fine aggregate in concrete production will reduce the demand placed on sand and encourage the use of excavated soil heap on our construction sites in concrete production. Finally, in line with the focus of sustainable development which is meeting the needs of the present without compromising the ability of the future generation to meet their needs, utilising sugarcane bagasse ash and laterite soil is in line with the world campaign on saving the environment and utilising locally available materials.

# CHAPTER 2

## 2.0 Literature Review

## 2.1 Partial Replacement of Cement and Fine Aggregates in Concrete

Many researchers have carried out various studies on such substitute materials in making cement composites like concrete and sandcrete (Olugbenga, 2007). It has therefore become an attractive practice by researchers to utilize locally available material to produce concrete. The reviews below shows the various studies performed on the partial replacement of cement and fine aggregate with sugarcane bagasse ash and laterite soil respectively.

### 2.1.1 Sugarcane Bagasse Ash as Partial Replacement of Cement in Concrete Production

It has become an attractive practice to replace ordinary Portland cement by some agricultural waste materials in the construction industry (Raheem & Suleiman, 2013;Utsev & Taku, 2012; Abhilash, Singh, & Sharma, 2011; Ettu, Arimanwa, Nwachukwu, Awodiji, & Amanze, 2013). In particular to sugarcane bagasse ash usage, a wide variety of residues are being used in the construction industry as mineral additives such as sugarcane bagasse ash (Marcos, Ilda, Conrado, & Jairo, 2009), sugarcane chaff ash, swine waste ash and ash from swine bedding with a base of rice shells (Marcos, Ilda, Conrado, & Jairo, 2009). Calcium hydroxide ($Ca(OH)_2$) which is one of the hydration products of Portland cement and greatly contributes toward the deterioration of cement composites. However, when a pozzolan is blended with Portland cement, it reacts with the lime to produce additional calcium-silicate-hydrate, which is the main cementing compound. The pozzolanic material therefore reduces the quantity of lime and increases the quantity of calcium-silicate-hydrate which enhanced the cementing quality, when the pozzolan is blended in suitable quantity with Portland cement (Padney, Singh, Sharma, & Tiwari, 2003). Currently, blended cements are used in many parts of the world (Bakar, Putrajaya, & Abdulaziz, 2010) to give the desired mix properties.

According to (Srinwasan & Sathiya, 2010 ) cement could be advantageously replaced with sugarcane bagasse ash up to maximum limit of 10%. Marcos, Ilda, Conrado and Jairo, (2009) also used sugar cane bagasse ash to substitute cement between 0-30% to produce concrete, the findings of their study shows that it is possible to substitute cement with sugarcane bagasse ash up to 20% in concrete without hurting its resistance. Muanglong, Sujjavanish, Boonsalee, Sumate and Chaysuwan (2013) investigated the effects of fine bagasse ash on the workability and compressive strength of mortars and concrete and found that the appropriate proportion of clinker replaced by fine sugarcane bagasse ash was 20%, which the highest compressive strength comparing to all ratios between 0-40% of resultant cements and near that of commercial cement. Kanchan and Jawaid (2013) utilised sugarcane bagasse ash as pozzolanic material in concrete and observed that sugarcane bagasse ash can improve the workability, compressive strength and durability of concrete.

Further investigations on the effect of sugarcane bagasse ash on the strength of concrete shows the strength increased up to 15% replacement of cement by sugarcane bagasse ash (Kawade, Rathi, & Girge, 2013) or in other words, there is a significant effect on workability and compressive strength with 15% cement replacement with sugarcane bagasse ash. Apiwaranuwat, Kitratporn, Chuangcham andPunmatharith (2013) looked at the use of sugarcane bagasse ash as a raw material in the production of autoclave light weight concrete and observed that the optimal production conditions for sugarcane bagasse ash containing autoclave light weight concrete were a cement/sand ratio of 65/36, a water/total composition ratio of 0.24, and a curing time of 16 hours. Maximum compressive strength was obtained in samples containing 20% sugarcane bagasse ash. In another study by (Sivakumar & Mahendran, 2013) on cement replacement by sugarcane bagasse ash showed that 20% replacement of cement by the bagasse ash resulted in concrete strength almost equal to the nominal strength of the concrete which was also cost effective as it mitigates the cost by 12% for 1 $m^3$ of concrete. These brings us to a conclusion that a cheaper concrete can be made with industrial waste products for desired strength.

### 2.1.2 Laterite as Partial Replacement of Fine Aggregates in Concrete Production

The rate at which the source of quality sand is fast diminishing resulting in ever increasing cost of construction and also the need to utilise available materials have motivated a lot of research in utilizing laterite as aggregate in concrete production. Laterite is now seen as a possible replacement for fine aggregate in concrete production. Several scholars have worked on the possibility of utilising laterite in concrete and have achieved considerable results. According to (Muthusamy & Kamaruzaman, 2012) replacing 10% coarse aggregate with laterite soil can produce laterised concrete exhibiting comparable strength with normal concrete. They also added that replacement of laterite aggregate up to 30% is able to produce laterised concrete exhibiting the targeted strength of 30 MPa. Ettu, Ibearugbulem, Ezeh and Anya (2013) looked at the suitability of using laterite as sole fine aggregate in structural concrete and found that laterite could be used as sole fine aggregate for making structural concrete under mild condition of exposure. They recommended using a combination of traditional concrete and laterised concrete for more sensitive structures; in which case traditional concrete could be used in casting members under moderate and harsher conditions of exposure such as foundations and other members in continuous contact with water while laterised concrete should be used for members under mild conditions of exposure.

In another development, the potential of laterite as fine Aggregate in foamed concrete production was investigated by (Falade, Ikponmwosa, & Ukponu, 2013) which reveals that foamed concrete produced with water/cement ratio of 0.7 containing up to 20% laterite, performed better in terms of workability and compressive strength and concluded that the introduction of laterite into foamed concrete improved the compressive strength of the concrete. Udoeyo, Brooks, Utam, Udo-Inyang and Ukpong (2010) compared the accelerated strength to that of moisture cured concrete and found that the values of accelerated strength of laterised concrete obtained were greater than the strength of standard moist-cured concrete of corresponding age, implying that there was an enhancement of hydration process and consequently the strength development through the boiling water method of accelerated strength testing. Festus, Adeniran and Oyegbile (2013) also in their study found that the presence of coarse grained good quality laterite in making of concrete would not only at least maintain the ultimate strength of concrete but could also improve its mechanical properties. They added also that for optimum performance of laterised concrete as structural members of a building, the content of laterite replacement in the concrete should not exceed 25% of sand in a standard mix.

Ikponmwosa and Salau (2011) studied the effect of short steel fibre reinforcement on laterised concrete columns and observed that the ductility of fibre reinforced laterised concrete increases as the percentage of fibre content increased and the ductility reaches its maximum at about 1% fibre content while samples with 0% fibre showed little or no deflection capacity. Ige (2013) investigated the behaviour of laterised concrete under harsh environmental condition and observed that for laterised concrete mix 1:2:4 and curing age of 28 days, with laterite-fine aggregate ratio variation as a factor, 20% replacement of fine aggregate with laterite soil had a reasonable compressive strength for temperature applications up to $100^oC$ whereas plain concrete and other percentage replacement suffered a reduction in compressive strength as the temperature increases. Babatunde, Ibrahim, Aliyu and Rasaq (2013) determined the flexural performance of laterised concrete made with blended fly ash cement, and found that the flexural performance of fly ash-lateritic concrete was satisfactory, having achieved a least ratio of 28 days design compressive strength of 0.273 which is not less than 0.07.

### 2.1.2.1 Laterised Concrete as a Structural Element

Looking at the behaviour of structural elements made with laterised concrete, (Olutage, Adeniran, & Oyegbile, 2013) investigated the ultimate capacity of laterised concrete with five classes of specimens incorporating 0, 10, 20, 30 and 40% laterite replacement of sand and reinforcement of 2, 3, 4 and five numbers of Y10 for each specimen class. Their analysis showed that laterised concrete gave a satisfactory performance compared with normal concrete when the replacement does not exceed 25%. Salau and Balogun (1990) also investigated the shear resistance of laterised concrete beams without shear reinforcement and observed that the mode of failure does not depend on the percentage laterite content but mainly on the shear span of the beam. They further observed that the ultimate cracking load decreases with increase in percentage laterite content and the ultimate shearing stress of laterised concrete compare favourably with that specified in the code of practice (CP110, 1987). As regard to the amount of longitudinal reinforcement, their results also showed that the ultimate shearing stress of a laterised concrete increases with increase in the amount of longitudinal reinforcement and the presence of laterite improves the post cracking ability and the serviceability conditions due to high ductility, stiffness, and superior crack control of lateritic content in comparison with plain concrete. A different study by (Salau & Sharu, 2004) investigated the behaviour of bamboo strips as reinforcement on 75 structural columns made with laterised concrete. They found that the reinforced laterised columns could sustained increased deformation and strain with superior post-yield and post- cracking behaviour.

## 2.2 Critique of Literature Review Findings

From the above reviews, it can be deduced that the effect of sugarcane bagasse ash and laterite individually in the production of concrete have been investigated. However, the reviews only considered the replacement of one material (Cement or aggregate) without studies on the combine effect of sugarcane bagasse ash and laterite soil in concrete with very few studies on the structural performance of structural members (Salau & Balogun, 1990; Olutage, Adeniran, & Oyegbile, 2013; Salau & Sharu, 2004). This study aimed at investigating the combine effect of sugarcane bagasse ash and laterite as partial replacement of cement and fine aggregate respectively on the performance of concrete. This performance measurement is based on determining the properties of both fresh and hardened concrete and also the performance of structural beams containing both bagasse ash and laterite through series of experimental tests. The effects of sugarcane bagasse ash and laterite content individually on the workability of fresh concrete was investigated using slump test, after which the combine effect of sugarcane bagasse ash and laterite soil was determined on the amount of water needed to produce concrete with 30mm slump value and the compressive strength, split tensile strength, flexural strength, and permeability property. Finally, the bending and shear performance of reinforced sugarcane bagasse ash laterised concrete beam was investigated using the two points loading test.

# CHAPTER 3

## 3.0 Methodology

The methods used to determine the effects of material replacement levels, combine material replacement levels and structural behaviour of sugarcane bagasse ash laterised concrete are enumerated as follows;

## 3.1 Material Properties

Different materials used in this study and their properties are enumerated as follows;

### 3.1.1 Coarse Aggregate

The coarse aggregate used in this study was purchased from Aristocrat Concrete Limited. This was crushed stone mixed in a ratio of 1:2 for 10mm: 20mm single aggregate sizes in accordance with building research establishment (BRE, 1988). The aggregate had a specific gravity of 2.8, a rate of water absorption of 3.4% and a moisture content 1.9% in accordance to (BS EN 1097, 2013). Figure 3.1.1 shows some laboratory acitivities in the determination of the properties of aggregate.

Figure 3.1.1: Determination of properties of coarse aggregate

### 3.1.2 Fine Aggregate

River sand and laterite soil were used as fine aggregate in this study. Sand was sourced from Masinga dam while laterite soil was sourced from around Jomo Kenyatta University of Agriculture and Technology, Juja campus. The results of sieve analysis of sand and laterite samples performed according to (BS 812, 1985) are shown in Figure 3.1.2a.

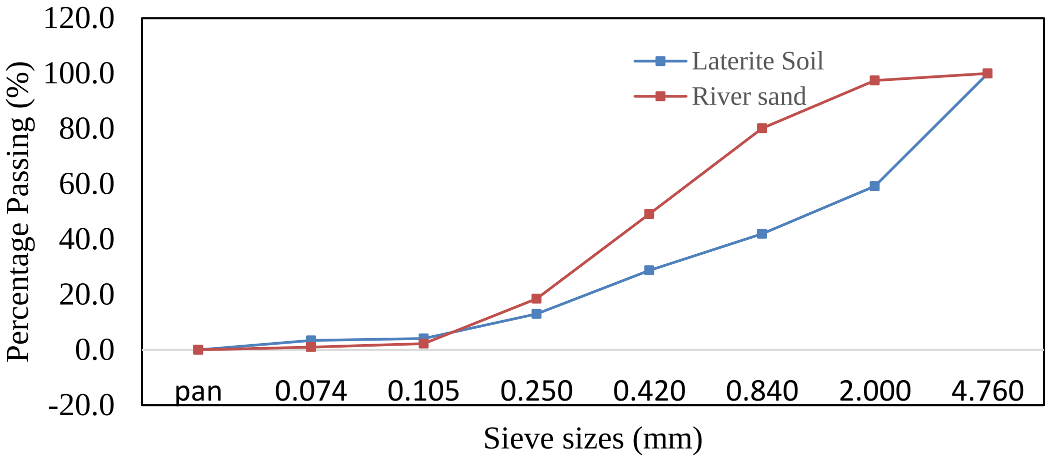


Figure 3.1.2a: Sieve analysis for sand and laterite

Other analysis carried out on sand sample according to (BS EN 1097-6, 2013) to determine its properties showed that it had specific gravity of 2.6, rate of water absorption of 0.45% and moisture content of 0.25%. Figure 3.1.2b shows some laboratory activities in the determination of the properties of sand.

Figure 3.1.2b: Determination of properties of fine aggregate

Laterite soil also had specific gravity of 2.5 according to (BS1377, 1990) , moisture content of 6.3% and chemical composition as shown in Figure 3.1.2c by an X-ray fluorescence elemental analysis carried out at the centre for nuclear science of University of Nairobi, Kenya.

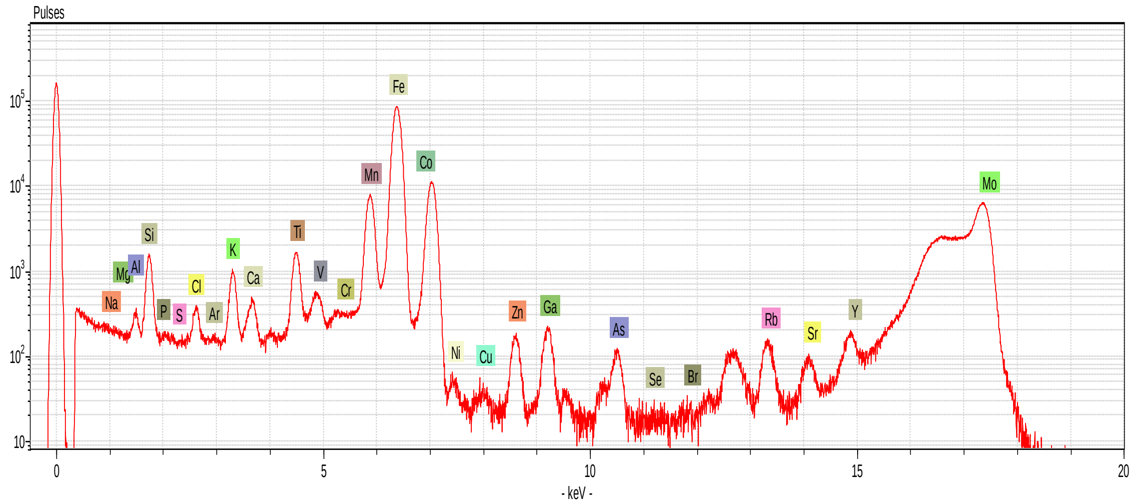


Figure 3.1.2c: X-ray fluorescence spectral analysis for laterite sample

### 3.1.3 Cement

Ordinary Portland cement from Bamburi Cement Limited, Kenya, known as PowerPLUS 42.5 was used, which conforms to the specification of (BS 12, 1996) and is formulated from Portland cement clinker and inter-ground with other constituents, in accordance to the requirements of (EN 197-1, 2000) used in medium to large constructions projects while sugarcane bagasse ash was gotten from Mumias Sugar Company in western Kenya. Sugarcane bagasse ash is a waste from boiler chimney of their cogenerating plant, obtained in the process of burning sugarcane bagasse to produce steam during electricity generation process. This ash was sieved through a sieve size of 75µm to remove the finer particles used in this study. The sugarcane bagasse ash had a density of 2.3g/cc determined according to (BS EN 196, 2010) and results of spectral analysis of sugarcane bagasse ash carried out at the centre for nuclear science of the University of Nairobi is as shown in Figure 3.1.3.

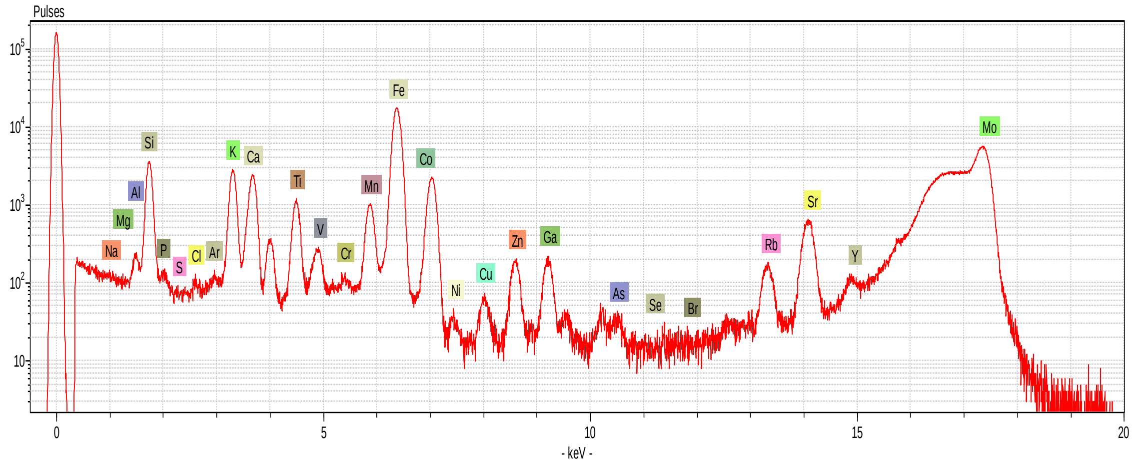


Figure 3.1.3: X-ray fluorescence spectral analysis for sugarcane bagasse ash sample

## 3.2 Concrete Properties

Different properties of concrete were determined in this study. These properties include for fresh and hardened concrete enumerated as follows;

### 3.2.1 Workability

In determining the effect of material replacement levels on workability of fresh concrete, concrete mix ratio of 1:2:4 and a water- cement ratio of 0.55 was used. The slump test, was performed according to (BS EN 12350, 2009) for each replacement of cement with 0, 5, 10, 15, 20% sugarcane bagasse ash and sand with 0, 5, 10, 15, 20, 25% laterite soil. Slump was later maintained at 30mm with a margin of ±3mm to investigate the combined material replacement levels and for reinforced beams. Figure 3.2.1 shows some graphic pictures on how slump was determined in the laboratory.

Figure 3.2.1: Determination of slump

### 3.2.2 Compressive Strength

Compressive strength of hardened concrete was determined in accordance to (BS EN 12390, 2000). The fresh samples after getting the slump was cast into iron moulds of dimensions 150mmx150mmx150mm in order to determine the 7, 14 and 28 days strength. Firstly, was to determine the effect of material replacement levels on compressive strength of hardened concrete and secondly, the effect of combine material replacement levels was determined on compressive strength of concrete. A total of 90 cubes were cast to measure the effect of material replacement levels on compressive strength while 45 cubes were cast to determine the effect of combined material replacement levels on compressive strength of concrete making the total number of cubes equal to 135. The specimen descriptions to determine the effect of combined material replacement levels are SB-LA-05-05C, SB-LA-10-15C, SB-LA-15-20C, SB-LA-20-25C and SB-LA-00-00C, labeled to reflect the percentage replacement of cement and sand by bagasse and laterite respectively. Further to the description of the specimens, SB-LA-XX-YYC, SB represent sugarcane bagasse ash, LA represent laterite soil, XX represent the percentage cement replacement by sugarcane bagasse ash, YY represent the percentage replacement of sand by laterite soil and C represent concrete. A universal testing machine with a load capacity of 1500kN was used for the compressive strength test as shown in Figure 3.2.2.

Figure 3.2.2: Compressive strength test

### 3.2.3 Tensile Strength

Six specimens for effect of combined material replacement levels with a constant slump of 30mm were cast into cylindrical prisms of dimensions 100mmx200mm for 7 and 28 days split tensile strength per material mix. The split tensile test was done for five materials mixes, SB-LA-00-00C, SB-LA-05-05C, SB-LA-10-15C, SB-LA-15-20C and SB-LA-20-25C making a total 30 specimens and carried out in accordance to (BS EN 1239, 2009) using a 1500kN capacity universal testing machine as shown in Figure 3.2.3.

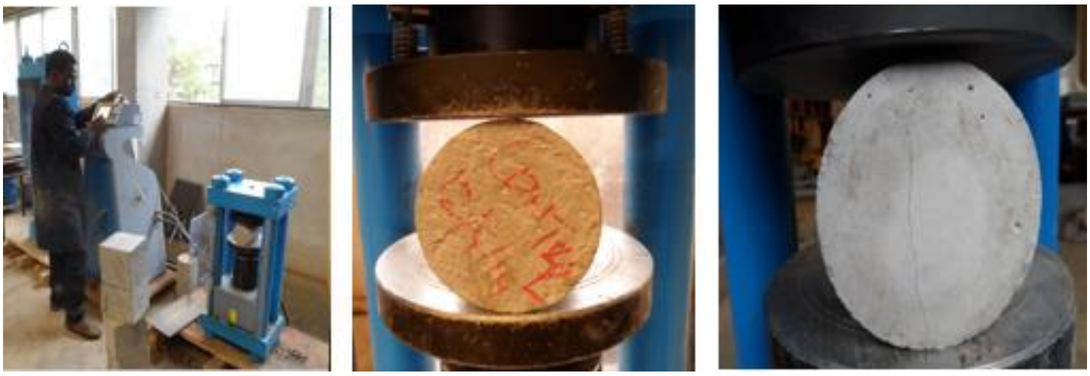


Figure 3.2.3: Tensile strength test

### 3.2.4 Flexural Strength

BS EN 12390 (2009) was used to determing the flexural strength of sugarcane bagasse ash laterised concrete. A total of 15 specimens of dimensions 150mmx150mmx560mm were cast with concrete mix of 1:2:4 and a constant slump of 30mm±3mm. The specimens were cast and demoulded after 24 hours and cured for 28 days in water. Before the 28 days test was carried out, the specimens were marked to have a clear span of 450mm and tested using the flexural test assembly of the universal testing machine as shown in Figure 3.2.4.

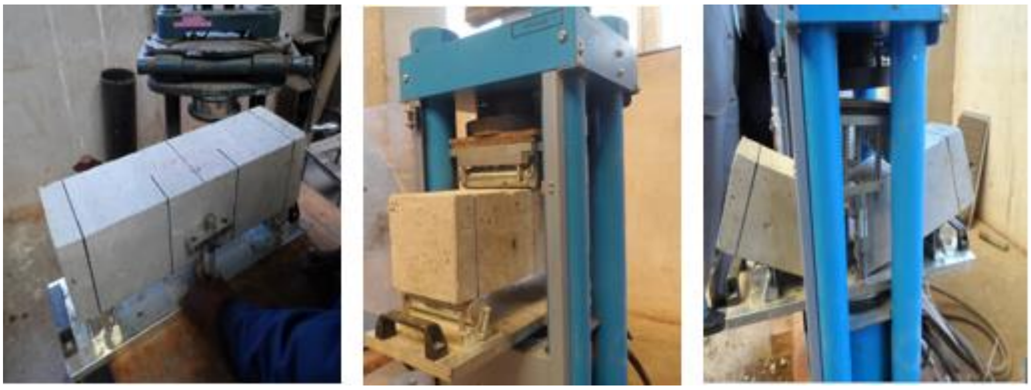


Figure 3.2.4: Flexural strength test

### 3.2.5 Concrete Permeability Test

Permeability can be defined as the ease in which a fluid flows through a solid. The resistance of concrete to water permeation is important in order to utilise the same in structures especially if the structure has possibilities of being exposed to moisture condition. The coefficient of permeability is the material characteristic describing the permeation of gases or liquids through a porous material due to a pressure head (Hilsdorf & Kropp, 1995). Several studies have shown that there is no universally accepted standard test method for measuring permeability of concrete. For example, in the United States, to determine the permeability properties of concrete, the ASTM C 1202-97 is used, which is based on chloride ion diffusion.

An equipment was therefore fabricated with steel walls and concrete base. The steel walls were made to produce an impermeable media and prevent water from moving in all direction but through the base which contained the concrete material whose permeability was to be measured. Concrete thickness of 85mm was cast to the base of an impermeable steel of dimensions 260mmx260mmx300mm with plastic rulers mounted to the inner side of the steel to measure the level of water penetrating the concrete on a daily basis for 52 days. Before water was added to the fabricated mould, the welded joints of steel and steel-concrete interface were sealed up by means of silicon sealant to avoid water from escaping. Figure 3.2.5 shows the moulds and various procedures used in the determination of permeability of the hardened concrete.

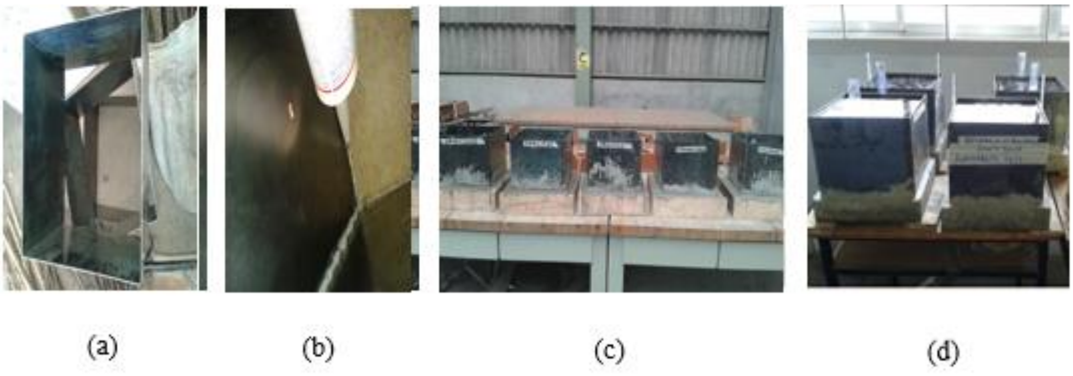


Figure 3.2.5: Procedure for permeability test (a) steel cage (a) sealing the interface (c) de-moulding concrete base and labelling (d) addition of water for permeability test

To account for loss of water due to evaporation, an impermeable pan was used alongside the steel-concrete moulds in which the amount of water evaporated from the impermeable pan was subtracted from drop in head in the five moulds to get the net water passing through the concrete. Comparative permeability performance of all the specimens with replacement of cement and sand by sugarcane bagasse ash and laterite soil, SB-LA-05-05C, SB-LA-10-15C, SB-LA-15-20C and SB-LA-20-25C were determined to that of control concrete, SB-LA-00-00C without sugarcane bagasse ash and laterite soil.

### 3.2.6 Concrete Production, Placement and Curing

Concrete mix ratio of 1:2:4 was throughout in this study but with different water-cement ratio. Batching of constituent concrete materials was done by weight and mixing was done manually and vibrated with an electric vibrator. Portable water conforming to (BS3148, 1980) was used for all the concrete mixes. After mixing, concrete was placed into various moulds for compressive, tensile, flexural and also in formworks made with block board to produce beam specimens. All specimens were demoulded after 24 hours and immersed in a curing tank containing water maintained at room temperature for 7, 14 and 28 days strength tests except reinforced concrete beams, which after de-moulding were wrapped in a membrane and water sprinkled on them for 28 days. The membrane was to retain water to the specimens. Figure 3.2.6 shows concrete production, placement and curing as carried out in the laboratory.

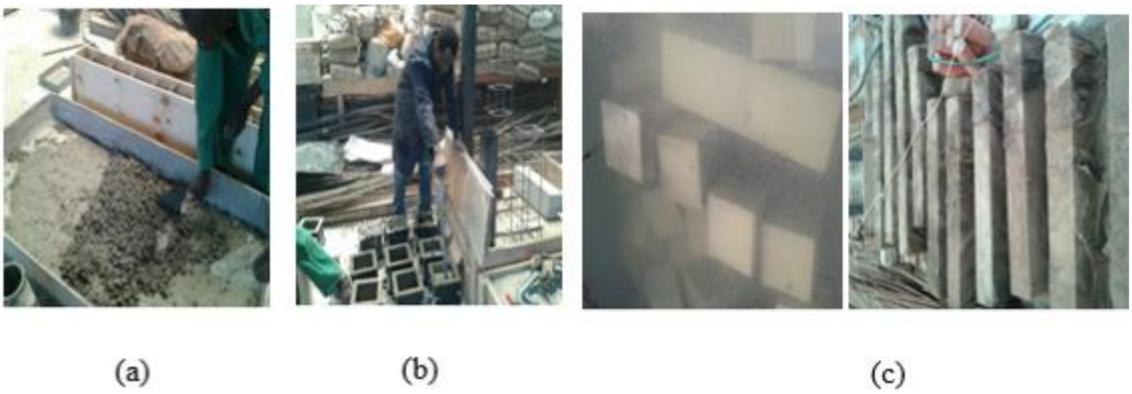


Figure 3.2.6: Procedures for (a) mixing, (b) placement and (c) curing of concrete

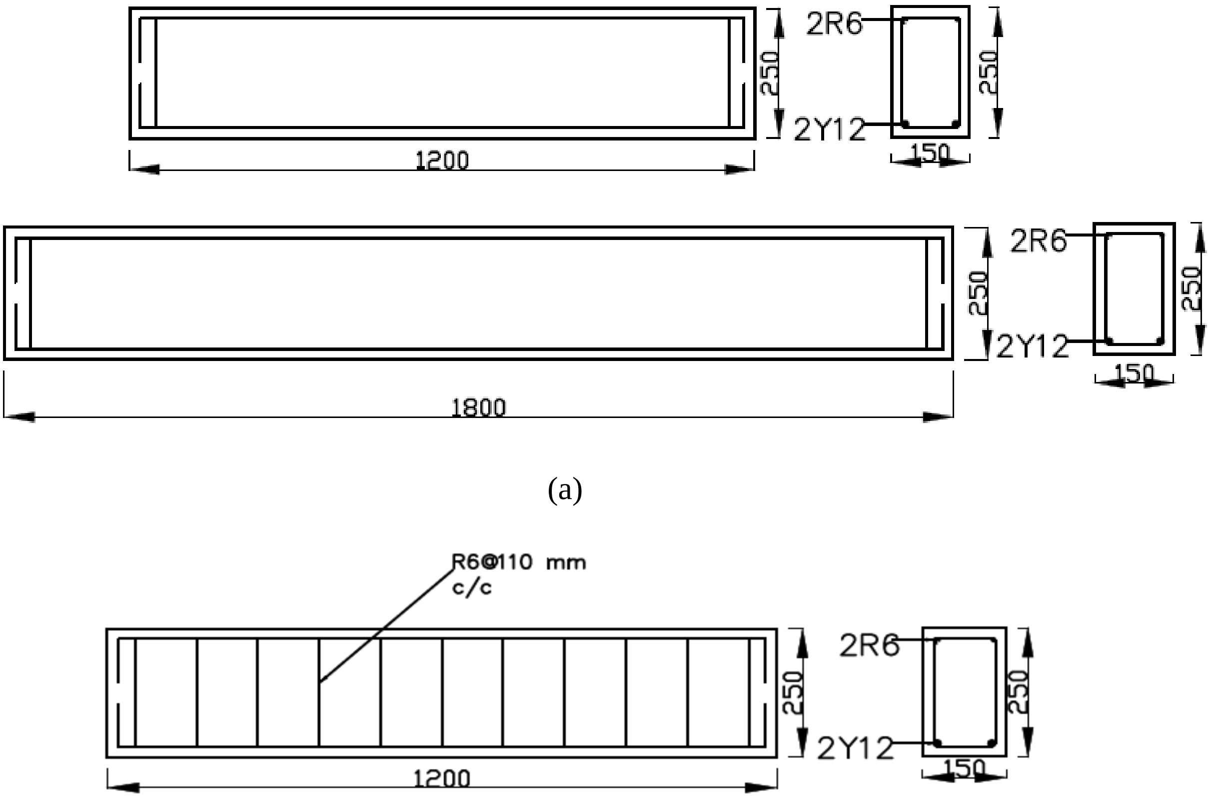
### 3.2.7 Tensile Test on Re-bars

Re-bars used as longitudinal reinforcement were tested for tensile strength according to (BS 4449, 1997) and the results gave a mean un-factored strength of 648N/mm$^2$ and an elongation percentage of 23%. After dividing the strength with a safety factor of 1.15, the design strength became 563 N/mm$^2$. The upper yield and lower yield strength are 648 N/mm$^2$ and 261 N/mm$^2$ respectively.

## 3.3 Beam Test

### 3.3.1 Beam Geometry and Setup

Figure 3.3.1 shows the geometry of beam specimens. These specimens were categorized into two groups, some with shear reinforcement and others without shear reinforcement but all have the same cross sectional dimension of 150mmx250mm. Six beam specimens in total were made with 15% replacement of cement by sugarcane bagasse ash and 20% replacement of sand by laterite (SB-LAB-15-20) without shear reinforcement. Three of which had a length of 1.8m while the other three were 1.2m long with effective spans of 1.5m and 1.0m respectively. Another six specimens were made with shear reinforcement but different percentage replacement of cement and sand in the concrete mix.



(a)

(b)

Figure 3.3.1: Beam geometry (a) with (b) without reinforcement

Various beam specimen designations in this study were as follows:

a. SB-LAB-00-00ns1.2-00
b. SB-LAB-15-20ns1.2-01 and 02
c. SB-LAB-00-00ns1.8-00
d. SB-LAB-15-20ns1.8-01 and 02
e. SB-LAB-00-00ysS1.2-00
f. SB-LAB-05-05ysS1.2-01
g. SB-LAB-10-15ys1.2-01 and 02 and
h. SB-LAB-15-20ys1.2-01 and 02

In the specimen specification SB-LAB-XX-YYys/ns1.2/1.8-ZZ, SB-LAB indicates sugarcane bagasse ash-laterised concrete beam made with XX replacement percentage of cement by sugarcane bagasse ash, YY percentage replacement of sand by laterite soil, ZZ indicates the serial number of the beam specimen, 1.2/1.8 is the overall length of the beam in meters, '*ys'* and 'ns' indicates the presence and absence of shear reinforcement respectively. For control beams XX, YY and ZZ were taken as 00. Some steel cages with attached strain gauges are shown in Figure 3.3.2a while Figure 3.3.2b shows beam setup for bending tests. Electrical resistance strain gauges was attached to the centre of longitudinal reinforcement to measure the induced flexural strains, to the shear reinforcement to measure the induced shear strain, at the bottom of the beam to measure the flexural strain induced in the beam and a strain rosette placed on concrete surface within the shear span region to measure the beam shear strain. A displacement transducer was also placed at mid-span of the beam to measure the central deflection and a load cell to measure the applied load. These stain gauges, displacement transducer and load cell were connected to a data logger to collect data at different loading intervals.

Figure 3.3.2a: Steel cages with attached strain gauges

Figure 3.3.2b: Sample beam set up and loading

# CHAPTER 4

## 4.0 Results and Analysis

## 4.1 Effect of Material Replacement Levels on Concrete Properties

From the study carried out to investigate effect of material replacement levels on workability and compressive strength of concrete, the following observations were made.

### 4.1.1 Effect of Material Replacement Levels on Workability of Concrete

Figure 4.1.1 presents the results of effects of material replacement levels on workability of concrete measured in accordance to (BS EN 12350, 2009). It was observed that as the replacement levels of cement and sand by sugarcane bagasse ash and laterite soil respectively in the concrete mix increases, the slump value decreases which made the concrete less workable. It can be said that sugarcane bagasse ash concrete and laterised concrete needs a platisizer to produce a workable concrete or better still higher water content.

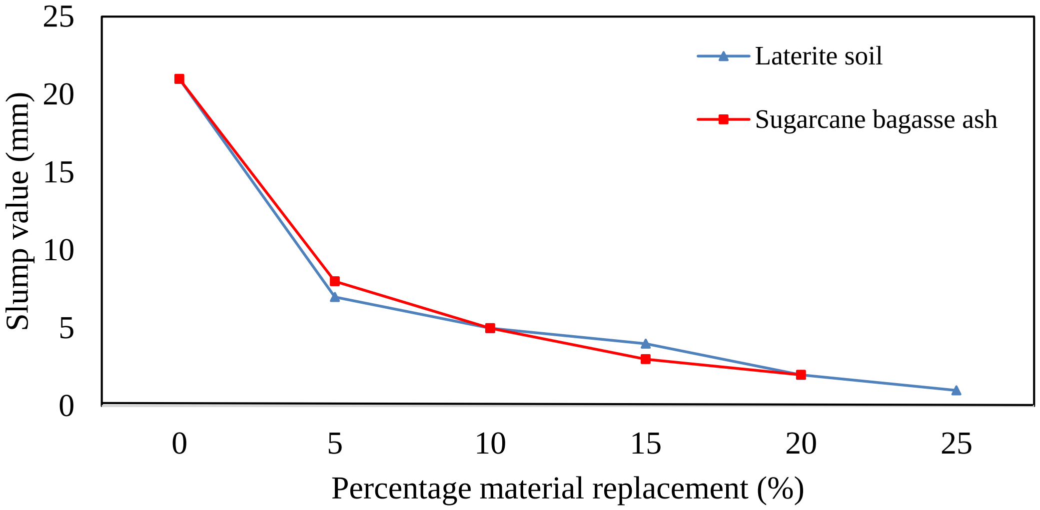


Figure 4.1.1: Effect of material replacement levels on workability of concrete

### 4.1.2 Effect of Material Replacement Levels on Compressive Strength of Concrete

A total of 90 cubes of size 150mm were tested to determine the effect of material replacement levels on compressive strength of concrete. Figures 4.1.2a and 4.1.2b show the results represented by a bar graph. Each value of compressive strength represented in the bar graph is the mean of triplicate test results.

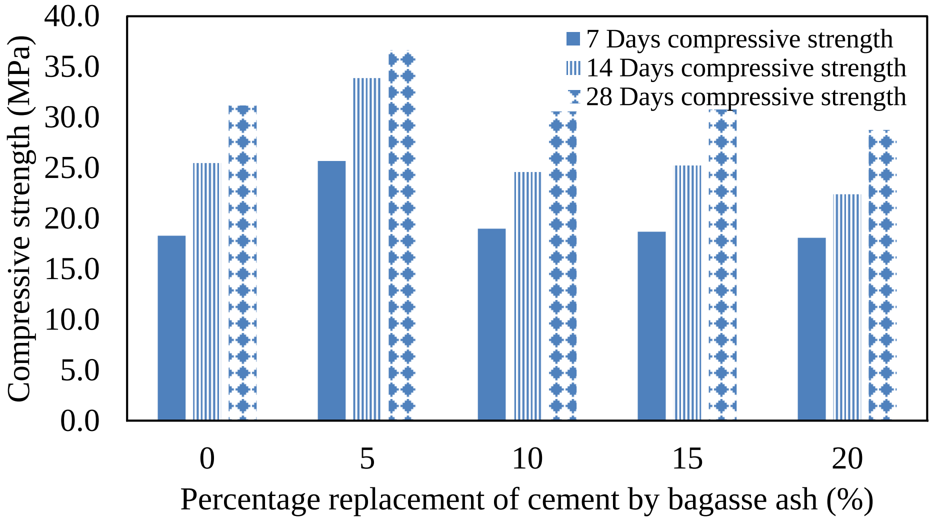


Figure 4.1.2a: Effect of sugarcane bagasse ash on compressive strength of concrete

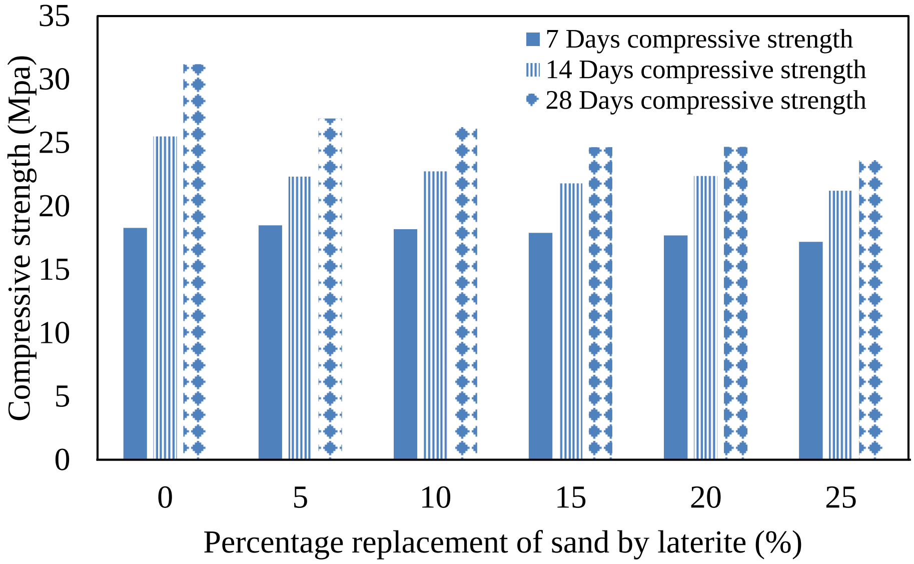


Figure 4.1.2b**:** Effect of laterite soil on compressive strength of concrete

The results from Figure 4.1.2a shows that as cement was replaced by sugarcane bagasse ash, the strength increased at 5% replacement and then decreased with increasing percentage replacement. The increase in strength may be attributed to the pozzolonanic properties of sugarcane bagasse ash as chemical composition showed the presence of Si, Al and Fe in the ash which comfirms the presence of $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ . As regards to the effect of laterite soil in Figure 4.1.2b, it was observed that as the laterite content increased, the compressive strength decreased.

## 4.2 Effect of Combined Material Replacemenet Levels on Concrete Properties

### 4.2.1 Effect of Combined Material Replacement Levels on Water Content Required to Produce 30mm Slump

After the effect of material replacement levels was done, the two materials, laterite soil and sugarcane bagasse ash were combined to determine the combined effect of the two materials on properties of concrete. The amount of water required to produce a slump of 30mm for different mixes is shown in Figure 4.2.1, it was observed that as the replacement level increases, the amount of water required also increase which indicates that sugarcane bagasse ash laterised concrete requires more water to be workable.

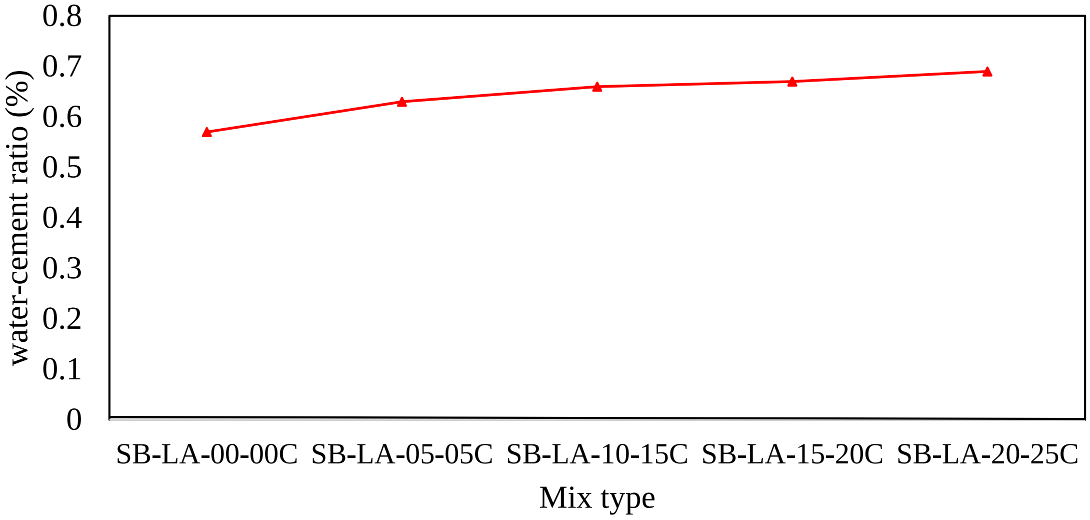


Figure 4.2.1: Water-cement ratio for sugarcane bagasse ash laterised concrete with a slump of 30mm

### 4.2.2 Effect of Combined Material Replacement Levels on Compressive Strength of Concrete

Table 4.2.2 shows the compressive strength of sugarcane bagasse ash laterised concrete with different material proportions at a constant slump of 30mm. This slump was maintained with a margin of ±3mm in all the mix in order to compare their performance. These concrete mixes were represented by SB-LA-XX-YYC, where the first two numbers XX represent the percentage cement replacement by sugarcane bagasse ash, YY represent replacement of sand by laterite soil and C represents concrete. This description of concrete was used to represent sugarcane bagasse ash laterised concrete in this study.

Table 4.2.2: Compressive strength of sugarcane bagasse ash laterised concrete

| Specimen type | Material combination (%) | | | | Compressive strength $f_{cu}$, (MPa) | | | |
|---|---|---|---|---|---|---|---|---|
| | Sand | Laterite | Cement | Sugarcane bagasse ash | 7 days | 14 days | 28 days | $f_{cu7}$/ $f_{cu28}$ |
| SB-LA-00-00C (Control) | 100 | 0 | 100 | 0 | 24.47 ±0.06 | 30.23 ±0.03 | 33.25 ±0.04 | 0.74 |
| SB-LA-05-05C | 95 | 5 | 95 | 5 | 18.80 ±0.07 | 24.20 ±0.06 | 27.10 ±0.03 | 0.69 |
| SB-LA-10-15C | 85 | 15 | 90 | 10 | 17.80 ±0.06 | 25.10 ±0.04 | 26.1 ±0.02 | 0.68 |
| SB-LA-15-20C | 80 | 20 | 85 | 15 | 15.30 ±0.03 | 18.70 ±0.06 | 23.54 ±0.03 | 0.65 |
| SB-LA-20-25C | 75 | 25 | 80 | 20 | 13.35 ±0.07 | 16.40 ±0.05 | 21.3 ±0.03 | 0.63 |

A total of 45 cube specimens were tested as shown in Table 4.2.2 with each value representing the mean of triplicate test results. The ratio of 7 days to 28 days compressive strength shows that none of the replacement level attained up to 70% of their 28 days strength at 7 days. However, compressive strength was found to increase with age of concrete but decreases with increase in combine replacement levels. Figure 4.1.4 shows the strength of sugarcane bagasse ash laterised concrete cubes (SB-LA-XX-YYC) expressed as a ratio of the control specimen (SB-LA-00-00C) strength of the same age. Comparatively, the compressive strength of sugarcane bagasse ash laterised concrete was less than that of the control specimen. However, the targeted strength of 20 Mpa was still attained for SB-LA-20-25C.

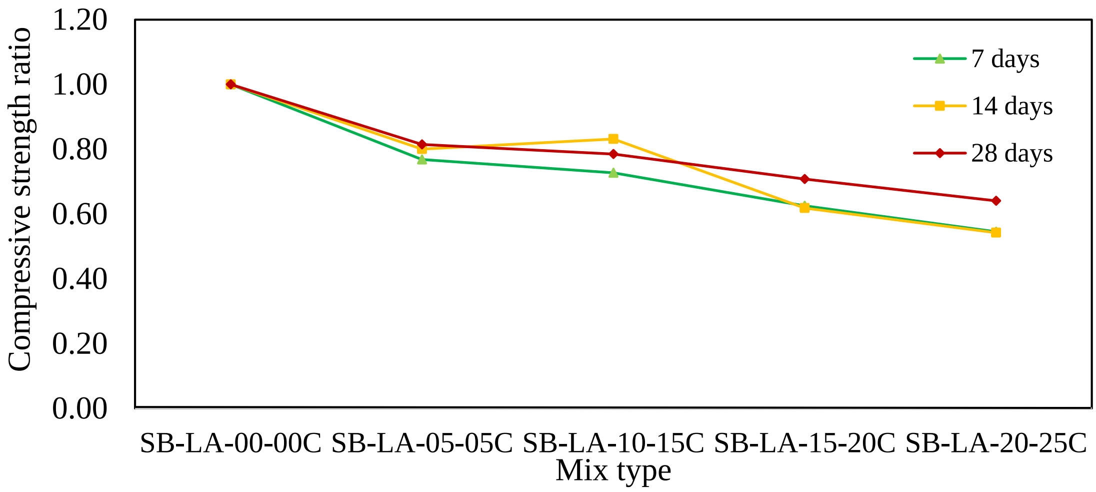


Figure 4.2.2: Compressive strength of sugarcane bagasse ash laterised concrete as ratio of control strength of the same age

### 4.2.3 Effect of Combined Material Replacement Levels on Split Tensile Strength

An average of three cylinders specimens were tested for 7 days and 28 days split tensile strength, making the total tested specimens to be 36 for 6 mixes. Table 4.2.3 shows the results of the 7 days and 28 days split tensile strength of sugarcane bagasse ash laterised concrete. Each value of strength represents the mean of triplicate test results.

Table 4.2.3: Tensile strength of sugarcane bagasse ash laterised concrete

| Specimen type | Combination (%) | | | | Tensile strength, $f_t$ (MPa) | | |
|---|---|---|---|---|---|---|---|
| | Sand | Laterite | Cement | Sugarcane bagasse ash | 7 days | 28 days | $f_{t7}/f_{t28}$ |
| SB-LA-00-00C (Control) | 100 | 0 | 100 | 0 | 1.87 ±0.02 | 2.50 ±0.04 | 0.75 |
| SB-LA-05-05C | 95 | 05 | 95 | 05 | 1.60 ±0.07 | 2.25 ±0.07 | 0.71 |
| SB-LA-10-15C | 85 | 15 | 90 | 10 | 1.50 ±0.03 | 2.20 ±0.03 | 0.68 |
| SB-LA-15-20C | 80 | 20 | 85 | 15 | 1.36 ±0.01 | 2.18 ±0.01 | 0.62 |
| SB-LA-20-25C | 75 | 25 | 80 | 20 | 1.30 ±0.05 | 2.15 ±0.06 | 0.60 |

Results of split tensile test for sugarcane bagasse ash laterised concrete showed that the split tensile strength increases with increase in age but decreases with increase in replacement level of cement and sand. The ratio of 7 days to 28 days strength ($f_{t7}/f_{t28}$) also shows that there is a reduction in the rate of strength gain as replacement level increases. In order to get the actual percentage tensile strength of sugarcane bagasse ash laterised concrete in comparison with that of control specimen of the same age, Figure 4.2.3a shows the tensile strength of sugarcane bagasse ash laterised concrete as a ratio of control concrete of the same age. In order to establish a mathematical relationship between the compressive strength and tensile strength of this concrete material, Figure 4.2.3b shows a graph of compressive strength against split tensile strength for sugarcane bagasse ash laterised concrete corresponding to the same mix proportion at 28 days. The mathematical relationship between compressive strength at 28 days and the corresponding split tensile strength at 28 days is represented in Equation 1 with an $R^2$ value of 0.98.

$$f_{cu28} = -109.59 f_{t28}^2 + 542.59 f_{t28} - 638.32 \quad \text{-----} \ (1)$$

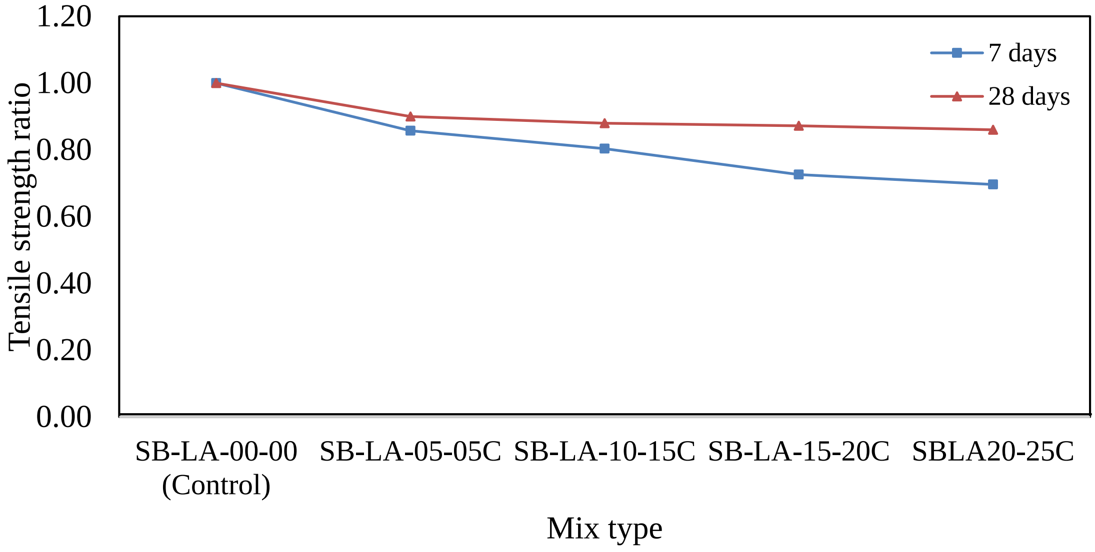


Figure 4.2.3a: Tensile strength of sugarcane bagasse ash laterised concrete as a ratio of control strength of the same age

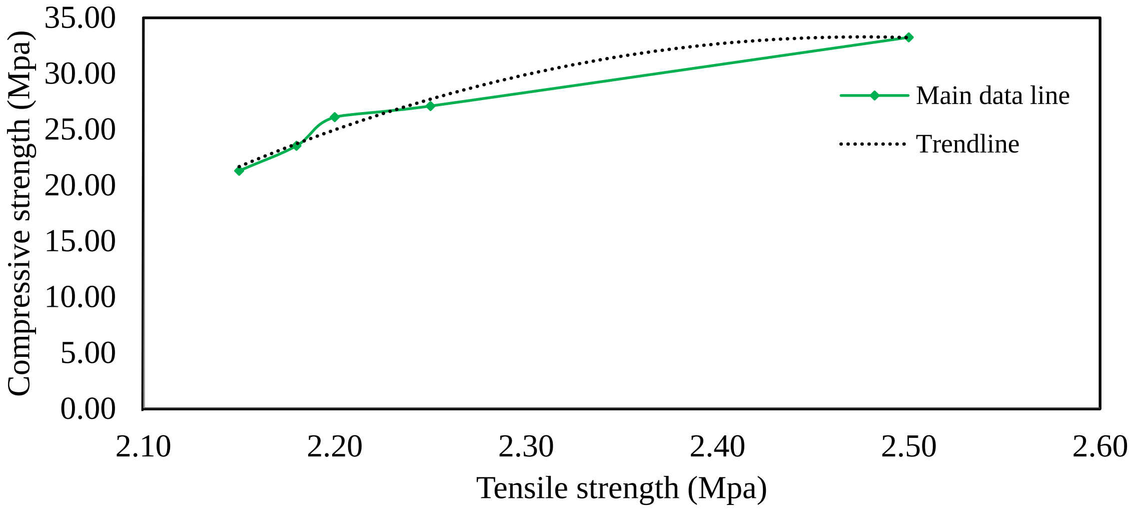


Figure 4.2.3b**:** Relationship between compressive strength and split tensile strength of sugarcane bagasse ash laterised concrete

### 4.2.4 Effect of Combined Material Replacement Levels on Flexural Strength of Concrete

Table 4.1.6 summarises the test results for the flexural strength for the tested specimens using a 1500kN universal testing machine. Each value of flexural strength represents the mean of triplicate test results. It was observed that as replacement level of sugarcane cement and sand increase, the flexural strength decreases. Sugarcane bagasse ash laterised concrete plain beams were observed to fail in the same manner in comparison to control specimen as all beams failed between the middle 150mm mark.

Table 4.2.4: Flexural strength of sugarcane bagasse ash laterised concrete

| Specimen type | Material Combination (%) | | | | Flexural strength (MPa) |
|---|---|---|---|---|---|
| | Sand | Laterite | Cement | Sugarcane bagasse ash | $f_{f28}$ (MPa) |
| SB-LA-00-00C (control) | 100 | 0 | 100 | 0 | 3.67 ±0.02 |
| SB-LA-05-05C | 95 | 05 | 95 | 05 | 3.28 ±0.05 |
| SB-LA-10-15C | 85 | 15 | 90 | 10 | 3.06 ±0.06 |
| SB-LA-15-20C | 80 | 20 | 85 | 15 | 3.02 ±0.05 |

Flexural strength of sugarcane bagasse ash laterised concrete as a ratio of control concrete is shown in Figure 4.2.4a, which shows that the strength continues to decrease as replacement level increase since none of the material attained a ratio of one as observed in control specimen.

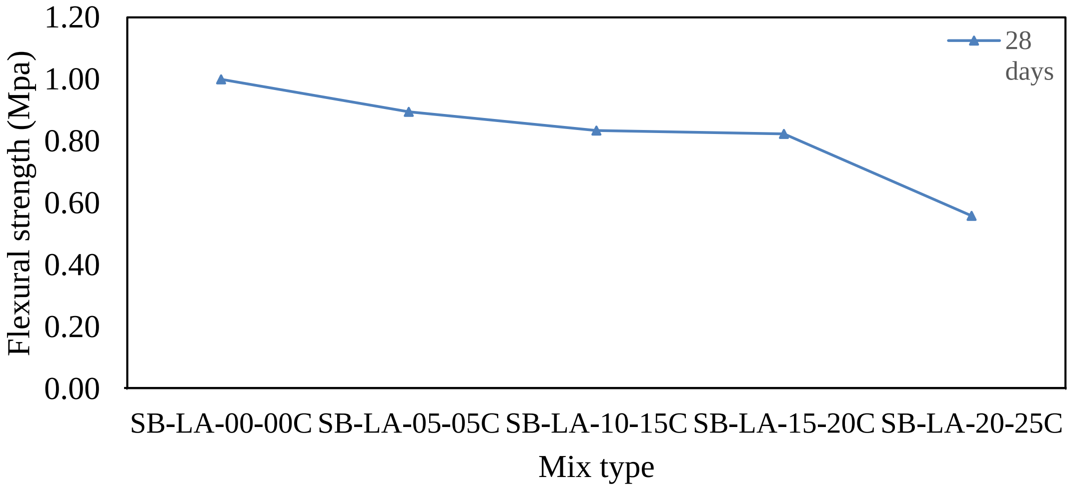


Figure 4.2.4a: Flexural strength of sugarcane bagasse ash laterised concrete as a ratio of control strength of the same age

To establish a mathematical relationship between the flexural strength and the compressive strength of sugarcane bagasse ash laterised concrete, Figure 4.2.4b shows compressive strength against flexural strength of sugarcane bagasse ash laterised concrete at 28 days. From the trend observed in Figure 4.2.4b a mathematical relationship between compressive strength and flexural strength of sugarcane bagasse ash laterised concrete can be represented by a polynomial in equation 2 with an $R^2$ of 0.85.

$$f_{cu28} = 5.3925f_{f28}^2 - 26.203f_{f28} + 53.217 \quad \text{---------} \ (2)$$

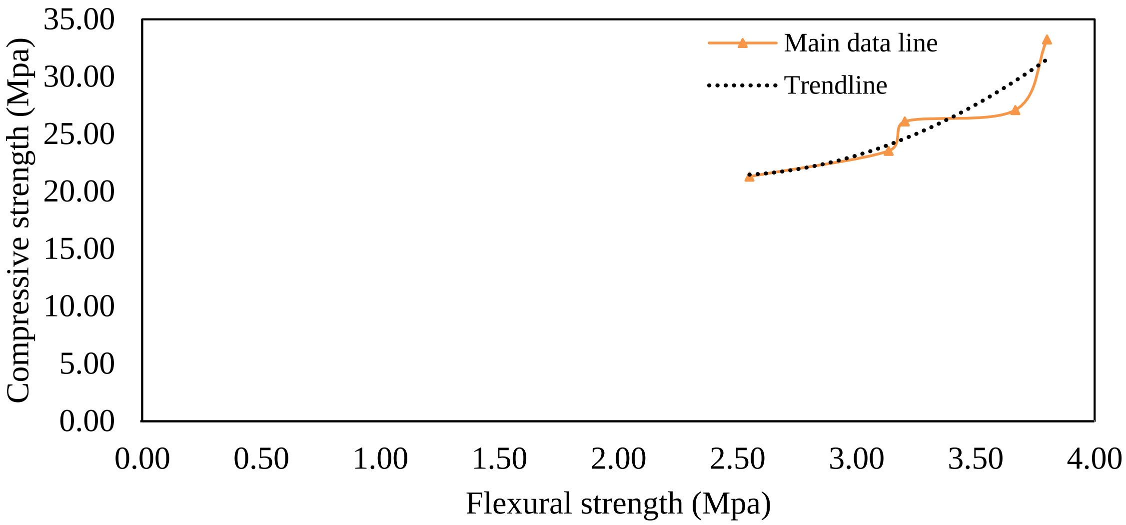


Figure 4.2.4b: Relationship between compressive strength and flexural strength of sugarcane bagasse ash laterised concrete

### 4.2.5 Effect of Combine Material Replacement Levels on Permeability of Concrete

Permeability of concrete is very important to a structural engineer as steel reinforcement embedded in concrete needs to be protected in order to prevent it from corroding. On this note, a comparative permeability performance of sugarcane bagasse ash laterised concrete was carried out to compare permeability performance of sugarcane bagasse ash laterised concrete in comparison to that of control concrete. The change in head was taken at intervals and amount of evaporation at every interval was deducted from various change in heads in order to account for water escaping due to evaporation and get the actual water penetrating the concrete. Figure 4.2.5a shows the graph of change in water head against time for all specimens. It was observed that the amount of water passing through the concrete increased with time for all the specimens. The results also show that at 52 days monitoring, the amount of water that penetrated the 85mm concrete thickness in SB-LA-00-00C, SB-LA-05-05C, SB-LA-10-15C, SB-LA-15-20C and SB-LA-20-25C were 67.6mm, 67.6mm, 54.6mm, 59.6mm and 58.6mm respectively. This shows that as the replacement level increases, the amount of water that penetrated the concrete base reduced which confirmed that concrete became less permeable.

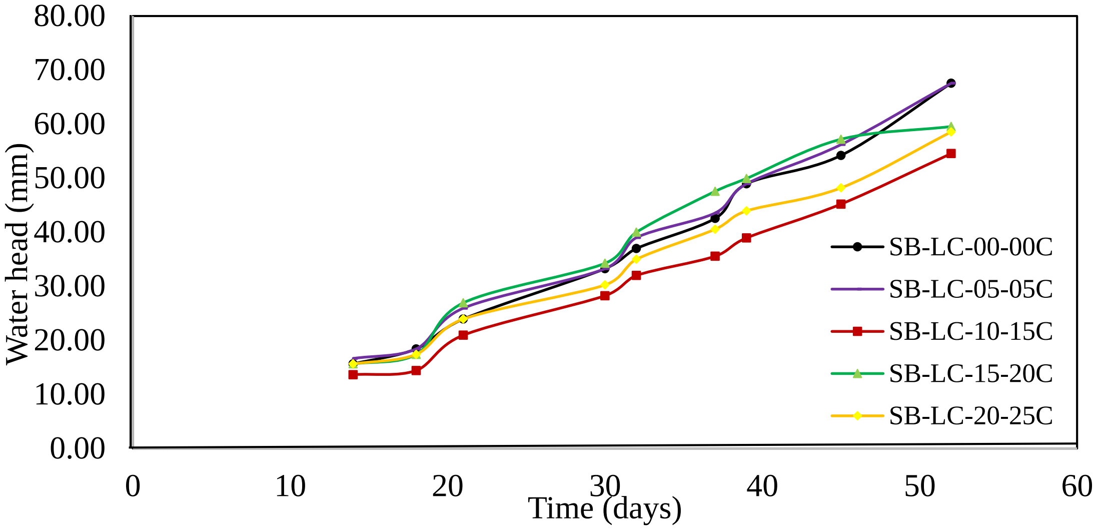


Figure 4.2.5a: Graph of change in head against time

The change in water head of each mix expressed as a ratio of that of control concrete was also plotted against time in order to picture the permeability behavior as shown in Figure 4.2.5b which shows the behavior of the control (SB-LA-00-00C) represented by the straight line with head ratio equal to 1.

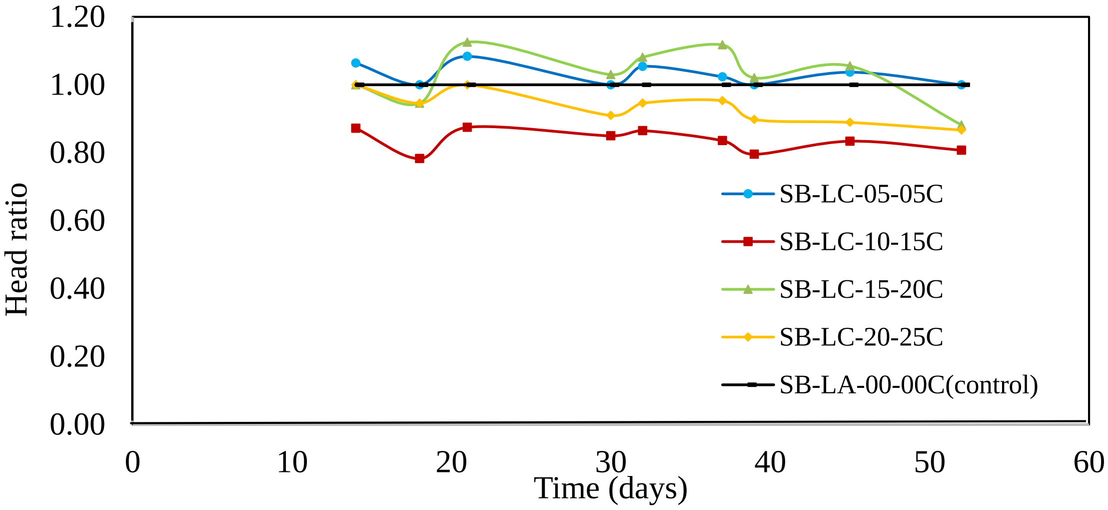


Figure 4.2.5b: Comparative permeability behavior of sugarcane bagasse ash laterised concrete with the control

The behavior of SB-LA-10-15C and SB-LA-20-25C below head ratio equal to 1 confirmed that these specimens showed a better permeability performance in comparison to control specimen SB-LA-00-00C.

## 4.3 Structural Behaviour of Sugarcane Bagasse Ash Laterised Concrete Beams

### 4.3.1 Load –Deflection Curves

A total of 12 beams were tested. Three of which were 1.8m long simply supported over an effective span of 1.5m and other 9 with a total length of 1.2m simply supported over an effective span of 1.0m. The behavior of the beam under load in terms of load-deflection characteristics are as follows;

#### 4.3.1.1 Beams without Shear Reinforcement

Three beams each were tested of length 1.8m and 1.2m simply supported over a length of 1.5m and 1.0m respectively. For each length of beam, two of the beams were produced with 15% cement replacement by sugarcane bagasse ash and 20% replacement of sand by lateritic soil (SB-LAB-15-20) and used to compare with the behavior of control beam (SB-LAB-00-00). It was observed as shown in Figures 4.3.1.1a and 4.3.1.1b that both 1.2m and 1.8m beams initially exhibited the same load-deflection characteristics until the ultimate load was achieved with a rapid decrease in initial stiffness at the appearance of major diagonal cracks. In respect to 1.2m beams, the deflection of beams in response to load application was also observed to be similar but the control beam attained a higher ultimate load than sugarcane bagasse ash laterised concrete beams, however, sugarcane bagasse ash laterised concrete beams showed superior post crack behavior than that of control beam. It was also observed generally that the applied load decreased suddenly once attained the peak point.

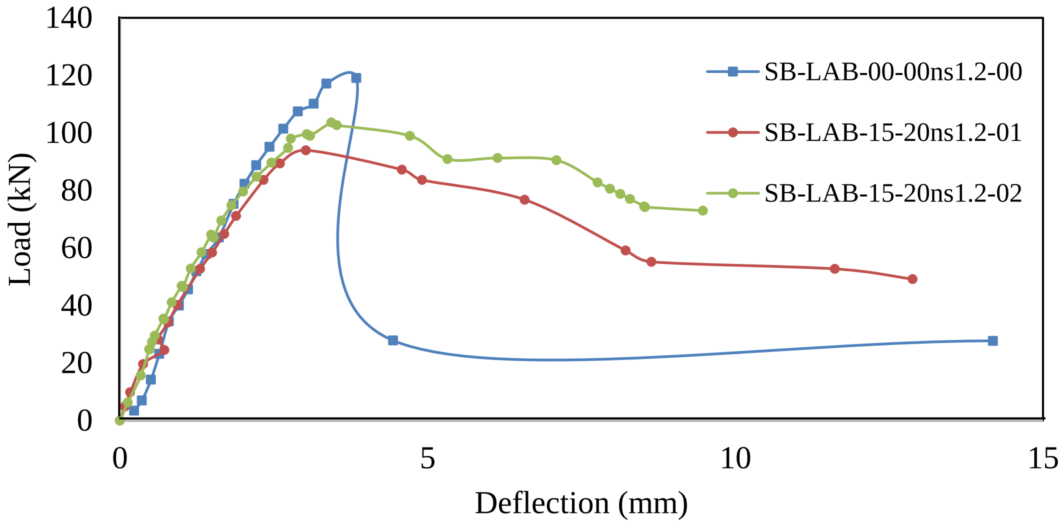


Figure 4.3.1.1a: Load-deflection curves of 1.2m beams without shear reinforcement

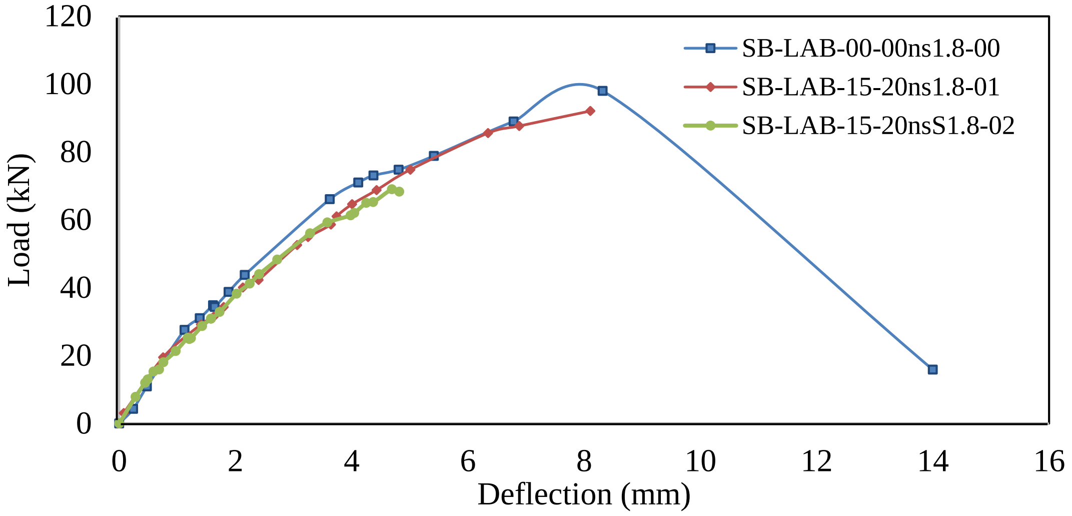


Figure 4.3.1.1b: Load-deflection curves of 1.8m beams without shear reinforcement

### 4.3.1.2 Beam with Shear Reinforcement

To determine the load-deflection behavior of reinforced sugarcane bagasse ash laterised concrete beams in comparison with that of the control, six beams with length of 1.2m simply supported over an effective span of 1.0m were used in total but with different combine replacement levels of cement and sand in the concrete mix. Figure 4.3.1.2 shows load-deflection curves of these specimens.

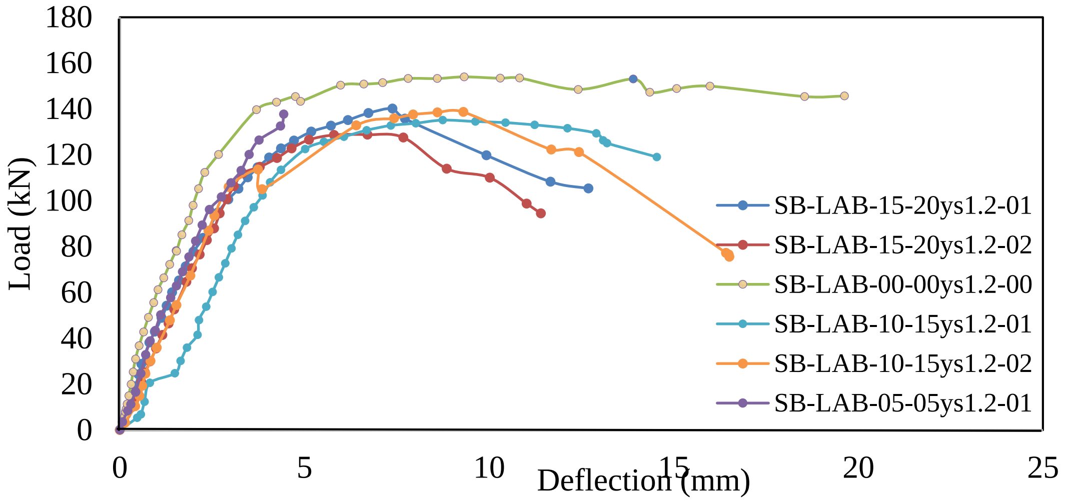


Figure 4.3.1.2**:** Load-deflection curves of 1.2m beams with shear reinforcement

The load–deflection curves in Figure 4.3.1.2 shows in comparison with control specimen that almost all the beams exhibited similar load-deflection characteristics but attained their ultimate at different points. However, SB-LAB-10-15ys1.2-01 show a different behavior between 20-40kN load applications as the deflection increased to a value close to 2mm at almost a constant load. Beams with shear reinforcement however showed a higher load capacity than those without shear reinforcement.

### 4.3.1.3 Deflection at Different Loading Stages

Table 4.3.1.3 shows summary of deflection of each beam at service and ultimate load. The service load was calculated by dividing the ultimate load by a factor of 1.5 according to (BS 6399, 1996), applied for family dwellings not exceeding three storey building.

Table 4.3.1.3: Deflection at different stages of the beams

| Specimen type | Service load (kN) | Ultimate load (kN) | Deflection at service load (mm) | Deflection at ultimate load (mm) |
|---|---|---|---|---|
| SB-LAB-00-00ns1.2-00 | 74.42 | 119.07 | 1.67 | 4.44 |
| SB-LAB-15-20ns1.2-01 | 61.74 | 98.77 | 1.68 | 3.23 |
| SB-LAB-15-20ns1.2-02 | | | | |
| SB-LAB-00-00ns1.8-00 | 61.25 | 98.00 | 2.50 | 8.32 |
| SB-LAB-15-20ns1.8-01 | 50.36 | 80.57 | 2.80 | 5.55 |
| SB-LAB-15-20ns1.8-02 | | | | |
| SB-LAB-00-00ys1.2-01 | 96.26 | 154.02 | 1.70 | 9.33 |
| SB-LAB-05-05ys1.2-01 | 86.07 | 137.71 | 2.10 | 8.43 |
| SB-LAB-10-15ys1.2-01 | 85.57 | 136.91 | 2.30 | 8.07 |
| SB-LAB-10-15ys1.2-02 | | | | |
| SB-LAB-15-20ys1.2-01 | 84.04 | 134.46 | 2.40 | 7.05 |
| SB-LAB-15-20ys1.2-02 | | | | |

The results in Table 4.3.1.3 shows that as percentage replacement of cement and sand increase, the service load decreases for all beams with or without shear reinforcement but service load for beams with shear reinforcement was higher than their counterparts without shear reinforcement. Deflections at service load was found to increase with increase in replacement levels of cement and sand, but for beams with shear reinforcement was higher than those without shear reinforcement. However, deflections at ultimate load were observed to reduce as the percentage replacement of cement and sand increase for both beams, with and without shear reinforcement.

### 4.3.2 Shear Behavior of Sugarcane Bagasse Ash Laterised Concrete

#### 4.3.2.1 Shear Stress-Shear Strain Relationship

The experimental shear stress-shear strain curve of beams were plotted to visualize the behavior of the sugarcane bagasse ash laterised concrete in comparison with that of control beams. Experimental shear stress was calculated by the relation in equation 3.

$$v = \frac{p}{2bh} \qquad \text{------------------} \ (3)$$

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

$$\gamma_{xy} = \varepsilon_{45^o} - (\varepsilon_{90^o} + \varepsilon_{0^o}) \qquad \text{------------------} \ (4)$$

where $\gamma_{xy}$ is the shear strain,
$\varepsilon_{45^o}$ is the strain at 45° inclination to the horizontal
$\varepsilon_{0^o}$ is the strain at 0° and
$\varepsilon_{90^o}$ is the strain at 90°

#### 4.3.2.2 Beams without Shear Reinforcement

Figures 4.3.2.2a and 4.3.2.2b show comparative shear stress-shear strain behavior of reinforced beam without shear reinforcement for 1.2/1.0m and 1.8/1.5m respectively, where the first number represents overall length of the beam and the other represents the simply supported span.

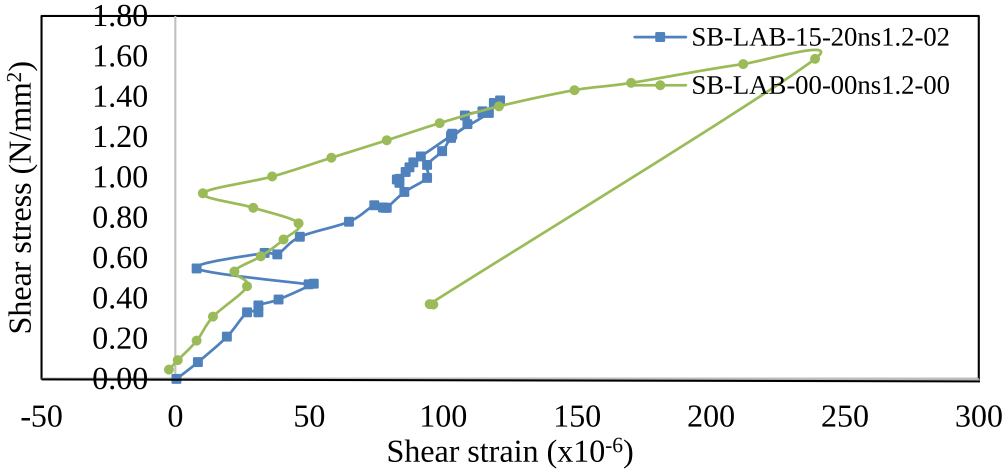


Figure 4.3.2.2a: Shear stress–shear strain curve of 1.2m beams without shear reinforcement

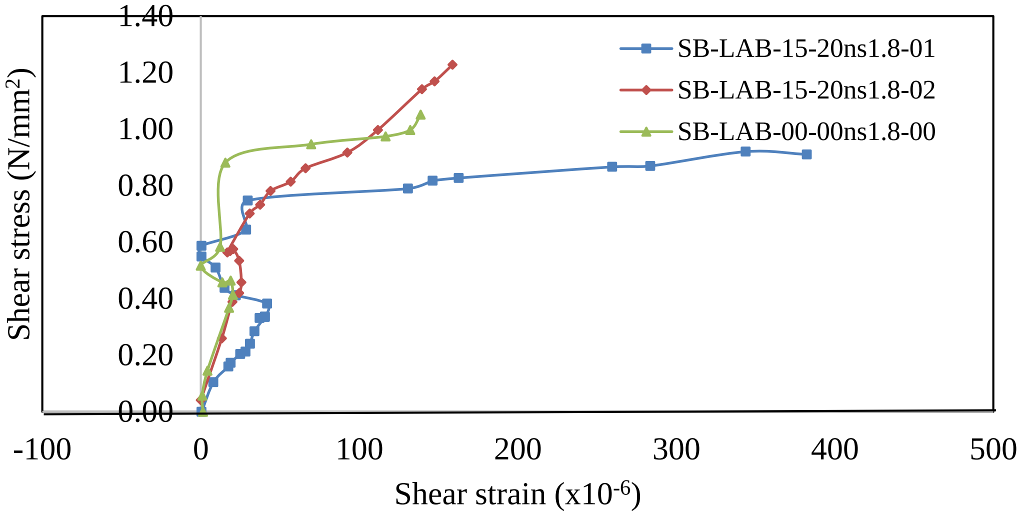


Figure 4.3.2.2b: Shear stress –shear strain curve of 1.8m beams without shear reinforcement

Results of shear stress-shear strain curve shown in Figure 4.3.2.2a and Figure 4.3.2.2b show that for 1.2/1.0 and 1.8/1.5m reinforced beams without shear reinforcement, negative strain relaxation was observed between shear stress, 0.4-0.6MPa and a sudden drop in shear stress was also observed after the ultimate shear stress was attained for 1.2m long reinforced beams while 1.8m long beams were observed to increase in strain after the ultimate shear stresses was attained. This strain increase was more pronounce in SB-LAB-15-20ns1.8-01 as it approaches a value of 400x10$^{-6}$.

### 4.3.2.3 Beams with Shear Reinforcement

A total of six beams were used with different replacement levels of cement and sand by sugarcane bagasse ash and laterite respectively in the concrete mixes. Figure 4.3.2.3 shows the shear stress–shear strain curves for beams with 6mm (R6) shear reinforcement at 110mm center-center. It was observed that there was negative strain relaxation between shear stress of 0.6-1MPa. It was also observed that beams with 5% replacement of both cement and sand (SB-LAB-05-05ys1.2) exhibits similar shear stress-shear strain response to that of control beam but did not achieve the same ultimate shear stress as the control beam.

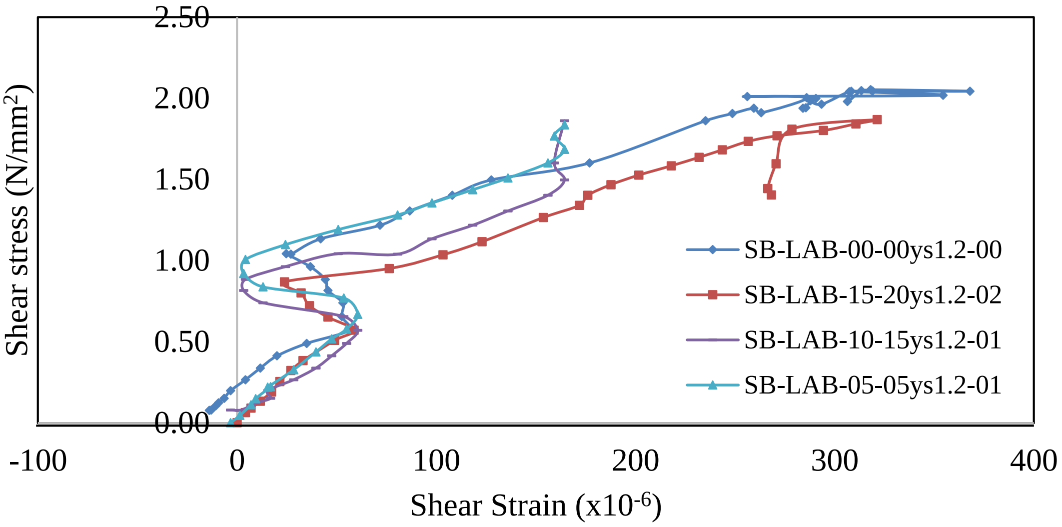


Figure 4.3.2.3: Shear stress –shear strain behavior of beams with shear reinforcement

### 4.3.2.4 Comparison of Shear Strength Behavior of Beams

Summarized values of shear strength for all beams with and without shear reinforcement is given in Table 4.3.2.4. This gives the nominal shear stresses at ultimate loads for all beams with and without shear reinforcement. It will be observed from the results that the ultimate shear load for beams with shear reinforcement are relatively higher than those without shear reinforcement which automatically translated to a higher maximum shear strength for beams with shear reinforcement compared to those without shear reinforcement. In addition to these, the ultimate shear load and shear strength of beams without shear reinforcement decreases as the replacement level increases. The values of shear stress contribution of concrete $v_c$ were also determined and were found to decrease as replacement levels increase. The moment capacities of all the beams were also determined as the ratio of ultimate shearing moment $M_u$ to flexural moment$M_f$. Flexural moment $M_f$ was calculated from the relation in equation 5.

$$M_f \;=\; 0.15bd^2 f_{cu} \quad \text{------------------ (5)}$$

where $f_{cu}$ is the compressive strength of the concrete as determined by the 28 days cube strength of the specimen
$b$ is the breath of the beam and
$d$ is the effective depth of the beam specimen

The ultimate shear moment $M_u$ was determined by the relation in equation 6

$$M_u = P_{max}\, a_v/2 \quad \text{------------------ (6)}$$

where $P_{max}/2$ is the maximum shear load of the beam calculated as half of the maximum applied load

$a_v$ is the clear shear span of the beam

Table 4.3.2.4 shows that the experimental ultimate shear moment decreases as the percentage replacement level increases. This was expected because the shear load also decreases with the replacement levels of cement and sand. All moment capacities shown in Table 4.3.2.4 were seen to be less than 1, but the smaller beams of 1.2m length showed a higher moment capacities than longer beams of 1.8m length. In addition, beams with and without shear reinforcement show increase in moment capacity as the replacement level of cement and sand increase. The use of equations 3 and 4 for the determination of moment capacity was adopted by (Salau & Balogun, 1990). The values for design concrete shear $V_c$ was calculated by equation 7 from (BS 8110, 1997).

$$v_c = \frac{0.79}{\gamma_m}\left(\frac{100A_s}{b_v d}\right)^{1/3}\left(\frac{400}{d}\right)^{1/4} \quad \text{----------------- (7)}$$

where $\gamma_m$ is the material factor for concrete taken as 1.25,
$d$ is the effective depth of the beam,
$b_v$ is the breath of the beam,
$A_s$ is the area of reinforcement.

For concrete mixes with compressive strength greater than 25N/mm$^2$, the value in equation 7 was multiplied by a factor $\left(\frac{f_{cu}}{25}\right)^{1/3}$ where $f_{cu}$ is 28 days compressive strength of the concrete mix, but compressive strength should not exceed 25MPa as specified by (BS 8110, 1997).

Generally, as replacement levels of cement and sand increased, the concrete shear contribution $V_c$ was observed to decrease. This can be attributed to the fact that the compressive strength of the mixes reduces as the replacement levels of cement and sand in the mix increased. However the percentage reduction in concrete shear contribution was between 4.0-10% for beams with shear reinforcement, 6.5% for 1.2m long beam without shear reinforcement and 12.2% for 1.8m beam without shear reinforcement. These percentage reductions were calculated in comparison to concrete shear contribution of control beams without cement and sand replacement.

Table 4.3.2.4: Comparison of shear strength behaviour of beams

| Specimen type | Beam length/ effective length m | $a_v/d$ d=230mm | Average cube strength at 28 days Mpa | Ultimate shear load kN | Ultimate shear stress $N/mm^2$ | Flexural moment $M_f$ kN-m | Ultimate shear moment $M_u$ kN-m | Moment Capacity $M_u/M_f$ | Shear limit $N/mm^2$ BS8110 | $V_c$ $N/mm^2$ | $V_c+0.4$ $N/mm^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SB-LAB-00-00ns1.2-00 | 1.2/1.0 | 1.50 | 31.04 | 58.55 | 1.70 | 36.95 | 20.20 | 0.55 | 3.58 | 0.48 | 0.88 |
| SB-LAB-15-20ns1.2-01 | 1.2/1.0 | 1.50 | 22.51 | 49.39 | 1.32 | 26.80 | 17.04 | 0.64 | 3.58 | 0.45 | 0.85 |
| SB-LAB-15-20ns1.2-02 | | | | | | | | | | | |
| SB-LAB-00-00ns1.8-00 | 1.8/1.5 | 2.00 | 33.65 | 43.02 | 1.25 | 40.05 | 19.79 | 0.49 | 3.58 | 0.49 | 0.89 |
| SB-LAB-15-20ns1.8-01 | 1.8/1.5 | 2.00 | 22.29 | 40.48 | 1.08 | 26.06 | 18.62 | 0.71 | 3.58 | 0.43 | 0.83 |
| SB-LAB-15-20ns1.8-02 | | | | | | | | | | | |
| SB-LAB-00-00ys1.2-01 | 1.2/1.0 | 1.50 | 35.68 | 77.01 | 2.05 | 42.46 | 26.57 | 0.63 | 3.58 | 0.50 | 0.90 |
| SB-LAB-05-05ys1.2-01 | 1.2/1.0 | 1.50 | 30.60 | 68.85 | 2.00 | 36.42 | 23.75 | 0.65 | 3.58 | 0.48 | 0.88 |
| SB-LAB-10-15ys1.2-01 | 1.2/1.0 | 1.50 | 27.99 | 67.78 | 1.81 | 33.31 | 23.38 | 0.70 | 3.58 | 0.46 | 0.86 |
| SB-LAB-10-15ys1.2-02 | | | | | | | | | | | |
| SB-LAB-15-20ys1.2-01 | 1.2/1.0 | 1.50 | 24.88 | 67.23 | 1.80 | 29.61 | 23.19 | 0.78 | 3.58 | 0.45 | 0.85 |
| SB-LAB-15-20ys1.2-02 | | | | | | | | | | | |

### 4.3.3 Load at Different Stages

Cracking of concrete is known to occur when the tensile strength of concrete is exceeded. First crack load was taken as the load in which the first visible crack was noticed, ultimate load was taken as the maximum load attained by the beams while service load was taken as the maximum load attained by each beam divided by a factor of 1.5 according to (BS 6399, 1996) for family dwellings not exceeding three storey building.Table 4.3.3 show crack load, service load, ultimate load, cracking moment, service moment and ultimate moment.

Table 4.3.3: Load at different stages

| Specimen type | First crack load kN | Service load kN | Ultimate load kN | Cracking Moment $M_c$ kN-m | Service Moment $M_s$ kN-m | Ultimate Moment $M_m$ kN-m |
|---|---|---|---|---|---|---|
| SB-LAB-00-00ns1.2-00 | 45.62 | 74.42 | 119.07 | 6.84 | 11.16 | 17.86 |
| SB-LAB-15-20ns1.2-01 | 29.99 | 61.74 | 98.77 | 4.50 | 9.26 | 14.82 |
| SB-LAB-15-20ns1.2-02 | | | | | | |
| SB-LAB-00-00ns1.8-00 | 34.83 | 61.25 | 98.00 | 10.10 | 17.76 | 28.42 |
| SB-LAB-15-20ns1.8-01 | 29.40 | 50.36 | 80.57 | 8.52 | 14.60 | 23.36 |
| SB-LAB-15-20ns1.8-02 | | | | | | |
| SB-LAB-00-00ys1.2-01 | 55.55 | 96.26 | 154.02 | 8.33 | 14.44 | 23.10 |
| SB-LAB-05-05ys1.2-01 | 50.24 | 86.07 | 137.71 | 7.54 | 12.91 | 20.66 |
| SB-LAB-10-15ys1.2-01 | 47.89 | 85.57 | 136.91 | 7.18 | 12.84 | 20.54 |
| SB-LAB-10-15ys1.2-02 | | | | | | |
| SB-LAB-15-20ys1.2-01 | 42.185 | 84.04 | 134.46 | 6.33 | 12.61 | 14.29 |
| SB-LAB-15-20ys1.2-02 | | | | | | |

Results in Table 4.3.3 shows that the crack load, service load and ultimate load for beams without shear reinforcement reduces as cement and sand replacement levels increased. Beams with shear reinforcement also showed the same trend; as the replacement level increases, the various load capacities also reduced.

### 4.3.4 Cracking and Failure Mode

This section discusses the different modes of failure and cracking pattern for all beams with and without shear reinforcement.

#### 4.3.4.1 Beams without Shear Reinforcement

Figure 4.3.4.1 shows the physical failure pattern of beams without shear reinforcement. At the initial stage of loading, flexural cracks were formed before the diagonal cracks began to develop as the load increases. The diagonal cracks propagated from the mid-height of the beams and propagating towards the support or the loading point. A sudden failure was observed after the maximum load was attained. Shear–compression failure near the support or loading point was observed for the control beams and also the longer beams of 1.8m irrespective of the level of replacement of cement and sand in the concrete mix. For shorter beams of 1.2m long, bearing failure was observed in SB-LAB-15-20ns1.2-01 and 02. It shows that the length of the beams have influence on their failure pattern for the beams with cement and sand replacement.

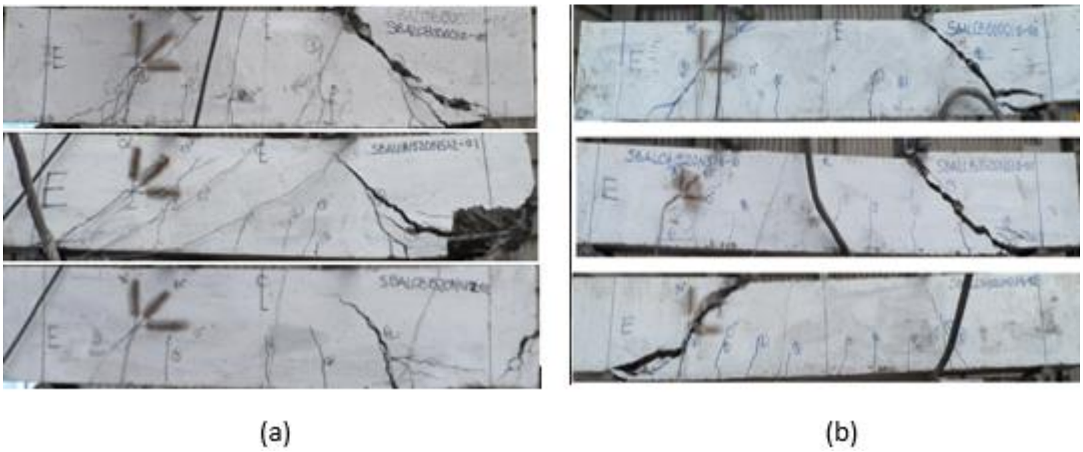

(a) (b)

Figure 4.3.4.1**:** Failure pattern of (a) 1.2m and (b) 1.8m beams without shear reinforcement

#### 4.3.4.2 Beams with Shear Reinforcement

Figure 4.3.4.2 shows failure patterns of beams with shear reinforcement. Flexural cracks were also formed in the early stages of load application in the pure bending region. As loading increases, diagonal cracks appeared also as in the case of beams without shear reinforcement within the clear shear span of the beams. While the diagonal cracks were developing across the length, their width were propagating within the shear span region. The failing mechanism identified were as follows;

a) Diagonal splitting along the loading point was observed in in some of the beams such as SBLCB-05-05ys1.2-01 and SBLCB-10-15ys1.2-02.
b) Shear –flexure was also observed in some beam like SBLCB-00-00ys1.2-00

c) Due to forming of several parallel diagonal cracks, strut - crushing was also observed in the control SBLCB-10-15ys1.2-01 and SBLCB-15-20ys1.2-01

d) Bearing failure was also observed in SBLCB-15-20ys1.2-01 as a result of the bearing stresses exceeding the bearing capacity of the concrete. These stresses according to (Subedi & Baglin, 1999) are assumed to range from 0.7-0.85fcu

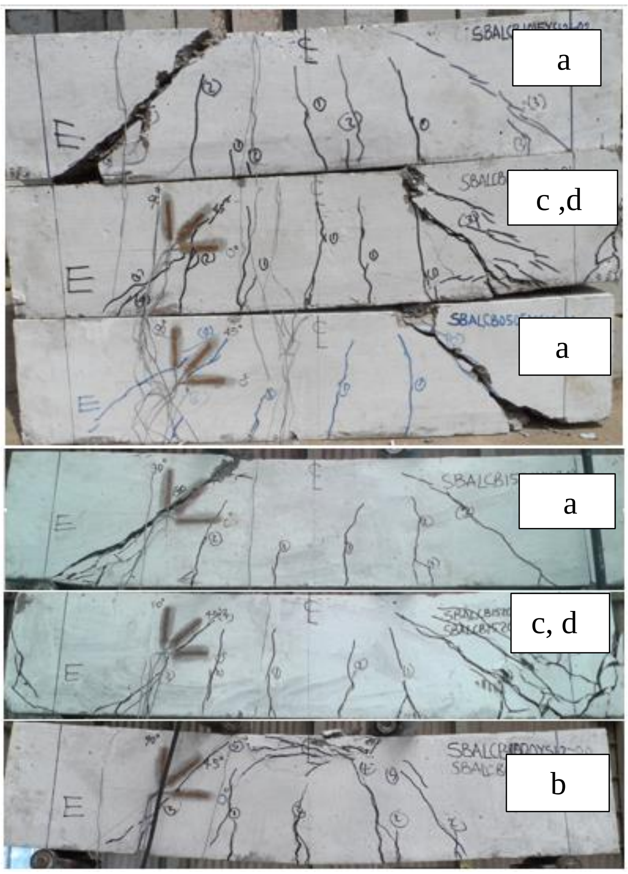


Figure 4.3.4.2: Failure pattern of 1.2m beams with shear reinforcement

### 4.3.5 Strain Induced in Reinforced Beams

Flexural strains induced at the centre of the longitudinal reinforcement embedded in the beams in response to load applications are shown in Figure 4.3.5a (I), (II) and (III). As observed in Figure 4.3.5a (I) and (II) for beams without shear reinforcement, the smaller beams sustained greater strain than the longer beams. In Figure 4.3.5a (I), both control and sugarcane bagasse ash laterised concrete beams exhibit linear elastic response to load applications. In addition, the beams with shear reinforcement sustained higher strain (between 1000-5000x$10^{-6}$) than their counterparts without shear reinforcement. This is obviously due to the presence of the shear reinforcement in the beams which enables it to withstand more loads.

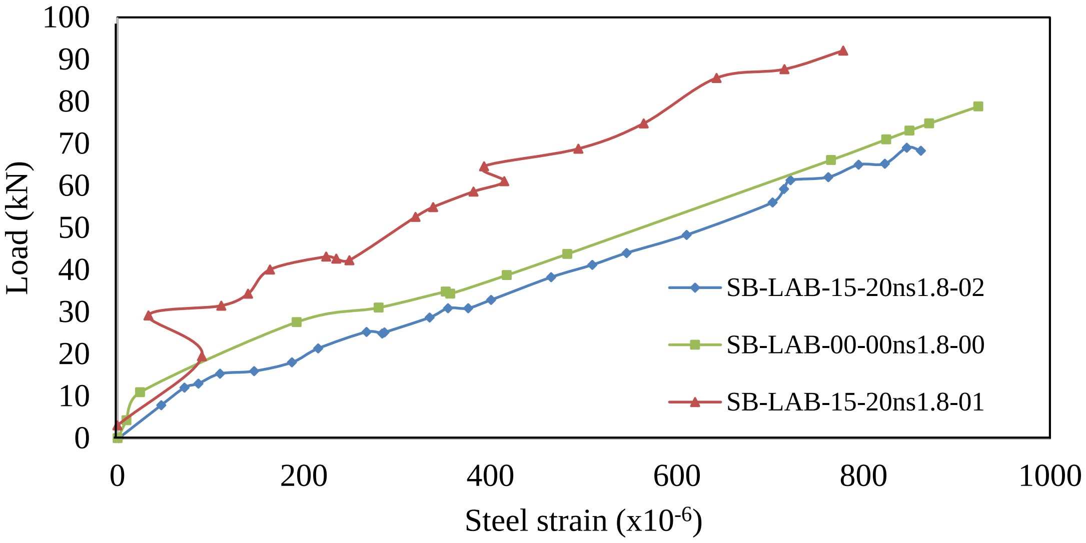


Figure 4.3.5 (I): Flexural strain induced at the centre of longitudinal reinforcement of 1.8m beams without shear reinforcement

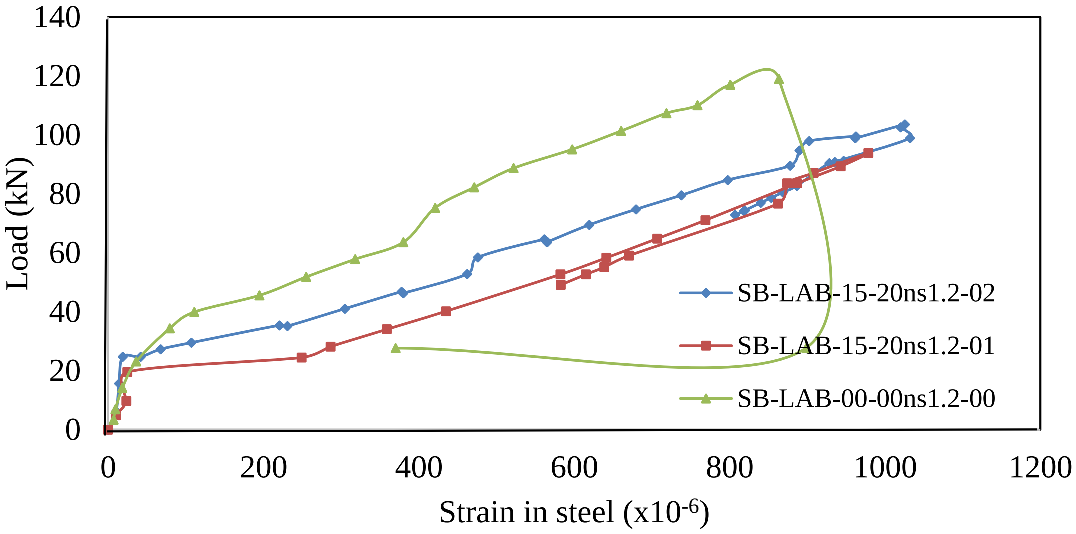


Figure 4.3.5a (II): Flexural strain induced at the centre of longitudinal reinforcement of 1.2m beams without shear reinforcement

Figures 4.3.5b (I), (II) and (III), show the relationship between loads applied and induced flexural strain at the bottom of concrete beam for all tested beams. In Figure 4.3.5b (I), SB-LAB-15-20ns1.2-01 and SB-LAB-00-001.2-00 exhibit the same response till about 25kN load. As the load intensified, SB-LAB-15-20ns1.2-01 exceeded a strain value of $1000 \times 10^{-6}$ and then returned back to a value close to $0 \times 10^{-6}$ while for SB-LAB-00-001.2-00, the strain only increased to around $200 \times 10^{-6}$.

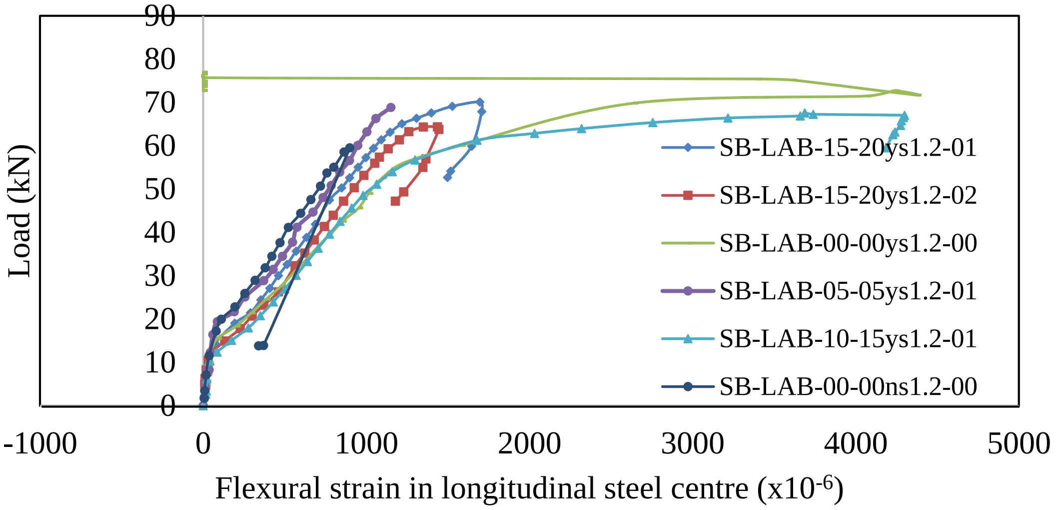


Figure 4.3.5a (III): Flexural strain induced at the centre of longitudinal reinforcement of 1.2m beams with shear reinforcement

Figure 4.3.5b (II) also shows that the 1.8m long beams initially behaves alike by inducing zero strain until the load reaches 10kN, SB-LAB-15-20ns1.8-01 continues with the zero strain as the load increases up to 30kN while for SB-LAB-00-00ns1.8-00 and SB-LAB-15-20ns1.2-02 the flexural strain increased after 10kN load application.

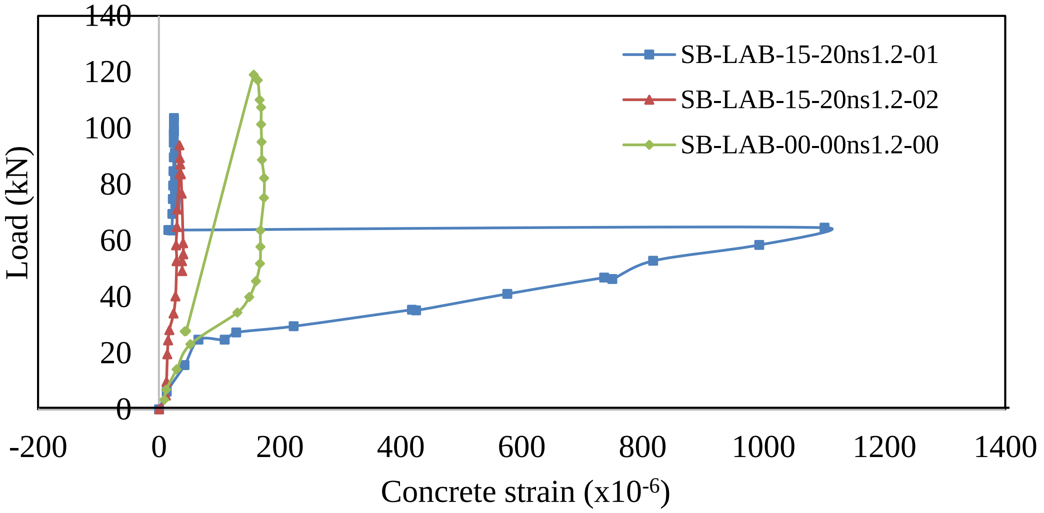


Figure 4.3.5b (I): Flexural strain induced at beam bottom of 1.2m beams without shear reinforcement

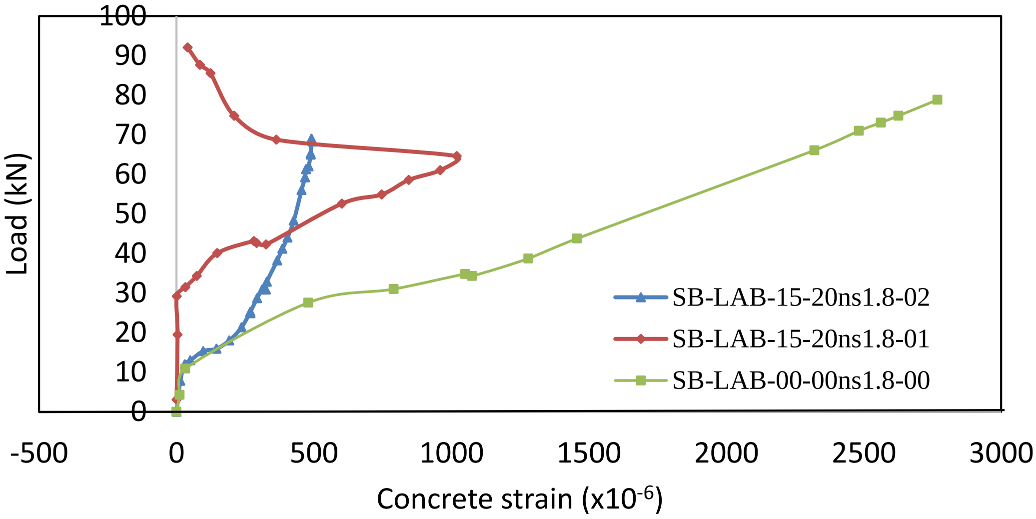


Figure 4.3.5b (II): Flexural strain induced at beam bottom of 1.8m beams without shear reinforcement

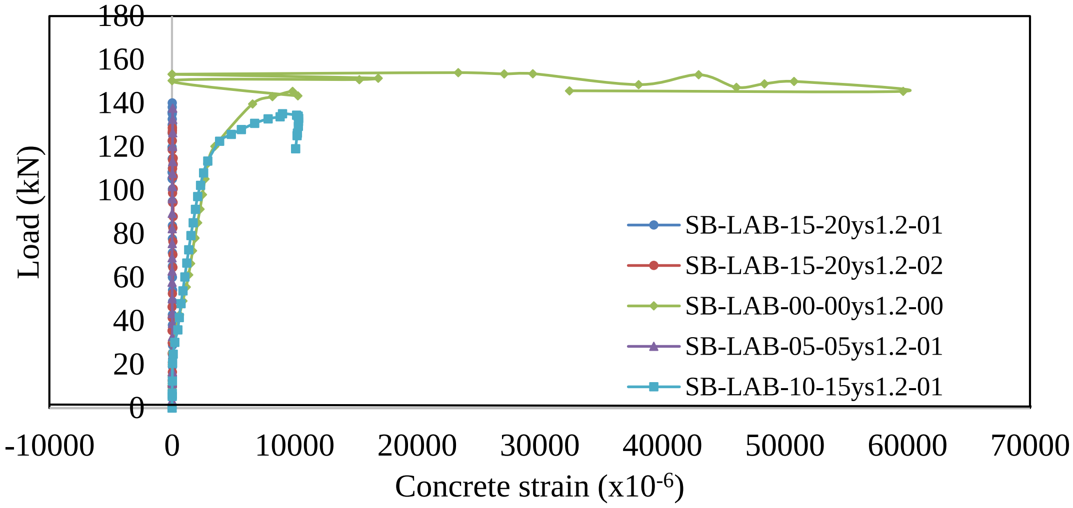


Figure 4.3.5b (III): Flexural strain induced at beam bottom of 1.2m beams with shear reinforcement

From the load-strain curve in Figure 4.3.5b (III), it was observed that all the beams initially maintained constant flexural strain as load increases until the applied load reaches a value of 40kN. After 40kN, SB-LAB-10-15ys1.2-01 and SB-LAB-00-00ys1.2-00 showed increase in strain up to the maximum load. In addition, SB-LAB-00-00ys1.2-00 showed a negative strain relaxation between the load of 140-160kN. Between 0-60kN in Figure 4.3.5c, for 1.2m long reinforced beams with shear reinforcement, the beams exhibit same load-strain characteristics. Beyond the 60kN load, the response began to differ due to difference in stiffness.

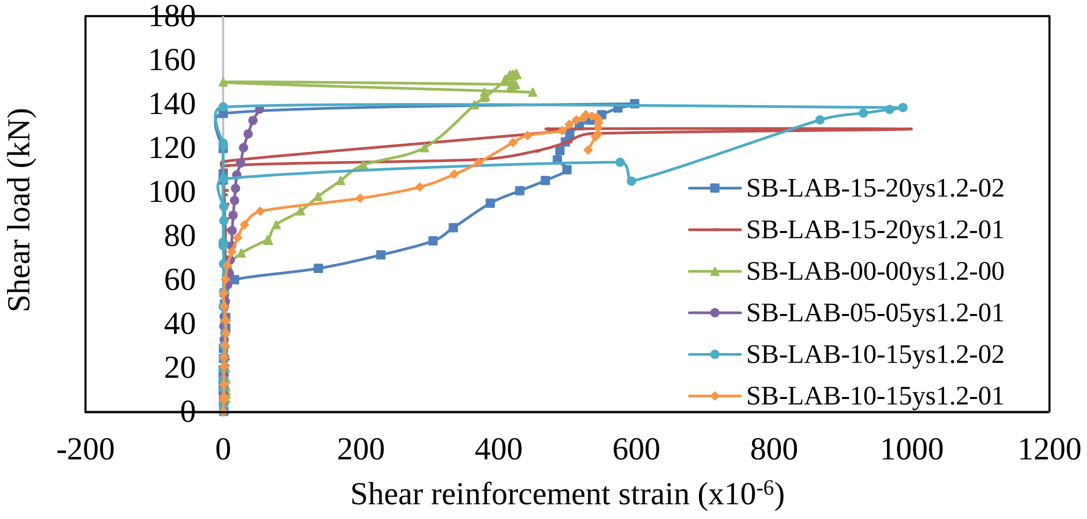


Figure 4.3.5 (c) Strain induced in stirrups of 1.2m beams with shear reinforcement

### 4.3.6 Comparison between Theoretical and Experimental Results

The theoretical ultimate loads for third point loading arrangement calculated from the flexural moment in equation 5 and effective length was also adopted by (Altun, Besdok, Harktanir, & Palancioglu, 2005) using equation 8 were compared to experimental values as shown in Table 4.3.6.

$$P_u = 3M_f/L \quad \text{------------------ (8)}$$

Where $P_u$ is the theoretical ultimate load
$M_f$ is the moment or resistance
$L$ is the effective length of the beam

Moment of resistance was taken as the flexural moment used in equation 5 for all beams. From the results in Table 4.3.6 the variance between the experimental and theoretical values of ultimate load for beam without shear irrespective of its length varies between 7.42-55.16% and that of beams with shear reinforcement increased up to 51.38%. This indicates that, application of empirical formulas in design would give safe but rather uneconomical predictions of the structural capacity. However, applying the empirical formulas give a more economical prediction for the beam without shear reinforcement.

Table 4.3.6: Comparison between theoretical and experimental ultimate loads

| Specimen type | Ultimate load $P_{u(exp)}$ kN | Ultimate load $P_{u(Theo)}$ kN | Percentage variance % |
|---|---|---|---|
| SB-LAB-00-00ns1.2-00 | 119.07 | 110.84 | 7.42 |
| SB-LAB-15-20ns1.2-01 | 98.77 | 80.39 | 22.10 |
| SB-LAB-15-20ns1.2-02 | | | |
| SB-LAB-00-00ns1.8-00 | 98.00 | 80.10 | 22.35 |
| SB-LAB-15-20ns1.8-01 | 80.57 | 52.12 | 55.16 |
| SB-LAB-15-20ns1.8-02 | | | |
| SB-LAB-00-00ys1.2-01 | 154.02 | 127.39 | 20.91 |
| SB-LAB-05-05ys1.2-01 | 137.71 | 109.26 | 26.04 |
| SB-LAB-10-15ys1.2-01 | 136.91 | 99.93 | 37.01 |
| SB-LAB-10-15ys1.2-02 | | | |
| SB-LAB-15-20ys1.2-01 | 134.46 | 88.82 | 51.35 |
| SB-LAB-15-20ys1.2-02 | | | |

# CHAPTER 5

## 5.0 Discussions of Results

## 5.1 Effect of Material Replacement Levels on Workability

From the results of slump test in Figure 4.1.1, it was observed that replacement of cement by sugarcane bagasse ash and sand by laterite soil reduces workability of concrete. It can be said then that sugarcane bagasse ash and laterised concrete require higher water content to produce a workable concrete. Reduction in workability may be attributed to the nature of the particle sizes of sugarcane bagasse ash and laterite soil replacing cement and sand respectively because it is a known fact that aggregate size and texture affect the workability of concrete. It may also be that part of the water required in the concrete was absorbed by sugarcane bagasse ash and laterite soil, which made less water available for proper flow of concrete. However, to reduce water content in laterised or sugarcane bagasse ash concrete, a water reducing admixture such as plasticiser can be used.

## 5.2 Strength of Sugarcane Bagasse Ash Laterised Concrete

It was generally observed that the more sugarcane bagasse ash and laterite soil replaces cement and sand respectively in a concrete mix, the lesser the strength in comparison with the normal concrete. However, replacement of cement by sugarcane bagasse ash of 5% gave an increase in compressive strength in comparison to control specimen. The increase in strength at 5% replcement of cement by sugarcane bagasse ash may be attributed to the pozzolonanic properties of sugarcane bagasse ash as chemical composition of sugarcane bagasse ash showed presence of Si, Al and Fe which comfirms the presence of $SiO_2$, $Al_2O_3$ and $Fe_2O_3$. This result is in consonant with the study carried out by (Srinwasan & Sathiya, 2010 ).

In addition, the results of compressive strength, tensile strength and flexural strength of combine replacement of cement and sand with 30mm slump showed that the strengths of sugarcane bagasse ash laterised concrete reduces as the replacement levels increase. Replacement level of up to 20% cement by sugarcane bagasse ash and 25% of sand by laterite soil, SB-LA-20-25C, gave little higher than the targeted design strength for 1:2:4 mix of 20MPa. The reason for weak compressive strength of sugarcane bagasse ash laterised concrete in comparison to control concrete may attributed to the presence of laterite soil that contains lower compressive strength than the sand it is replacing in the concrete mix. However, achieving the targeted compressive strength of concrete is more important to a structural engineer as we know, when concrete is utilised in a structure as an element such as beams, slabs etc., the tensile stresses of the structural element is carried by introducing reinforcement into the element.

## 5.3 Permeability of Sugarcane Bagasse Ash Laterised Concrete

Permeability of concrete is also a very important property to a structural engineer. A permeable concrete will allow the passage of water into the concrete which caused corrosion of reinforcement embedded in the concrete. This makes it of paramount important to check the permeability of a material before utilising it as a building material. Hardened Sugarcane bagasse ash laterised concrete showed a better permeability performance than control specimen. This may be attributed to the introduction of sugarcane bagasse ash and/or laterite soil which reduces decomposition and leaching of the main hydrates (C-S-H) in concrete, thereby reducing the porosity of the concrete (Berner, 1998).

## 5.4 Performance of Sugarcane Bagasse Ash Laterised Concrete Beams

### 5.4.1 Comparative Deflection Performance

It can be observed from the results of load-deflection characteristics that deflections at ultimate shear loads continue to decrease as combine material replacement levels increases for all beams. This may be due to the visco-elasticity of laterite indicating that the ductility of the beams increase as the percentage replacement of cement and sand increase. The values of deflection at service load however slightly increases as the replacement levels of cement and sand by sugarcane bagasse ash and laterite soil increases, but these values satisfied the requirement provided in (BS 8110, 1997); not exceeding span/250.

### 5.4.2 Comparative Shear Behaviour of the Beams

Shear capacity is defined as the maximum shear force that a critical section can sustain. The negative strain observed in all the shear stress- shear strain curves could be attributed to the shear deformations at the onset during strut crushing. The results of shear behaviour in Table 4.3.2.4 shows that the maximum shear strength of all the beams satisfied the limit set by (BS 8110, 1997); not exceed $0.8\sqrt{f_{cu}}$. Where $f_{\text{cu}}$ as used in Table 4.3.2.4 is characteristics strength of 1:2:4 mix, which is 20MPa. Further checks also showed that none of the ultimate shear stresses exceeded the sum of concrete shear contribution and minimum shear resistance provided by minimum links ($v_{\text{c}}$+0.4), meaning that sugarcane bagasse ash laterised concrete can be designed based on provisions contained in (BS8110, 1997).

### 5.4.3 Load at Different stages of Loading

The crack, service and ultimate loads and their moments were found to decrease as the replacement level of cement and sand by sugarcane bagasse ash and laterite soil increase. This may be due to the fact that beam stiffness decreases as the replacement levels of cement and sand increases. Since stiffness is given by $EI/L$ , where $E$ is the young's modulus, $I$ is the moment of inertia and $L$ is the span of the beam. It is obvious that all the beams will have the same moment of inertia since the cross section is the same and the effective length. Therefore the decrease in stiffness may be caused by reduction in elastic modulus of the concrete material as the replacement levels of cement and sand increased.

### 5.4.4 Crack pattern and propagation

The difference in the crack pattern of the control beams in comparison with the sugarcane bagasse ash laterised concrete beams may also be attributed to the visco-elasticity of laterite indicating that the ductility of the beam increases as the percentage replacement of cement and sand increases. Sugarcane bagasse ash laterised concrete also showed superior post crack behaviour than that of normal concrete. This may be due to the presence of laterite in the mixes as stated in (Salau & Balogun, 1990;Salau & Sharu, 2004) that the presence of laterite soil improves the post cracking behaviour of an element.

### 5.4.5 Comparison between Theoretical and Experimental Results

Application of theoretical formulas gave a safe but rather uneconomical predictions of the structural capacity. However, applying the empirical formulas gave a more economical prediction for beam without shear reinforcement. This may be attributed to the fact that the calculation of moment of resistance only took into consideration the concrete compressive strength and does not consider the contribution of the reinforcement.

# CHAPTER 6

## 6.0 Conclusions and Recommendations

### 6.1 Conclusions

Performance of sugarcane bagasse ash-laterised concrete in terms of compressive strength, split tensile strength, flexural strength, permeability and structural beams have been experimentally studied in this work. The following conclusions may be drawn from this study;

a) Sugarcane bagasse ash and laterite soil individually reduces workability and compressive strength of concrete. However, sugarcane bagasse ash gave an increase in compressive strength at 5% replacement.

b) The strengths of sugarcane bagasse ash laterised concrete reduces as the replacement level of cement and sand by sugarcane bagasse ash and laterite soil increases. However, the replacement level of up to 20% of cement and 25% of sand (SB-LA-20-25C) produce concrete with a compressive strength of 21.3MPa, greater than the targeted strength of 20MPa which is of more importance to a structural engineer as the tensile and flexural stresses in a reinforced member are carried by introducing reinforcement in the tensile zone of the member.

c) A comparative permeability analysis of hardened sugarcane bagasse ash laterised concrete showed that as the replacement level of cement and sand increases the permeability performance seems to improve in comparison with the control specimen.

d) The deflections for all beams at service loads satisfied the requirement specified by (BS 8110, 1997); not exceeding span/250.

e) From beam tests, it was observed that the experimental ultimate shear load reduced as replacement levels increased. However, all the ultimate shear stresses satisfied the requirement set by (BS8110, 1997) for shear stress; not exceeding $0.8\sqrt{f_{cu}}$.

f) The crack load, ultimate load and service loads reduces for all beams as the replacement levels of cement and sand increase. However, beams with shear reinforcement showed higher load capacity than beams without shear reinforcement. Sugarcane bagasse ash laterised concrete also shows superior post-cracking behaviour than that of control concrete.

## 6.2 Recommendations

From experimental results and analysis carried out, sugarcane bagasse ash laterised concrete beams with up to 20% replacement of cement by sugarcane bagasse ash and 25% replacement of sand by laterite soil can be used as lintels in family dwelling. However, lesser replacement levels can also be used as structural beams in family dwellings by providing appropriate reinforcement as specified by relevant codes but not exceeding 1 storey building. It is also recommended for future research work on performance of sugarcane bagasse ash laterised concrete that:-

a) Materials from other sources other than sugarcane bagasse such as from burnt rice husks, fly ash, wood ash, etc. as partial replacements of cement in laterised concrete production.

b) Effect of variation of shear span/effective depth ratio on shear strength of sugarcane bagasse ash laterised concrete beams should be investigated.

c) Durability of both reinforced and unreinforced sugarcane bagasse ash laterised concrete is needed in order to complement the findings on the serviceability criteria.

d) Effects of different types of fibres on properties of sugarcane bagasse ash laterised concrete can also be investigated.

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# Appendix

## List of Publications

Shuaibu, R.A., Mutuku, R. N., Nyomboi, T. (2014). A review of the properties of laterised concrete. *International Journal of Civil and Structural Engineering*. (Accepted)

Shuaibu, R.A., Mutuku, R. N., Nyomboi, T. (2014). Strength properties of sugarcane bagasse ash laterised concrete. *International Journal of Civil and Environmental Research*. (Accepted)