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UTILIZATION OF BAUXITE TAILINGS AS PARTIAL REPLACEMENT OF SAND IN BLOCKS

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A DISSERTATION/THESIS IN THE DEPARTMENT OF CONSTRUCTION AND WOOD FACULTY OF TECHNICAL EDUCATION, SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, UNIVERSITY OF EDUCATION, WINNEBA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF THE MASTER OF PHILOSOPHY IN CONSTRUCTION TECHNOLOGY DEGREE.

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DECLARATION

Student's Declaration

I, **Isaac Mpae,** declare that this Thesis / Dissertation / Project, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

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

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

Supervisor's Declaration

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Thesis / Dissertation / Project as laid down by the University of Education, Winneba.

Name of Supervisor: **DR. PETER PAA-KOFI YALLEY**

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

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

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DEDICATION

This thesis is dedicated to my lovely mother Ante Akua Atei and my trinity children Noble Abokye Mpae, Adansi-Bondah Mpae Bright Jnr. and Mummy.

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ABSTRACT

Disposal of bauxite tailings in Ghana and globally is not properly managed and leads to environmental degradation. There is possibility for their recycle to facilitate proper disposal, one way is to partially replace sand with bauxite tailings in building blocks. A study was carried out on cement composite blocks made from sand and bauxite tailings/residue, a mining by-product at varying levels from 10% to 50% with incremental level of 10%. Composite blocks were produced to dimensions of 150mm × 150mm × 150mm for the various replacement levels consisting of 0%, 10%, 20%, 30%, 40% and 50% by weight of sand. A total of 120 blocks were produced and tested for their densities, compressive strengths, and resistance to abrasion and water absorption after 28 day of curing. Results from the study showed that composite blocks with the bauxite tailings replacing up to 20% of the sand content recorded the highest compression strength, lowest abrasion loss with the least water permeability. Even though, there was a general decline in the properties of the composite blocks with bauxite tailings replacement beyond 20%, blocks produced satisfied the minimum requirements for blocks for wall construction. The compressive strength of the composite blocks saw a significant decline from 15.907N/mm^2 to 8.427N/mm^2 as the bauxite tailings content increased beyond 20% up to 50%. It was observed that there was a systematic fall in the average dry densities of the blocks as the quantity of bauxite residue was increased. Comparatively, the composite with B_{50} grade was 14.16% lesser dense than the control block. It was evident that abrasion loss significantly increases as the quantity of bauxite residues increases beyond 20% replacement in the composite blocks. The addition of bauxite tailing content thus resulted in lower migration of water into the block (i e. lower permeability). A strong correlation existed between the composite blocks produced from the different batches and the properties of the blocks studied. The results indicate that at the replacement level of 20%, the bauxite tailings have a good potential for use as a masonry material for wall construction.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In the hierarchy of needs theory, Cole and Kelley (2011) cited Maslow et al. (1987) identifies five basic needs which are organized into successive levels of importance in an ascending order. He identified physiological needs as the most basic needs of human beings which include air, food, water, shelter (housing), sex and sleep.

The need of shelter started from the Old Stone Age whereby people started using the local building materials such as timber, stones, clay, laterite, bamboo, thatch, sticks, mud and leaves etc to build all kinds of houses.

Regarded as having Africa's 3rd largest bauxite reserves Ghana's bauxite production rose to 295,993 tonnes during the first half of 2012, up from 173,601 tonnes produced in the comparative period in 2011 (Biswas, 2012). Major deposits in the country (as shown in appendix A plate iv) can also be found in Kibi, and Mt. Ejuamena near Nkawkaw, Atewa Range in the Eastern Region and Nyinahin in Ashanti Region, Asafo Asempanaiye and Awaso (only deposit producing) in the Western Region of Ghana (Patterson, 1967).

Bauxite tailings or red mud as popularly referred to has been produced globally by the Aluminium industry since the late nineteenth century. According to Power et al. (2009), by 2000, the alumina industry had produced circa 2 billion tons of bauxite tailings. This production rate is expected to grow by approximately 120 million tonnes per annum (Aluminuim Association, 2013).

Basically, bauxite tailings or red mud is the insoluble product generated as a result of the Bayer process; an alkaline leaching process which extracts alumina from the bauxite ore

Rai et al. (2012). It is generated in vast quantities as slurry having a high solid concentration of 30-60% composing of iron oxides, titanium oxide, silicon oxide and un-dissolved alumina together with a wide range of other oxides. Aluminium Association (2013) explained that bauxite tailings resulting from the Bayer extraction process are classified as 'red mud' as there is high concentration of iron compounds whilst those from different routes using other aluminous materials give rise to 'bellite/white muds'.

According to Snars et al. (2002), for every tonne of alumina produced, there is between 0.3 and 2.5 tonnes of bauxite tailings produced which depends on the type and grade of bauxite while the physical and chemical characteristics of the tailings depend mostly on the nature of the processing procedure and bauxite. They further explained that the tailings consist of very fine grained particle sizes mostly less than 150µm in diameter.

In Ghana and other countries where bauxite is mined, the detrimental environmental footprint has vehemently been seen. Gräfe et al. (2010) stated that these tailings are strongly alkaline with pH > 11 and high electrical conductivity (EC) mostly dominated by sodium ions (Na^+) which is attributed to the residual caustic soda present making their disposal problematic. Studies have shown that improper disposal of these tailings could pose enormous health risks via leaching into water bodies or direct intake by living organisms as a result of the high levels of thorium and uranium (notable heavy metals) they sometimes exhibit (Cooper et al. 1994). According to Gawu (1997) some of the effects of improper disposal of bauxite tailings include dust pollution, increase in turbidity, while Anon (1995) pointed out that Lake Batata in Brazil has been inundated with these tailings.

It is worth noting that as the demand for alumina and aluminium products keeps surging, bauxite tailings are expected to reach 4 billion tonnes globally by 2015 as reported by (Power et al., 2009).These substantial quantities of by-products have unfortunately not been satisfactorily handled as they are disposed in mined pits, terrace dams and nearby dumps (as shown in the Figure1.1 and appendix A) without a reliable and long term disposal system which adheres to environmental regulations.

Figure 1.1: Disposal of the bauxite tailings at Awaso (Source: Field study)

It is in light of this, immense efforts are being undertaken globally to find alternative options rather than storage which is to recycle these bauxite tailings as a starting materials for engineering applications. Dodoo-Arhin et al. (2013) posited that recycling such waste or by-products can ensure environmental sustainability as it eliminates disposal cost and avoids pollution.

Many researchers have enumerated the various applications of bauxite tailings as a construction material, geopolymers, coagulant, adsorbent and catalyst and in paints or pigments (Shing, 1977; Singh et al., 1996; Cablik, 2007; Kalkam, 2006). Schwarz and

Lalík (2012) further indicated that bauxite tailings tend to harden and form stable and durable compounds after mixing with lime in the presence of water when used in the production of ceramic materials.

The use of bauxite tailings in cement products according to Liu et al., (2009) not only serves as an effective recycling mechanism, it also improves the engineering properties due to the pozzolanic properties they exhibit. Amritphale and Patel(1987) further reiterated that, bauxite tailings pressed into blocks and calcined at high temperature (>1000C) have incredible compression strength suitable for high rise building construction with exceptional fire resistance, low water absorption and an appealing colour (Dimas et al., 2009).

Even though bauxite tailings are being generated in Ghana information regarding its suitability as a replacing material for sand is limited. This study thus seeks to determine the suitability of sandcrete blocks using bauxite tailings as a partial replacing material for the sand.

1.2 Statement of the Problem

Today due to technological advancement, improvement and research interventions, scientists and researchers have come out with many complex and sophisticated methods of construction through the use of conventional local building materials such as glass, steel, blocks, burnt bricks and T&G are very common in our construction industries.

The red mud/ bauxite fines / waste /residue/ tailings is one of the major solid wastes coming from mining of Bauxite and Bayer process of alumina extraction. At present about 3 million tonnes of bauxite waste is generated annually world wide which is not being disposed or recycled satisfactorily and Ghana Bauxite is not exempted. The conventional method of disposal of bauxite waste/ residue in ponds has often adverse environmental impacts during raining season in Ghana. The waste may be carried by run-off to the surface water courses and result of leaching may cause contamination of ground water and also destroy the fertility of soil (Sawant, Kumthekar, Diwan and Hiraskar 2012).

Blocks commonly used by many Ghanaians and to be precise the local developers in the Bibiani Anhwiaso Bekwai District are sandcrete as compared to other types. This can be supported by the fact that many Ghanaians prefer to use blocks to build as compared to other local building materials because blocks are affordable as well as cost effective. The commonest blocks mainly used by the local contractors and other developers are normally sandcrete blocks and laterite bricks.

According to Jiakuan, Yang and Xiao (2008), the optimal proportions of red mud brick are suggested as the following: 25–40% red mud, 18–28% fly ash, 30–35% sand, 8–10% lime, 1–3% gypsum and about 1% Portland cement.

In Ghana, Solomon-Ayeh 2008 cited Hammond (1987) Initial studies on possible pozzolanic materials in Ghana using bauxite waste from the Awaso mines. Other materials that possess pozzolanic properties were identified as the vast clay deposits in the Greater-Accra region of Ghana (Hammond, 1978) and agricultural wastes such as rice husks, coconut fibres, groundnut husks, sugar-cane biogases etc.(Hammond, 1987). The research on bauxite wastes indicated that with 20 to 30% replacement of ordinary

Portland cement (OPC) with calcined (at 700-900oC) bauxite-wastes, mortars and concretes produced with these blended cements produced strengths comparable to those using OPC only.

In Ghana (Atiemo, 1994) has confirmed that satisfactory strengths are obtainable with up to 30% replacement of OPC with pulverized burnt clay and additionally such pozzolanic cements have shown better performance in saline atmospheres. However, from the above mentioned assertions made by Jiakum, Yang and Xiao (2008) who used red mud in the manufacturing of bricks, Hammond and Atiemo also used bauxite waste / fines in the manufacturing of pozzolanic cement. However, the people of Awaso and its surrounding villages also use bauxite waste/fines or red mud as a partial replacement of sand in making blocks. But there is no research to that effect to ascertain or authenticate the quantity of the fines to be used in the matrix in order to achieve the requisite mechanical properties (density and compressive strength) of the blocks produced by the people. This issue prompted the researcher to look into the problem.

1.3 Aim of the Study

The aim of this study is to investigate the physical, mechanical and durability properties of blocks produced with bauxite waste /red mud as a partial replacement for sand.

1.4 Objectives of the Study

In line with the general aim set for the study, the following specific objectives have been formulated:

I. To determine the mechanical properties of blocks with bauxite fines as aggregate

II. To determine the durability and properties of blocks with bauxite fines as aggregate

III. To determine the optimum quantity of bauxite fines that can be used to achieve desired strength.

1.5 Research Hypothesis

Hypothesis 1

- Alternative hypothesis (H_1): The addition of bauxite fines has effect on the compressive strength of blocks.
- Null hypothesis (H_0): There is no change in the compressive strength of blocks when a bauxite fine is added.

Hypothesis 2

- Alternative hypothesis (H_1): The addition of bauxite fines / wastes will affect the abrasion resistance of blocks.
- Null hypothesis (H_0): There is no change in the abrasion resistance of blocks when bauxite wastes are added.

1.6 Scope of the Study

The study would focus on;

I. Properties of blocks produced based on density, compressive strength, abrasion resistance test,

II. Other properties include: specific gravity test, particles distribution test and permeability tests, compaction test, natural moisture content test, jar test and organic matter test.

1.7 Significance of the Study

- The study will contribute to existing knowledge in the production of blocks using/ composite materials.
- Efficient use of bauxite wastes to mitigate detrimental effect on the environment.
- Benefit to Nation that is saving in using sand and cement would reduce cost of construction using bauxite residue as a partial replacement.
- Benefit to industry – additional knowledge and skills in the use of alternate materials.

1.8 Limitations of the Study

A lot of difficulties were encountered in carrying out this research work. Some of them may be attributed to time and financial constraints as a result of transporting the bauxite residues all the way from Awaso to Takoradi Polytechnic laboratory. The weather condition as at the time of the study and method of test samples preparations were done was not friendly. The field and laboratory experimental studies into the properties of the sand to assess its suitability, and the bauxite waste as partial replacement in sandcrete blocks for the main experiment were conducted from August – November, at the time the weather in the area of study was cold, rainy and storm. However, the influence of the weather adversely affected some of the experimental activities as some of the tests were repeated over and over again in order to achieve accurate and reliable results. To make certain that the consistency of the test outcome was not affected by the bad weather elements, all field and laboratory soil quality identification tests were done in a controlled laboratory environment. The climatic condition however, affected the scheduled time frame predicted for the study and as a result the researcher was compelled to spend more input resources to be able to meet the desired results.

1.9 Delimitations of the Study

This study was directed on the potential utilization of neutralized bauxite waste as a partial replacement of sand. It is expected that the outcome of this research work will add to existing literature or knowledge on effective use of bauxite waste will serve as a cheap local building material to supplement or partial replacement of sand in blocks making industry where there is availability of bauxite in Ghana, other African countries and the world wide where bauxite waste are available.

Furthermore, this study was generally channeled to finding out the potential utilization of bauxite fines as the partial replacement of sand in blocks. However, the materials used were delimited only to red mud (bauxite waste/fines/residue/tailing), fine aggregate (sand) cement and water to be precise, compacted by hand into block samples with the 'Manual Hand-Operated' block making machine for the block's strength and durability properties experiments. These materials were used because they are the type of materials commonly used by the local contractors/ developers within the vicinity to build all kinds of houses in the area of the study. Ghana Bauxite Company – Awaso within Bibiani Anhwiaso Bekwai District, (240km) by rail from the Takoradi Port in the western region of Ghana was the geographical scope or setting where the bauxite residues were taken for the experiment.

1.10 Organization of the Study

The body of the thesis has been sub-divided into six chapters. The first chapter presents the background of the thesis, identifies the key research problem under investigation and defines the purpose of the study. The chapter further states the specific objectives for the study, formulates the research hypotheses, highlights the significance for the topic; outline the limitations and delimitations of the study.

Chapter two deals with various issues in literature and previous research work which are relevant to this study. It starts by introducing the chapter by stating the housing deficit in Ghana and some walling materials are explained. The importance of this area of study to stakeholders in construction industry is also highlighted. Walling materials include, sand, cement, aggregates, metals, stones, wood plastics etc. blocks types as well as properties are described. Testing and choosing soil, soil preparation, stabilized soil block making techniques, strength and durability properties of bricks and types of blocks are also identified.

Discussions on soil stabilization techniques, the basics of using cement, lime, sand as stabilizers, and the need to introduce bauxite residue as supplement or partial replacement to the more utilized conventional materials are also included. Furthermore, past and present techniques used in bricks/blocks buildings are explained as well. This chapter is very relevant because it provides theoretical and practical information needed in the subsequent chapters of the study.

Chapter three describes the study materials and test methods used for the soil quality identification and preliminary experiment on blocks production to determine water content ratio and compaction strokes for the production of bauxite waste composite blocks. Again, the main laboratory experiments that were done to assess the strength and durability properties of bauxite waste composite blocks (dry density, compressive strength, abrasive strength, water absorption by immersion) are also presented. This chapter provides guidelines as how to conduct both field and laboratory experiments.

Chapter four presents the results of the preliminary experimental tests to determine water content and compaction strokes (pressure) that could be used to mould bauxite waste composite blocks is also presented. Finally, the results of the experimental investigations into the strength and durability properties of the partially replaced bauxite blocks (dry density, compressive strength, abrasive strength, water absorption by immersion) have been presented as well. The chapter also gives the necessary data to support the conclusion of the experiments, comparisons of blocks properties, strength and durability performance of bauxite waste replaced blocks that represent the core of the experimental work in this study. It also presents the correlation of the results. This is a very important chapter in the research because it provides answers to the research hypotheses and forms the basis for the conclusions and recommendations made regarding the suitability of bauxite waste as partial replacement of blocks.

Chapter five presents and discusses the experimental results of the main experiments on partially replaced blocks' strength and durability properties tests (dry density, compressive strength, abrasive strength, water absorption) that were conducted.

Chapter six is the concluding chapter of the thesis summaries the key findings, conclusions and recommendations of the study. It gives the implications of the research findings and identification of areas for further research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The quest for providing affordable housing units has been a major problem facing governments in most developing countries around the globe due to the increasing demand for a place of shelter.

Housing is a vital issue in government policy in Ghana in the early 21st century but its direction awaits the acceptance of the current draft housing policy. As Compared with many countries in Sub-Saharan Africa Ghana's urban population is very poorly housed. About 60 per cent of all urban households occupy single rooms. While a taxi-driver in Lilongwe, Malawi's capital routinely lives in two or three rooms, one in Accra is likely only to have one room. Ghanaians are, like many other peoples, greatly concerned about owning a home of their own. Reflecting this, government policy over the years has concentrated on home-ownership, but usually through developments occupied by the rising middle class; single household dwellings on serviced plots (Ghana Statistical Service; 2010).

Ghana as it stands now has the population of over 25 million with the housing deficit staggering 1.7 million housing units. President of Republic of Ghana's State of Nation Address (2014).

Table 2.1 Population and housing in Ghana, 1970 to 2000

Year	Population	Housing demand	Housing supply (dwelling units)	Housing deficit
1970	8,559,313	1,678,296	941,639	736,657
1984	12,296,081	2,410,096	1,226,360	1,184,636
2000	18,912,079	3,708,250	2,181,975	1,526,275
2010	24,233,431	-	n/a	n/a
2020	30,043,278	-	n/a	n/a

(Source: Ghana Statistical Service; 2010)

In developing countries, like Nigeria, the construction industry is a very important sector of the economy. It plays critical role in a nation's economy such as Nigeria because of the transient trend in national growth. The rapid growth in the country's economy and population requires additional physical infrastructures to accommodate additional various components of the Gross National Product (GDP). These physical infrastructures include residential and commercial buildings, agricultural and health facilities to mention a few on the other hand require the integration of engineering, project, and production management techniques to provide (Ko, 2011). Over 90% of physical infrastructures in Nigeria are being constructed using sandcrete blocks (Baiden and Tuuli, 2004). This makes sandcrete blocks a very important material in building construction. It is widely used in Nigeria, Ghana, and other African countries as load bearing and non-load bearing walling units. British Standard 6073: 1981 Part 1 defines a block as a masonry unit of larger size in all dimensions than specified for bricks but no dimension should exceed 650mm nor should the height exceed either its length or six times its thickness.

According to Adedeji and Fa, (2012), the process of housing development should be based on sustainability principles, which could be applied in the conception, construction and use of the buildings. The goals of the process are to decrease the environmental costs incurred by inadequate constructive systems and solutions, minimizing the impacts on natural resources, and improving users' comfort (Amado et al., 2007). Gilkinson and Sexton (2007) defined sustainable housing as a form of affordable housing that incorporates environmentally friendly and community-based practices. It attempts to reduce the negative impact that homes can have on the environment through choosing better building materials and environmental design. Sustainable housing provision requires proper definition of housing needs, and the participation of the end users to ensure their satisfaction. The general goal of sustainable development is to meet the essential needs of the world's poor while ensuring that future generations have an adequate resources base to meet theirs. It is thus geared towards meeting the needs of the present generation without compromising the ability of future ones to meet their own needs (Adedeji, 2007). It further includes the production of materials, which must use resources and energy from renewable sources instead of non-renewable ones. Sustainable building materials are environmentally responsible because their impacts are considered over the complete life time of the products. Sustainable building materials should pose no or very minimal environmental and human health risks (Calkins, 2009).

They should also satisfy the following criteria: rational use of natural resources; energy efficiency; elimination or reduction of generated waste; low toxicity; water conservation; affordability. Sustainable building materials can offer a set of specific benefits to the owner of a building such as reduced maintenance and replacement costs, energy conservation, improved occupant's health and productivity, lower costs associated with changing space configurations, and greater flexibility in design (www.GreenBuilding.com, 2009). Achieving sustainability in housing provision requires major societal changes, restructuring of institutions and management approaches. It requires the appropriate political will based on the conviction of the responsibility of government to its citizens, and the need to create humane and decent environment for dignified living (Joseph, 2010). In order to realize sustainable housing provision the housing needs of the Nigerian population have to be put into proper focus, and a coordinated programme to achieve this should be thoroughly worked out. With due consideration given to the input of the local communities, government may initiate aided self-help programmes and low-cost core housing units. Walls cover the greater part of the building component estimated over 60% and above, hence it is necessary to focus on the walling if cost of housing construction is to be reduced.

2.1 Materials for Walling

Building materials constitute approximately 60 to 70 present of the total housing cost, therefore attempts at improving housing delivery should of course be directed at this high singular sensitive component (Osei-Tutu and Ofori,2009).The high cost of building materials used is negatively having an impact on construction of walls and other component parts. Walls cover the greater part of the building component estimated over 60% and above. Majority of walls built in Ghana and other West African Countries are made of blocks, stones, bricks and few others built of other materials like timber, glasses, steel, aluminium and plastic materials. According to Obande (2001) materials used for making building blocks include natural sand and crushed stone, by-product of industrial production such as clinker, foamed or air-cooled slag, sintered pulverised fuel ash, sawdust and wood shavings and expanded clay or shale. Among these various materials, natural sand and crushed stone are more likely to be available in most developing countries. Since block work cover the greater part of the structural unit, it is therefore necessary to make it cost effective by using the affordable local building materials to produce them. The commonest materials used to manufacture blocks and bricks in our constructional industries are mainly sand, clay, laterite (soil), mining and quarrying waste (e.g. bauxite waste) and agriculture waste (as stabilizers). The major quantity of waste generated from agriculture sources are sugarcane baggase, rice husks, cotton stakes, ground nut hulls, coconut husks, etc which are artificial pozzolanic materials and available in large quantities (Atiemo,1994; Hammod,1987; Pattanaik 2010).

2.2 Types of Walling Materials

2.2.1 Blocks

A block can be defined as a wall unit exceeding the BS dimensions specified for bricks and its height shall not exceed either or six times its thickness (Chudley & Greeno, 2005). There are various materials that can be used as aggregates for blocks. The choice of materials will depend upon the type of block to be manufactured and it is essential to make the right choice. The most common aggregate used for these types of blocks should be hard, cleaned, durable and free from organic matters (Obande, 2001).

There are numerous kinds of walling materials available in Ghana and other West African sub-regions and the world in general. Below are a few ones the researcher studied into details:

- Sandcrete blocks
- Concrete blocks
- Soil blocks
- Compressed Stabilized earth blocks
- Bricks and
- Stone

2.3 Sandcrete Block

A block can be defined as a wall unit exceeding the BS dimensions specified for blocks and its height shall not exceed either or six times its thickness (Chudley and Greeno 2005).

Block is a composition of usually (1:6) mix of cement and sharp sand with the barest minimum of water mixture, and in some cases admixture, moulded and dried naturally. NIS 87(2000) defines sandcrete block as a composite material made up of cement, sand and water, moulded into different sizes.

According to Abdullahi (2005), the word sandcrete has no standard definition, what most workers have done was to define it in a way to suit their own purpose. The word for it in some local dialects means brick earth and the name 'Sandcrete is merely a translation solely to the use to which these blocks are put. Though sandcrete varies within wide limits one feature remains constant; the same amount of combined silica in proportion to the alumina present, and it is in this respect that sandcrete differ from days (Baiden and Tuuli, 2004). It appears increasingly difficult to give a purely physical definition of sandcrete. In view of the fact that no general agreement has been reached on the definition and what materials should be classified as sandcrete, the trend at present is to lay emphasis on the grading i.e. sieve analysis, specific gravity test and bulk density, without much regard for mode of formation, geological and geo-morphological condition (Ezeji, 1993).

The qualities of blocks are inconsistent due to the different constituent materials. The composition of a sandcrete block is usually (1:6) mix of cement and sand moistened with water and allowed to dry naturally (Anosike & Oyebande, 2012). According to them, they are masonry units which when used in its normal aspect exceeds the length or width or heights specified for bricks. The block can therefore be made either in solid and hollow rectangular types (for normal wall) or decorative and perforated in different designs, patterns, shapes, sizes and types (for screen wall or sun breakers). The jointing of beddings and perpends are 25mm thick in both the normal and screen wall. Sandcrete blocks are widely used as walling units and over 90% of houses in Nigeria are being constructed of sandcrete blocks (Baiden and Tuuli, 2004).

Sandcrete blocks are available for the construction of load bearing and non-load bearing structures (Hodge 1971). Load bearing blocks must conform to building bye law with regard to their crushing and to the amount of solid mineral contained in section e.g. the total width of block. Sandcrete blocks also participate mainly in the task of transforming the actual load from the overlaying structural element to the foundation. In this case the load bearing walls are those walls acting as supports for the whole structure to transmit the weight to the ground surface underneath if for stability (NIS 87:2000). Sandcrete blocks possess an intrinsic low compressive strength making them susceptible to any tragedy such as seismic activity.

For this reason, sandcrete blocks are globally considered appropriate and very adaptable in the building materials industry.

Possible factors that can affect the properties of sandcrete blocks have been broadly categorized into two namely:

- Chance; and
- Assignable factors (NIS 87: 2000).

The former are related to less controllable environmental factors such as temperature, noise etc., while the latter are largely man-made factors induced by machine, material constituent, and the degree of quality control observed during production, with possible consequences for the strength, durability and workability of the product.

Improper use of these blocks leads to micro cracks on the wall after construction (Anosike & Oyebande, 2012; Baiden & and Tuili, 2004). In most cases, the producers and users of these blocks lack adequate engineering knowledge on the strength requirement of sandcrete blocks.

In the hardened state, sandcrete has a high compressive strength which increases with density. The range of minimum strength specified in NIS 87:2004 is between $2.5N/mm^2$ to $3.45N/mm^2$. According to Abdullahi (2005) the quality of sandcrete blocks, however, is inconsistent due to the different production methods employed and the properties of constituent materials. Abdullahi (2005) studied the compressive strength of sandcrete blocks produced in some parts of Minna, Niger State, Nigeria and discovered that they were below the minimum NIS standard requirement. Uzoamaka (1977) found that the crushing strength of sandcrete blocks increases with decreasing specific surface of sand and that curing of block by water sprinkling enhances their strength.

Oyekan and Kamiyo (2011) carried out research work on effect of granite fines on the structural and hydrothermal properties of sandcrete blocks. They reported that the compressive strength values at 28 days increased by over 15 % for the blocks made with a mix proportion of 1:6 and over 4% for the blocks made with a mix proportion of 1:8. They also observed that the optimum percentage granite fines content was about 15%. Oyekan and Kamiyo concluded that the use of granite fines as a partial replacement of sand in the production of the blocks gave blocks with appreciably higher strength values than blocks without granite fines. The compressive strength of sandcrete blocks was reported to fall as the granite fines content went above the optimum value which was found to be about 25% when the mix proportion was 1:6 and between 12 & 15% when a mix proportion of 1:8 was used.

They concluded that the use of granite coarse aggregate to partially replace sand in sandcrete block production gave blocks with much higher compressive strength values irrespective of the size of the coarse aggregate used for the replacement. they also reported that the optimum aggregate content was 25% when 5mm single size aggregate was used; 30% when 10mm single size was used,; 35% when 15mm single size aggregate was used and about 25% when a mixed coarse aggregate (10mm & 15mm) was used.

Oyekan carried out research on crushed waste glass as a partial replacement of both sand and cement in sandcrete block production. In their report, they concluded that the optimum crushed waste glass content was found to be 15% for 1:6mix and 20% for 1:8 mixes.

Sampaio et al (2000) carried out assessment on performance of concrete obtained with partial replacement with Portuguese rice husk ash in different percentages. It was reported that there was increase in the strength as the percentage of the rice husk ash increased in the mix. Cisse and Laquerbe (2000) concluded that the mechanical resistance of sandcrete blocks obtained when unground rice husk ash was added revealed that the use of unground rice husk ash enabled production of a lightweight sandcrete with insulating properties and at a reduced cost. The ash pozzolanic reactivity was responsible for the enhanced strength obtained.

Oyetola and Abdullahi, (2006) carried out research work on the use of rice husk ash in low – cost sandcrete block production. In the test conducted, it was concluded that the compressive strength of the blocks for all mixes increased with age and decreased as the rice husk ash content increased and that the maximum compressive strength was obtained at 20% cement replacement with rice husk ash. Okpalla & Ihaza (1987) concluded that if rice husk ash was found adequate for replacing cement in sandcrete blocks, it would drastically reduce the cost of buildings in Nigeria. His results revealed that a sandcrete mix of 1:6 ratio with up to 40%replacement with RHA and 1:8 ratio with cement replacement of up to 30% with RHA are sufficient for sandcrete block productions to be used for both urban and rural dwellers in Nigeria.

2.4 Soil Blocks

Many different materials are used around the world for walling. Where quarried stone and timber are not readily available, earth is the most common material used. Earthen architecture has been used for centuries in many different parts of the world according to Jones (1985). Archaeological evidence in very dry areas had also shown that earth building was a highly popular material for dwelling construction. Earth is still used today in many parts of the world where access to other forms of building material is restricted by location or cost.

Each building material has its own **advantages and disadvantages**. Some of the problems with existing building materials are their poor use of environmental resources, poor quality control of the finished product and consequently a significant variation in durability. Alternative building materials that have suitable strength and durability, and also environmental sustainability are being sought after by researchers.

2.5 Soil Stabilisation

The addition of a stabiliser to soil in soil block construction is to stabilise the soil, making it more durable, and subsequently also any structure made from it. Soil stabilisation with cement improves the characteristics of the soil so that it can tolerate greater loading and perform better when it is exposed to the weather. The two most common techniques used in block manufacture are binding (with chemical additives such as cement or lime) and increasing the density through compaction (Yalley, 2008).

2.5.1 Cement as Soil Stabilizing Agent for Blocks

As a stabilising material, cement is well researched, well understood and its properties clearly defined. Portland cement is readily available in all countries all over the world, as it is one of the major components for any building construction. Earlier studies have shown that cement is a suitable stabiliser for use with soil in the production of CSSB (Montgomery, 2002). Cement is mainly composed of Lime (CaO) and Silica (SiO_2), which react with each other and the other components in the mix when water is added. This reaction forms combinations of Tri-calcium silicate and Di-calcium silicate referred to as C3S and C2S in the cement literature (Neville, 1995). The chemical reaction eventually generates a matrix of interlocking crystals that surround any inert filler (i.e. aggregates) and provides a high compressive strength and stability.

2.5.2 Compressed Soil Blocks

Stabilized and compacted/compressed blocks and bricks refer to soil blocks and bricks made of soil with modified properties of the soil – water – air system in order to obtain lasting properties which are compatible with a particular application, United Nations Centre for Human Settlement – Habitats (UNCHS, 1986). Stabilizing the soil and compressing it into blocks and bricks increase or improve its compressive strength and durability properties Such as natural durability, strength and at times workability, (Attoh-Okine, 1990). Soil stabilization has been used widely since 1920s mainly for road construction. When a soil is successfully stabilized, one or more of the following effects will be evident: strength and cohesion of the soil will increase; permeability of the soil will be reduced; the soil will be made water repellant; the durability of the soil will increase; soil will shrink and expand less in dry and wet conditions.

The concept of soil stabilization is not new, since, natural stabiltsation e.g. natural oil and plant extracts, animal dung and crushed ant-hill materials have been used for many centuries. Recently, more rigorous scientific rather than adhoc methods of soil stabilization have been introduced, developed mainly from early techniques devised for the stabilization of earth roads.

Many stabilizers have been tried, including manufactured ones like Portland cement, pozzolanas, animal blood, lime bitumen, gypsum, alkalis, sodium chloride, calcium chloride, aluminum compounds, silicates, resins, ammonium compounds, polymers, and agricultural and industrial wastes. These stabilizers have been used extensively to manufacture many different types of compressed stabilized soil blocks (CSSB) for the building industries.

According to Asquith & Vellinga (2006), the input of stabilization allows building higher with thinner walls, which have much better compressive strength and water resistance. With cement stabilization, the block must be cured for four weeks after manufacturing. Compressed stabilized earth blocks were among the first materials to be used in modern earth building during the revolution in the eighteenth century. It is a building component which has the versatility of a brick, but social, economic and the environmental potential of rammed earth (Real, 2008). Harris (2010) also reiterated that stabilized compressed earth blocks perform well as commonly used cement blocks in terms of their load bearing capacity, long life and less maintenance works. Hammond (1973) recommended the use of cement, lime, bitumen, coal tar, oils, stearates, earthworm cast and many others to stabilize soil building materials. Stabilized soil blocks and stabilized rammed soil for modern building is proving highly successful in the United States of America and Australia, where in some regions it accounts for up to 20 percent of all new building projects (Hall, Damms and DJ, 2004). The oldest lime stabilized rammed soil building in the world is the Horyoji Temple in Japan, built approximately 1300 years ago (Hall et al, 2004).

2.5.3. Advantages of (CSEBS)

There are many advantages compressed stabilized soil blocks (CSEB) offer us. Few among them are;

- Raw materials for the CSEB production are readily available, since most of them are in our vicinities.
- The blocks are usually made with a manually operated block press.
- No firing is needed, hence, overall cost is significantly minimized and also our forest reserves are not affected because trees will not be cut down for fire woods.
- There is no wastage in production
- Fast to build with and unskilled people can learn how to build with the block fast.

2.6 Clay Bricks

Approximately 96% of bricks in the United Kingdom are manufactured from clay. Geologically, brick making clays are composed of quartz and clay minerals, the type of clay depending on the locality of the brickworks. Raw materials for brick making are extracted from quarries or pits and then processed and mixed with water. Most manufacturers stockpile clay to minimise the need for extraction in wet weather when the movement of trucks on the clay material is difficult. Stockpiles may contain sufficient raw materials for a year's production.

When clay is removed from the stockpile, a full vertical cut is made so as to produce a consistent material for the next stage of the brick making process. A flow diagram illustrating the clay brick manufacturing process is shown in Figure 3.

Figure 2.1: Clay brick production:

Excavation of clay —> Weathering —> Processing —> Moulding —>Drying —> Firing

Clay processing involves grinding and working the material to obtain plasticity and uniform workability. Fineness of the clay influences not only the external appearance of the finished brick but also physical characteristics such as compressive strength and water absorption.

The mixing stage involves the addition of water to produce a homogenous material, the quantity added depending on the production method being used. In some works, other materials such as lime, pulverized fuel ash or crushed clinker may be added to act as fuel, while pigments may also be incorporated to produce specific colours, (Mineral Products Association, (MPA), 2013).

2.6.1 Firing

Historically bricks were dried in 'hacks', stacks about seven courses high. Today, most bricks are dried either in a drier or in a kiln.

2.6.2 Properties

The following are brick properties to be taken into account: Dimensions, Compressive strength, Durability, Abrasion and Water absorption.

Dimensions BS EN 771-1 states that, the manufacturer of a clay masonry unit shall declare the dimensions for length, width and height in terms of the work size.

The degree of sintering and / or verification therefore controls the main properties of the bricks (strength, porosity, density etc.). Commonly, clay bricks are fired in the range 850ºC to 1300ºCand are sintered/ vitrified to varying degree (McArthur and Spalding 2011).

2.7 Soil Block from Rubber Tyres

A high-tech' solution to recycling rubber tyres was developed by researchers at The Hong Kong University of Science and Technology, which has resulted in double benefit for the environment. The first benefit is the development of a process of recycling used waste vehicle tyres. The second is on turning of the recycled material into rubber soil blocks for use in civil engineering work such as road widening, land reclamation, and the building of embankments, retaining walls and slopes. The rubber soil block has many advantages over compacted soils. They are lighter, stronger, permeable, energy absorbing, flexible for construction, and dust free. The new soil block is also highly porous, eliminating water pressure build-up, and has 5-10 times the compressive strength of compacted granular soils. The resulting material is about half the weight of conventional compacted soil which reduces structural loadings and results in cost savings (Lee et al., 2005). The method of extracting steel wires from the used tyres was not mentioned in this particular research work. For the purpose of providing a low cost housing for the rural and urban poor in developing countries at a low-cost technique for extracting steel wires and formulating "soil" blocks from rubber ‘crumbs’, needs to be examined.

Clay bricks have a vast range of compressive strengths ranging from less than 10 N/mm^2 for a soft mud brick to more than 100 N/mm^2 for an engineering brick. Building Regulations (1985) also specified that, the unit compressive strengths of bricks and blocks should be $5N/mm^2$ and $2.8N/mm^2$ respectively. BS 3921 specified a minimum compressive strength of $5N/mm^2$ for clay bricks. Density 2000kg/m3, k = 0.96w/mk at 1% moisture content.

2.7.1 Durability and Water Absorption

Water absorption does not necessarily indicate the behaviour of a brick in weathering. Low absorption i.e., less than 7% by mass, usually indicates a high resistance to damage by freezing, although some types of brick of much higher absorption may also be frost resistant. Very small quantities of salts, usually sulfates, which may be present in the bricks, may produce efflorescence during the period when the building is drying out. Perforations in a brick result in a number of advantages.

2.7.2 Advantage

Firstly, less material is required to produce the unit giving savings in raw material and associated processing costs.

Secondly the more open structure results in a reduction in drying time and hence costs. The hardened unit also has slightly enhanced thermal insulation properties.

Thirdly the lower masses of these units make them less tiring for the bricklayer to lay. The technical standard for clay masonry units (BS EN 771-1) groups units according to the percentage of voids.

2.8 Types of Burnt Brick

Many developers are nowadays used Clay brick in construction industries. The main material used in making this type of brick is clayey soil. The use of clay brick in construction is with reference to BS 3921: 1985 (specification for clay bricks). By the size of clay brick had been set to 215mm x 102.5mm x 65mm. BS 3921: shows the size of the clay brick and further classified it into three categories as the following common brick, facing brick and engineering brick:

2.8.1 Common Bricks

Common bricks are suitable for general building work but are not designed for good finished appearance or high strength. These are the cheaper clay brick available.

2.8.2 Facing Bricks

Specially made or selected to give good finished appearance. This category of bricks is specially made or selected to give an attractive appearance when used without rendering or plaster or other surface treatment of the wall. These bricks are available in a wide range of colours and textures. The various colours to the facing bricks depend on the mineral content of the raw clay used for the bricks production. The surfaces of the bricks have high durability as they can resist the extreme weather conditions. However, facing bricks have lower compressive strength compared to common bricks and engineering bricks.

2.8.3 Engineering Bricks

Designed to be dense and strong semi- vitreous body characterized by limited water absorption and high strength, Engineering bricks are dense and strong compared to the previous two categories. Engineering brick is further sub-divided into two classes. Engineering A and Engineering B, based on their compressive strength and water absorption properties as stated in BS 3921: 1985.

2.9 Concrete Bricks

Some 4% of UK bricks are made from concrete. Raw materials used for their production are Portland cement and aggregates, with a pigment generally being incorporated into the mix. Constituent materials are proportioned, mixed, placed in moulds, vibrated or compacted, de-moulded and then cured. Performance requirements for concrete bricks are given in BS EN 771-3. A range of compressive strengths are produced, typically from 7- 40 N/mm^2 Concrete bricks are typically 30-40% heavier than clay bricks of similar dimensions. Water absorption in average is less than 7% after 24 hours.

2.10 Concrete Blocks

Concrete blocks are also known as concrete masonry units and have become increasingly important as a construction material. Technological developments in the manufacture and utilization of the units have accompanied the increase in their use. Concrete masonry walls, correctly designed and constructed, will satisfy a variety of building requirements including fire resistance, durability, aesthetics and acoustics. In the UK, concrete blocks have traditionally been divided into three types:

- Solid blocks which have no formed voids or cavities
- Cellular blocks which have one or more formed voids or cavities, which do not pass right through the block
- Hollow blocks, which have one or more formed voids or cavities, which pass right through the block.

In April 2006, the new standard for aggregate concrete masonry units (BS EN 771-3) was introduced. This requires that products are identified according to the following groupings:

Group 1 < 25% voids

Group 2 > 25; < 60% voids

Group 3 > 25; < 70% voids

Group 4 > 25; < 50% voids (horizontal holes)

Concrete blocks were first produced in the early part of the last century by placing fresh concrete into moulds made of steel or wood. The moulds were stripped when the concrete had hardened.

The disadvantage of this method was that large quantities of moulds were required to produce a number of blocks. A development from single moulds was the so called 'egg layer' machine. Using this, mixed concrete was loaded into a hopper on the machine; material was fed into moulds, vibrated and left on a slab to cure. The machine then moved a short distance and repeated the process. Concrete blocks can be manufactured from either natural or lightweight aggregates. Individual blocks have a mass ranging from 5.0kg to 40.0kg and compressive strengths ranging from 3.6 - 40.0 N/mm^2. Cellular blocks are manufactured with a thickness ranging from 100 to 215mm with individual blocks having a mass ranging from 8.0 to 27.0kg and a compressive strength of 3.6 - 22.5 N/mm^2 Hollow blocks are produced with a thickness ranging from 100 to 215mm. Compressive strength is generally 3.6 - 22.5 N/mm^2 and the weight of the individual blocks ranges from 8.0 to 27.0kg.Concrete blocks are generally very stable and durable and can be used for a wide range of applications including below ground where they may come into contact with aggressive soils. (www.mortar.org.uk).

McArthur and Splalding (2011) reported that, concrete blocks densities range from about 420 to 2200kg/m^3 corresponding to a range of compressive strengths of about 2.8 to 35N/mm^2. Standards for concrete blocks are BS EN 771 – 4 which will replace BS 6073 in the near future. BS 6073 requires minimum compressive strength for all concrete blocks of:

- Greater than or equal 75mm thickness. Average compressive strength of 10 blocks is less than or equal to 2.8 N/mm^2 with no individual block to be less than 80% of this value.

- Less than 75mm thickness. Average transverse strength of 5blocks less than or equal to $0.65N/mm^{2}$.

2.11 Precast Concrete Blocks

The manufacture of precast concrete blocks or masonry units is covered by BS 6073. Classification is by compressive strength categories 2.8, 3.5, 5.7, 10, 15, 20 and $30N/mm^2$. The density of a precast concrete blocks gives an indication of its compressive strength – the greater the density the stronger the block. Density will also give an indication as to the thermal conductivity and acoustic properties of a block. The lower the density the lower the thermal conductivity factor whereas the higher the density the greater the reduction of airborne sound through the back. The actual properties of different types of precast concrete block can be obtained from manufacturers' literature together with their appearance classification such as plain, facing or special facing (Chudley and Greeno, 2005).

2.12 Aerated Concrete Blocks

Aerated concrete for blocks is produced by introducing air or gas into the mix so that when set a uniform cellular block is formed. The usual method employed is to introduce a controlled amount of fine aluminum powder into the mix which reacts with the free lime in the cement to give off hydrogen which is quickly replaced by air and so provide aeration. Concrete blocks shrink on drying out, therefore they should not be laid until the initial drying shrinkage has taken place (usually this is about 14days under normal drying conditions) and should be protected on site to prevent them becoming wet, expanding and causing subsequent shrinkage possibly resulting in cracking of the blocks and any applied finishes such as plaster (Chudley, 1994).

Table 2.2: Properties of Blocks

Block Type	Compressive Strength N/mm^2	Weight per block Kg	Nominal dry Density Kg/m^3	Thermal cond. W/m^{3}k
Dense aggregate.	7.3 – 40	10.0 – 40.0	1800 – 2100	1.25
Light weight aggregate.	3.6 - 17.5	5.0 – 3.0	650 – 1500	0.47
Aerated	2.9 – 8.4	3.0 – 24.0	400 – 800	0.10 -0.1

2.12.1 Strength Against Abrasion and Skidding

The aim of the abrasion test is to ascertain the effect that wearing would have on the blocks. Wind, rain storms, scratches, water and other factors generally have the wearing effect on building walls. It is useful at this stage to know how the blocks would stand the test of the weather conditions so as to improve the stabilization of the block (Yalley and Bentle, 2009). Abrasion resistance test is important when the aggregate is to be used in an area that is subject to heavy abrasive use, such as factory floor, aggregate for abrasion resistance is tested following ASTM C131 standards. To give skid resistance, the siliceous particle content of the fine aggregate should be 25% or more.

According to Naik, Singh and Ramine, (2002), abrasive wear occurs in pavements, floors or other surfaces upon which friction forces are applied due to relative motion between the surface s and moving objects; it also determines the effects of weathering on soil when used as masonry block. The more compacted the material is the better its resistance to abrasion and vice –versa. This means that, a material which enhances the binding forces during stabilization tends to have an improved resistance to abrasion. Yalley and

Bentle (2009), reiterated that blocks moulded with optimum moisture content had the highest abrasive resistance. This was a fact because blocks moulded with optimum moisture content have the highest density, and thus resulted the best resistance to abrasion from rain water and other form of rubbing against the blocks.

2.13 Stone Masonry Construction

For centuries, stone was used as a material to build structural load-bearing walls. Today it is used mainly as a veneer or facing, which greatly reduces the weight of a building while still enabling a designer to take advantage of stone's beauty as finish material.

Rock is solid mineral matter, occurring in individual pieces of large masses, such as an outcropping. Stone is a rock that is quarried and shaped to size for construction purposes.

Stone laid in mortar may be rubble or ashlar masonry.

Rubble refers to stone found naturally in irregular shapes and sizes.

Ashlar masonry uses units cut into squared shapes. Stone may be laid in a random or coursed pattern. The coursed pattern uses irregular courses Spence and Kultermann, (2011).

2.13.1 Classification of Stones

According to Ghose (2002) stones may be classified in four ways. These are:

- Physical (depending on structure)
- Geological (depending on mode of formation)
- Scientific or Engineering (depending on chemical composition of the prime constituent)
- Practical (depending on usage)

2.13.2 Characteristics of Good Stones

A good stone should be:

I. hard, strong and durable to resist wear and tear due to atmospheric actions of acids, fumes and smokes.

II. It should be closed-grained and homogeneous, and free from cricks, cavities, flaws, soft materials patches, loose organic matters, iron oxides, it should be of uniform colour and compact texture.

III. As a rule, it should not absorb more than 5% water.

2.13.3 Choice and uses of Stones

Choice of stones as a building material depends upon the nature of work, quality of stone, availability and transportation cost.

2.14 Sand-Bauxite Waste Blocks Composite

The bauxite waste used was clean, durable and of proper grading, free from silt and clay which may result in increased shrinkage or increased permeability in addition to poor bond characteristics**.**

2.14.1 Bauxite Residue

Bauxite residue has been produced since the development of the alumina or aluminium industry in the late nineteenth century. It is one of the largest industrial by-products in modern society with global levels estimated at around 3000 million tonnes at the end of 2010 (Power et al, 2009). Developing and impacting effective storage and remediation programmes remains essential as the inventory grows by approximately 120 million tonnes per annum.

Aluminium is a material with global annual production of some 45 million tonnes in 2011 and an estimate of nearly 50million tonnes in 2013. Aluminium metal does not occur naturally although elemental aluminium ranks after oxygen and silicon in abundance in the earth crust. Aluminium is a constituent of many rocks, minerals and ores and has to be extracted and converted to metal through a combination of chemical and electrolytic process. The normal precursor to aluminium metal is aluminium oxide (alumina) although routes based on aluminium chlorides have also been developed and employed on a very small scale. Over 95% of the alumina manufactured globally is derived from bauxite by Bayer process. There is some limited manufacture of alumina using other processes, for example the VIMI and sinter route processes in Russia and China. Bauxite and neplelinesyenite are the principal raw material sources but experimental work is continuing using kaolin and high alumina containing clays. Residual materials arise during these alumina manufacturing processes: those using the Bayer process extraction of bauxite are termed ‘red mud’ whilst those from different routes using other aluminous materials give rise to ‘bellite or white muds’. It is mined in many countries include Australia, Brazil, China, Ghana, Greece, Guinea, Guyana, Hungary, India, Indonesia, Jamaica, Sierra Leone, Suriname, Venezuela and Vietnam (Aluminium Association,2013).

2.14.2 Production of Bauxite Residue

The amount of bauxite residue produced by an alumina plant or refinery is primarily dependent on the sources of the bauxite and secondarily on the extraction conditions used by the plant. In the extreme, this can vary from 0.3 to as high as 2.5 tonnes of residue per tonne of alumina produced, though typically it lies between 0.7 and 2 tonnes of residue per tonne of alumina produced. The most important factors are aluminium content of the bauxite, the type of aluminium oxide or hydroxide present (e.g. gibbsite, beohmite or diaspore), and the temperature and pressure conditions used for the extraction. The last two factors are dictated by the nature and form of the alumina present, the local cost for energy, and the cost and distance the bauxite needs to be transported. Bauxite high in boehmite need higher processing temperatures and diaporic bauxite even more aggressive conditions of temperature causticity. A processing temperature of 140-150˚C is generally used for bauxite high in gibbsite, a temperature of 220-270˚C for boehmitic bauxites and a temperature of 250-280 ˚C for diasporic bauxites.

The Bayer process has been used since 1893 and there are approximately 60 Bayer alumina plants in the world currently in operation outside China. The number of alumina refineries in China is growing extremely rapidly and has increased from 7 in 2011. The total operating plants are therefore over one hundred. New alumina plants and expansions are being added as the demand for aluminium continues with long term annual growth rate in excess of 6% projected. It is estimated that the annual generation of bauxite residue from all these plants is of the order of 120 million tonnes a year.

There are approximately 30 Bayer alumina reflneries that have closed and have left associated legacy bauxite residue sites. It is estimated that the amount of bauxite residue stored in operating and closed sites is some 3 billion tonnes (Sloot and Kosson, 2010).

2.14.3 Chemical Composition of Bauxite Residue

The chemical and physical properties of bauxite residues are determined by the nature of the bauxite and the effect of the Bayer process. The technology and operating procedures at individual refineries will impact the water content and pH valve of the material being discharged two key factors in bauxite residue management.

Bauxite residue is mainly composed of iron oxides, titanium oxide, silicon oxide and un-dissolved alumina together with a wide range of other oxides which will vary according to the bauxite. The high concentration of iron compounds in the bauxite gives the by-product its characteristic red colour, and hence its common name 'red mud'. A typical chemical composition is shown in Table 2.3 and a typical mineralogical composition is shown in Table2.4

Table 2.3 Chemical composition range for bauxite residue for main components

Component	Typical range (%)
Fe_2O_3	20 – 45
Al_2O_3	10 – 22
TiO_2	4 – 20
CaO	0 – 14
SiO_2	5 – 30
Na_2O	2 – 8

Source: Aluminium Association (2013

In addition there are various other minerals sometimes found including hydrogarnet, chantalite, hydroxycancrinite and sodium titanate.

A wide range of other components are present at trace levels in the bauxite, most especially metallic oxides idea such as those of Arsenic, beryllium, cadmium, copper, gallium, lead, manganese, mercury, nickel, potassium, thorium, uranium, vanadium, zinc and a wide range of rare earth elements. Some of the elements remain un-dissolved so are eliminated with the bauxite residue, whilst some are soluble in the Bayer process and either build up in the Bayer liquor, or precipitate along with the aluminium hydroxide. Depending on the temperature used in the extraction process some element will increase in concentrations and others will in the bauxite residue.

Table 2.4 Mineralogical composition range for bauxite residues

Component	Typical range (%)
Sodalite ($3Na_2O.3Al_2O_3.6SiO_2.Na_2SO_4$)	4 – 40
Goethite (FeOOH)	10 – 30
Hematite (Fe_2O_3)	10 – 30
Magnetite (Fe_3O_4)	0 – 8
Silica(SiO_2) crystalline and amorphous	3 – 20
Calcium aluminate ($3CaO.Al_2O_3.6H_2O$)	2 – 20
Boehmite (AlOOH)	0 – 20
Titanium Dioxide (TiO_2) anatase and rutile	2 – 15
Muscovite ($K_2O.3Al_2O_3.6SiO_2.2H_2O$)	0 – 15
Calcite ($CaCO_3$)	2 – 20
Kaolinite ($Al_2O_3.2SiO_2.2H_2O$)	0 – 5
Gibbsite ($Al(OH)_3$)	0 – 5
Perovskite ($CaTiO_3$)	0 – 12
Cancrinite ($Na_6[Al_6Si_6O_{24}].2CaCO_3$)	0 – 50
Diaspore (AlOOH)	0 – 5

Source: Aluminium Association (2013)

Non-metallic elements that may occur in the bauxite residue are phosphorus and sulfur. A wide variety of organic compounds can also be present, these are derived from vegetable and organic matter in the bauxite and include carbohydrates, alcohols, phenols, and the sodium salts of polybasic and hydoxyacids such as humic, fulvic, succinic, acetic coroxalic acids. In addition, small quantities of some of the sodium compound on the dewatering and washing systems used.

The Bayer process requires the introduction of caustic soda as the major compound in alumina production. A key focus of alumina refineries is to maximize the recovery of the valuable caustic soda from the residues in order to reuse it during the extraction process. Apart from the residue caustic soda remaining after this recovery process, the ore residues contain only traces of additives used in the process such as flocculants. The residual soluble sodium species, predominantly a mixture of sodium aluminate and sodium carbonate, give rise to an elevated pH for bauxite residue slurries. Over time the residual sodium species are partially neutralized by carbon dioxide from the air to form sodium carbonate and other metal carbonate species, resulting in both a lower pH as well as an improved hazard profile.

2.14.4 Characteristics of Bauxite Residue

The bauxite used will have a major impact on the characteristic, particle size distribution, and behaviour of the residue; the coarse fraction (greater than 100 µm) which is high in quartz may be separated from the finer silty muds (typically 80% less than 10 µm). Sometimes these coarse fractions are given particular names such as ‘red oxide sand’ or 'sand residue', and the fine fractions are termed 'red mud'. Red mud, according to Sawant et al (2012) is reddish brown in colour. Its characteristics depend on the nature of bauxite ore used in the extraction of aluminium, which significantly differs from place to place. These coarse and fine fractions are handled very differently in the plant. The coarse fraction sands are often used for road construction in the residue areas, to provide a drainage layer under the mud, or as a capping material for the residue sites. The coarse fraction is much easier to wash, has much better draining behaviour of the bauxite residue is much improved. Bauxite from some regions, such as Western Australia, is especially high in the coarse sands and in some instances these can account for 50% of the content of bauxite.

2.14.5 Properties of Bauxite Residue

During the preparation of bauxite for export the ore is washed and the washings containing about 25% of solid are collected in ponds. When the ponds dry up during the dry season a red coloured mud is left behind. This mud is the bauxite waste (BW) or fines. It is the mud which has accumulated over the years at Awaso, there is an accumulation of about three (3) million tonnes of BW at Awaso. The accumulation increases at the rate of 300 tonnes per day. In Ghana, the mud is being utilized to manufacture pozzalana. Physically, this mud looks like clay but its chemical and mineralogical composition is identical to that of bauxite (Hammond, 1980).

2.14.6 Environmental Concerns

Residue is disposed as dry or semi dry material in red mud pond or abandoned bauxite mines and as slurry having a high solid concentration of 30-60% and with a high ionic strength. The environmental concerns relate to two aspects: very large quantity generated and its causticity. The problems associated with the disposal of red mud / residue includes:

- Its high PH (10.05-12.5)
- Alkali seepage into underground water
- Instability of storage
- Alkaline air borne dust impact on plant life
- Vast area of land consumed

Up to 2 tonnes of liquid with a significant alkalinity of 5-20g/l caustic (Rai et al, 2012).

2.15 Disposal of Residue

Red mud waste is usually managed by discharge into engineered or natural impounded reservoirs, with subsequent dewatering by gravity-driven consolidation and sometimes followed by capping for closure. Red mud disposal methods include traditional closed cycle disposal (CCD) methods and modified closed cycle disposal (MCCD). A new class of dry stacking (DS) technology has also emerged which requires much less land. Due to various problems associated with disposal of red mud, it may cause economical as well as ecological problem in near future (Rai et al, 2012).

Safe treatment and storage of high volume industrial waste streams pose unique waste management challenges. Seawater discharge, lagooning, dry stacking and dry disposal are the methods currently in use for the disposal of bauxite residue. In seawater discharge, after washing and thickening process of red mud, the slurry is disposed directly via a pipeline into the deep sea. This process reduces environmental impact of land disposal but may release toxic metals to the marine environment and increase the turbidity of the sea due to the fine mud and the formation of colloidal magnesium and aluminum compounds. Nevertheless, French and Japanese practices have favoured disposal at sea as the best option on economic and environmental grounds. In Japan, the alumina plants are restricted to available land area for disposal of residues, and so have discharged the residue into the deep sea. The plants of Gardanne Alumina in France and Aluminum De Greece in Viotia, Greece still use marine dumping but are now pursuing other alternatives.

Lagooning is the conventional disposal method in which the residue slurry is directly pumped into land- based ponds. This consists of the construction of clay-lined dams into which bauxite residue slurry is simply pumped and allowed to dry naturally. Hind Bhargave & Grocott,(1999). This minimizes the liquor leakage to the underlying water. The red mud ponds are lined with soil and bentonite. This process requires lowest capital cost, suppresses dust generation but requires substantial storage land and increases environmental hazards such as contact of humans and wild life with caustic liquor and contamination of ground water. Most of the alumina refineries till 1975 were using lagooning method for red mud disposal but some of them such as Pinjarra, Kwinana and Wagerup refineries in Australia have shifted to Dry stacking method. Queensland Alumina Ltd (Australia) after treatment of its red mud with seawater and CVG Bauxilium (Venezuela) still use wet disposal method by disposing their red mud in lagoons (Emmett and Klepper,1991). In dry stacking method, the residue slurry is thickened to 48-55% solids and discharged in thin layers, dewatered and air dried before discharge of next layer on it. After the consolidation of paste to about 65%, it can be safely stacked. This reduces the area of disposal but may increase dust generation and requires funds for its long-term closure. This method has been successfully applied at the MOTIM plant in Hungary (Solymar Ferenezi and Papanastassiou, 2002). The original wet disposal method at NALCO, India has been replaced by Thickened Tailings Disposal (TTD) system. Dry disposal is a method in which the residue is filtered to a dry cake (>65% solids) and the material is washed on the filter with water or steam to recover soda and minimize the alkalinity of residue. Without further treatment, the dry residue is carried by truck or conveyor to the disposal site. This reduces the storage area but requires installation and operation of filtration plant. Solids contents of greater than 75% have been achieved with Bokela hyperbaric filtration technology at the Stade plant in Germany. Even with the excellent washing performance offered by hyperbaric steam filtration, significant alkalinity remains associated with the solids because of the complex nature of red mud. Hence these hazards associated with alkalinity may be further reduced by employing suitable methods of neutralizing the red mud slurry, (Rai et al, 2012).

2.16 The Current Uses of Bauxite Waste

Investigations of the use of red mud and fly ash for the production of heavy clay products have been extensively undertaken at the Central Building Research Institute, Roorkee, India (Hajela, Gupta & Goel, 1989). Ekrem, (2006) studied the potential use of red mud for the preparation of stabilization material. The test results show that compacted clay samples containing red mud and cement–red mud additives have a high compressive strength, decreased hydraulic conductivity and swelling percentage as compared to natural clay samples. Consequently, it was concluded that red mud and cement–red mud materials can be successfully used for the stabilization of clay liners in geotechnical applications. Study on the exploitation of red mud as a clay additive for the ceramic industry or as a compound for self-binding mortars in the fabrication of stoneware. A study carried out by (Pontikes, Angelopouos and Kim, 2006) was aimed at using bauxite residue in heavy clay industry in which the plasticity of clay mixtures with bauxite residue and polymer addition was evaluated. They found that addition of 30 wt% bauxite residue substituting the clay mixture increases the maximum cohesion of the mixture. To make its use as a traditional ceramic, behavior of bauxite residue was studied in different firing atmospheres (Air, N^2, Ar/4 % H^2), for different maximum temperature (950-1050°C) and different soaking time (30-300 min).

2.16.1 Use of Bauxite Waste as Cementitious materials

Red mud from HINDALCO, Renukoot, India was investigated for its application in cement-sand. It was found that cements made from lime + red mud + bauxite + gypsum exhibit strengths comparable or superior to ordinary Portland cement (OPC). It was stated that as red mud is very rich in iron, red mud can be used as cheap pigment for coloured concrete Pera Boumaza and Ambroise,(1997). Also a uniform and durable coloured concrete could be obtained using white cement inter ground with 11% of burnt red mud. The red coloration could be enhanced by calcination in the range of 600 to 800°C. Preparation of building materials aluminium hydroxides (goethite and boehmite) and clays minerals into pozzolanic admixtures that are able to consume the calcium hydroxide produced by cement hydration. Thus, it is possible to develop a new admixture for concrete: a pozzolanic pigment (Rai et al, 2012).

In Ghana, Solomon-Ayeh (2008) cited Hammond, (1987) Initial studies on possible pozzolanic materials in Ghana using bauxite waste from the Awaso mines. Other materials that possess pozzolanic properties were identified as the vast clay deposits in the Greater-Accra region of Ghana (Hammond, 1978) and agricultural wastes such as rice husks, coconut fibres, groundnut husks, sugar-cane biogases etc.(Hammond, 1987). The research on bauxite wastes indicated that with a 20 to 30% replacement of ordinary Portland cement (OPC) with calcined (700-900oC) bauxite-wastes, mortars and concretes produced with these blended cements produced strengths comparable to those using OPC only. In Ghana (Atiemo, 1994) have confirmed that satisfactory strengths are obtainable with up to 30% replacement of OPC with pulverized burnt clay and additionally such pozzolanic cements have shown better performance in saline atmospheres.

2.16.2 Bauxite Waste in the Production of Ceramics

Red mud is made into useful ceramics articles by mixing 51-90% by weight of red mud with 49-10% by weight of at least one mineral and/or silicate containing material, shaping the mixture and firing it at a temperature of 950° -1250°C (Puskas, 1983). However, the investigators (Nimje, Sharma & Sengar, 2007), have successfully converted red mud into glass ceramic products which involve addition of a small quantity of glass former along with traces of nucleating agents to a specific mixture of red mud, fly ash, followed by melting at around 1200°C and verification by cooling. The feasibility of recycling red mud and fly ash by producing glasses and glass-ceramics has also been investigated by Yanga et al.(2008). Glass has been obtained by melting red mud from Shandong Province in China with different additives. Suitable thermal treatments were employed to convert the obtained glass into nano-crystal glass-ceramics. X-ray diffraction (XRD) patterns showed that the main crystalline phase in both the glass-ceramics is wollastonite (CaSiO3). These crystals are homogeneously dispersed within the parent glass, with an average crystal size of less than 100 nm. The size of nano-crystals varies when different thermal processes were used. These glass-ceramics have potential for a wide range of construction application.

2.16.3 Bauxite Waste as Fired Bricks

United States Patent 3886244 Garhard,(1975) claims a process for manufacturing fired bricks wherein 50-90 wt % of red mud can be used along clay and a water fixing agent. The raw bricks are dried with heated gases at a temperature below 70°C, and subsequently fired at a temperature between 900° -1,100°C. Efforts have been made at Central building Research Institute, CBRI, India (Dass & Malhotra, 1990) to produce burnt clay bricks by partially replacing the clay with red mud (from the Indian Aluminium Company), lime and fly-ash, Non-fired building materials. Efforts have also been made at CBRI to incorporate a small percentage of lime in red mud and compress the mix at optimum moisture content in the form of bricks with the purpose of examining their strength and stability to the erosive action of water. A maximum wet compressive strength of 3.75 MPa with 5% lime and 4.22 MPa with 8% lime has been obtained after 28 days of casting and humid curing of these bricks in the month of August. Studies were carried out at Jamaica Bauxite Institute and the University of Toronto,(Peter,1997) using red mud to make bricks for inexpensive housing. The red mud was pressed into bricks using a standard brick press, immersed in sodium silicate followed by drying in the sun. (Liu Yang & Xiao, 2009), studied the recovery of iron from Bayer red mud with direct reduction roasting process followed by magnetic separation, and then building materials were prepared from aluminosilicate residues. Then brick specimens were prepared with aluminosilicateresidues and hydrated lime and the mean compressive strength of specimens was 24.10 MPa. It was indicated that main mineral phase nepheline ($NaAlSiO_4$) in aluminosilicate residues transformed into gehlenite($Ca_2Al_2SiO_7$) in brick specimens as demonstrated by X-ray diffraction (XRD) technology. Combining the recovery of iron with the reuse of aluminosilicate residues, it can realize zero-discharge of red mud from Bayer process. Unsintered bricks have been developed from red mud disposed from Chinese sintering alumina process cured at ambient conditions. The optimal proportions of red mud brick are suggested as the following: 25–40% red mud, 18–28% fly ash, 30–35% sand, 8–10% lime, 1– 3% gypsum and about 1% Portland cement Jiakuan et al, (2008).

2.16.4 Bauxite Waste as Pigment for Concrete Production

Red mud from Birac Alumina Industry, Serbia was tested as a pigment for use in the building material industry for standard concrete mixtures. Red mud was added as a pigment in various proportions (dried, not ground, ground, calcinated) to concrete mixes of standard test blocks (ground limestone, cement and water) (Cablik, 2007). The idea to use red mud as pigment was based on extremely fine particles of red mud (upon sieving: 0.147 mm up to 4 wt%, 0.058 mm up to 25 wt% and the majority smaller than 10 microns) and a characteristic red colour. Compressive strengths from 14.83 to 27.77 MPa of the blocks that contained red mud between 1 and 32% were considered satisfactory. The reported tests have shown that neutralized, dried, calcined and ground red mud is usable as pigment in the building materials industry. Red oxide pigment containing about 70 % iron oxide was prepared from NALCO red mud by Satapathy Patnaik and Vidyasagar (1991) after hot water leaching filtration, drying and sieving.

CHAPTER THREE

EXPERIMENTAL STUDIES

3.1 Introduction

This chapter of the research describes the materials used for the study and the in-depth procedures used. It also describes all the physical properties of the samples used. To simplify the procedures for testing samples, materials were moulded in the form of cubes. Laboratory experiments were conducted to attain the engineering properties of the composite cubes (sand-bauxite cubes) to determine their suitability as a masonry unit. The laboratory investigations on the composite cubes were undertaken at the Civil and Building Technology Laboratory in Takoradi Polytechnic.

3.2 Materials Used

The materials used in this study include sand, cement, water and bauxite residue. The under listed sections give full description of the materials used in the study.

3.2.1 Bauxite Residue

The bauxite residue used in this study was taken from Awaso a bauxite mining town in the western region of Ghana. The bauxite residues used were the main solid by-product in the production of alumina by alkaline extraction routine from bauxite ore via the Bayer process. The bauxite residue samples were collected from an impoundment area stored in sacks and transported to Takoradi Polytechnic Laboratory as shown in Fig. 3.1

Figure 3.1 Parked bauxite residues for sieve analysis

Figure 3.1 b. Sample of bauxite residue heaped at GBC washing plant

3.2.2 Water

Potable tap water in the laboratory supplied by the Ghana Urban Water Company Limited was used for the study.

3.2.3 Cement

Ordinary Portland cement to specification BS 12 was used for the study.

3.2.4 Sand

The sand sample used for this study was clean, sharp pit sand obtained from Ehyiem in the Western Region.

3.3 Testing Methods and Procedures for sand and bauxite residue

The sand was mixed with the bauxite residue (as partial replacement of sand) in different proportions. Six different levels of partial replacement (i.e. 0, 10, 20. 30, 40 and 50 per cent) of the bauxite residue content by weight were adopted in this study. The various test methods and procedures conducted on the sand and bauxite residue have been outlined in the next sections.

3.3.1 Compaction Test

According to BS 1377 (1990), compaction test is performed to determine the relationship between the moisture content and the dry density of a specified compactive effort.

After thoroughly mixing of each batch, four representative samples each of 6 kg of air dried material were prepared. The mould with the attached base plate was weighed (C_1).

The mould was placed on the concrete floor whiles the extension collar was attached. A quantity of moist bauxite residue was placed in the mould and compacted such that it would occupy a little over 1/3 of the mould height. Uniformly distributed weight of fifty-six blows from rammer was dropped over the surface of the moist bauxite residue in the mould. The rammer was removed while the next layer of the bauxite residue was filled. The ramming process was repeated two more times by applying fifty-six blows to all the layers and the mould was filled. The extension collar was carefully removed, after compacting all the five layers. The surface of the compacted material was level to the top of the mould using trowel by striking off excess. Removed coarse particles were replaced in the levelling process by using finer materials from the sample. The moist bauxite residue and the mould with the base plate attached were weighed (C_1).

The compacted bauxite residue from the mould was removed and placed on a large metal tray and 400g sample of the bauxite residue was taken for its moisture content determination while the rest of the sample was thrown away. This process was repeated for all the remaining three portion of the sample until the moisture content and the dry density were obtained for the batch. Results of the compaction test performed on the bauxite residue have been recorded in chapter four.

3.3.2 Organic Content Test

The organic matter in the soil are mainly carbon based and can strongly influence the properties of the specimen. The high quantity of organic compound in the soil need to be treated before it can be used to produce the blocks with satisfactory strength. To determine the organic content of the soil, a dried soil sample was randomly taken and weighed (m_1). A clean dried metal container with lid used for the study was also weighed (m_2). The dried soil sample was placed in the container and strongly fired in an electric oven to a high temperature of 140^0c which resulted in fume generation. The container containing the sample was allowed to cool before being weighed (m_3) and the change in weight in weight was calculated and used to determine the percentage of organic compound in the sample.

3.3.3 Specific Gravity

Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature (Handbook of material testing 2006). A clean volumetric flask of 500ml was used for this experiment, weighed and recorded as M. Dry sand was randomly taken, weighed and also recorded as Ms. Potable tap water was poured into the volumetric flask to about 2/3 full and its weight recorded as M_2. The dry sand was poured into the volumetric flask with water gradually to prevent the sand sample from displacing. The flask with its content was shaken for two minutes and its weight recorded as M_3. The method was repeated for four different times to prevent error due to random sampling before the specific gravity was calculated. The same procedure was also used for the bauxite residue and the obtained results are shown in the next chapter.

3.3.4 Natural Moisture Content

To determine the natural moisture content of the soil sample, first a portion of the soil sample was collected from the pit and placed in a plastic polythene bag and closed tightly to prevent the moisture from evaporating. A sample was taken, formed into cone- line shape and divided into four by quartering. Three of the quartered soil samples were poured in the three separate cleaned pans and weighed (m_1). The pans with the samples were placed in an oven for 24 hours at a temperature of 110^0C. The pans with the samples were removed from the oven and allowed to cool down completely before weighed again (m_2). The natural moisture contents of the samples were determined and the average moisture content was then calculated and the results obtained have been illustrated in Table 4.3.

3.3.5 Sieve Analysis Test

The sieve analysis test was performed to determine the particle size distribution of fine aggregates by sieving as per BS 1377–1:1990. By passing the sample downward through a series of standard sieves, each of decreasing size openings, the aggregates are separated into several groups, each of which contains aggregates in a particular size range (Handbook of material testing 2006).

The test sample was dried to a constant weight at a temperature of 110 + 5˚C and weighed. The sample was sieved by using a set of IS Sieves and on completion of sieving, the material on each sieve was weighed. Cumulative weight passing through each sieve was calculated as a percentage of the total sample weight. Fineness modulus was obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100. The results are presented in a table form in the chapter four.

3.3.6 Silt Test of Sand

Sand sample was spread on a pan and air dried under laboratory environment. All roots trash etc. was removed. A tall slender jar was filled with the sand to about ¼ the height of the jar. Potable water was added until the jar was ¾ full. The jar was covered with a tight lid and shaken vigorously for 2 minutes suspending the sand particles in the solution. It was then left undisturbed for 48 hours. When the water cleared i.e. after the 48 hours, the total depth of the sand and silt were taken and the results are tabulated the next chapter.

3.4 Testing Methods and Procedures for the Production of Block Specimens

This section of the chapter outlines procedures used in moulding the sand-bauxite composite cubes alongside methods used in the testing of the moulded cubes (See appendix B).

3.4.1 Mix design, batching and mixing of sand-bauxite residue composite samples

Samples were moulded into cubes of dimensions 150mm×150mm×150mm. Each mix had the sand and bauxite residue samples thoroughly mixed with cement until there was a uniform colour before the required quantity of water was added. Further mixing was done until a homogeneous mix was achieved before they were filled in the moulding machine. Mixing of the materials was done by hand in an aluminium mixing pans with trowels and hand. The tamping as shown in Figure 3.2 and Figure 3.3 was done manually with a brick moulding machines after ensuring a uniform mix.

In total, One Hundred and Twenty (120 No.) cubes were produced. This was enough for the four destructive tests (dry density, crushing or compressive strength, abrasion resistance and water absorption) investigated. The densities of the composite cubes were determined before performing the other destructives tests. For each test, five (5) cubes were randomly selected for the various batches (0%, 10%, 20%, 30%, 40% and 50%).

Figure 3.2 Tamping of samples

Figure 3.3 Removal of samples from the moulding machine

Table 3.1: Total quantity of materials used

Batches (%)	Sand (kg)	Cement (kg)	Bauxite residue (kg)	Water (kg)
0% B_0	90.72	28.35	0	12.76
10% B_{10}	81.648	28.35	11.34	12.76
20% B_{20}	72.576	28.35	22.68	12.76
30% B_{30}	63.504	28.35	34.02	12.76
40% B_{40}	54.432	28.35	45.36	12.76
50% B_{50}	56.70	28.35	56.70	12.76
Total	**419.58**	**170.10**	**170.10**	**76.56**

NB:

B_0 – Control specimen (specimen with sand cement only)

B_{10}- Specimen with 10% of bauxite as replacement of sand

B_{20} Specimen with 20% of bauxite as replacement of sand

B_{30} Specimen with 30% of bauxite as replacement of sand

B_{40} Specimen with 40% of bauxite as replacement of sand

B_{50} Specimen with 50% of bauxite as replacement of sand

3.4.2 Curing

The cubes were air dried (as shown in Fig. 3.4) amidst daily sprinkling with water for the first 7 days, so as to prevent quick drying. The composite cubes were then dried at ambient temperature and humidity for further twenty one (21) days.

Figure 3.4 Curing of composite cubes

3.5 Properties of the Composite Cubes Studied

After 28 days of curing, five (5) cubes from each batch were selected for each of the following tests: dry density, compressive strength, abrasion resistance and water absorption by total immersion. They were performed to determine their conformity with standard masonry units and the effects of the bauxite residue on the composite cubes.

3.5.1 Compressive Strength Test

The compressive strength is one of the valuable properties of masonry products. The blocks were expected to achieve a 28-day compressive strength of not less than 7MPa for load-bearing concrete masonry units according to the requirement of BS 6073 (1981). Shown in Figure 3.5 is a cube being compressed to determine it strength.

Four cubes were randomly selected from each batch for crushing using the ADR 2000 compressive strength machine. They were oven-dried to a temperature of 40°C until constant masses were obtained. They were then removed from the oven and left to cool in open air and wiped clean, removing any loose sand or other material which would be in contact with the compression platens. One cube was placed in the machine in such a manner that the load could be applied to the opposite sides of the cube, through the top and the bottom. The axis of the cube was carefully aligned with the center of thrust of the spherically seated platen. The cube was then tested for its compressive strength when load was applied without shock and increased continuously at a rate of approximately 140kg/sq.cm/minute. This was repeated for the remaining cubes before finding the average. The compressive strength test results are itemized in Chapter 4.

Figure 3.5: Conducting the compressive strength test using the ADR 2000 compressive machine

3.5.2 Abrasion Resistance Test

The abrasion resistance of the cube were attained by subjecting a cube to mechanical erosion by brushing with a stiff wire made of 16mm flat 26 gauge wire bristles assembled in 50 groups of 10 and mounted to form 5 longitudinal and 10 transverse rows. The selected cube were initially weighed (W_1) before being brushed at a constant pressure in turns with wire brush at one forward and backward motion for 3 minute on the face of the cube as shown figure 3.6 and 3.7. The brushing was done along the entire length of the cube.

When brushing was completed all loose matter was then removed from the cubes by using napkin and weighed after the test as W_2. The removed matter was calculated as (i.e. W1- W2) before the abrasive coefficient was then calculated. The steps were repeated for the remaining three composite cubes since four composite cubes were used to average one. The results of the test have been shown in Chapter 4

Figure 3.6: Conducting the abrasion test

Figure 3.7: Sample cube after abrasion test

3.5.3 Water Absorption Test by Total Immersion

This test was done to determine the rate at which water absorption takes place the sand-bauxite residue composite cubes. The water absorption by total immersion was measured by the increase in weight of composite cubes after curing for 28 days in laboratory environment and then immersed in 200mm depth of water for certain hours thus (1 hour, 2 hours, 4 hours, 6 hours, 12 hours, 24 hours, 48 hours and 72 hours) as shown in figure 3.8. In this study, four cubes were taken from each batch and place in an oven at a temperature of 40˚C until a consistent mass was recorded indicating a thoroughly dried cube. The final masses before conducting the tests were recorded as V_1. The cubes were then immersed in the water. They were removed and its new weight recorded, it was then immersed back in the water for the subsequence hours. The result of this test is presented in Chapter 4 of the study.

Figure 3.8: Conducting water absorption by total immersion.

CHAPTER FOUR

TEST RESULTS

4.0 Introduction

This chapter presents and analyses the results of the different test conducted on the sand-bauxite residue composite cubes. This chapter is divided into two sections. It commences with the characteristics of the material used to determine their suitability for masonry works. The second section also looks at the results obtained after conducting the various laboratory tests on the sand-bauxite residue composite cubes.

4.1 Bauxite Residue and Sand Used

The tests conducted on the bauxite residue and sand includes:

(a) Organic matter content

(b) Particle size distribution

(c) Natural moisture content

(d) Specific gravity

(e) Silt test; and

(f) Compaction

4.2.1 Organic Matter Content

Sands containing organic matter may cause serious deteriorations when being used as a walling material as these organic materials are eligible to decay. After strong heating of the sand sample, the difference in weight and the corresponding percentage of organic content were found as shown in Appendix C1. An experimental study of the sand used showed an organic matter content of 0.46%.

4.2.2 Particle size distribution of sand and bauxite residue

This test was conducted to determine the particles size distribution of sand and bauxite residue particles. The results have been presented in Appendix C.2 and illustrated in Figures 4.1 and 4.2.

Based on the results and illustrated in Figure 4.2, the pit sand used in the study fell within the grading envelope for sand suitable for construction or masonry works. The grading curve for the bauxite residue on the other hand, slightly deviated from the range especially at the quantity of fines (> 0.150mm) were higher than what was specified by the BS 882 (1992).

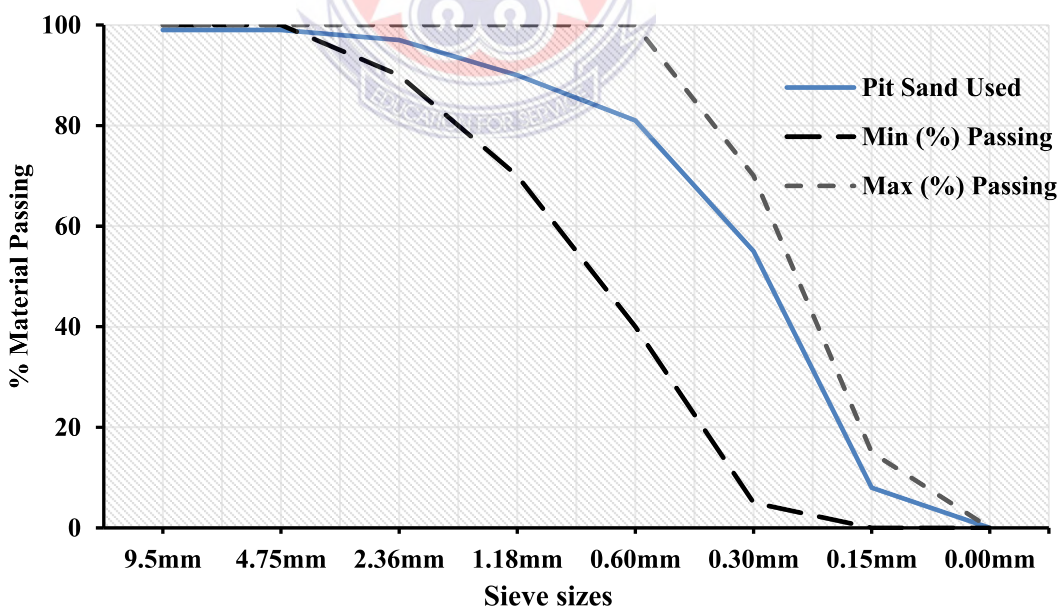

Figure 4.1: Grading curve for the Pit sand used

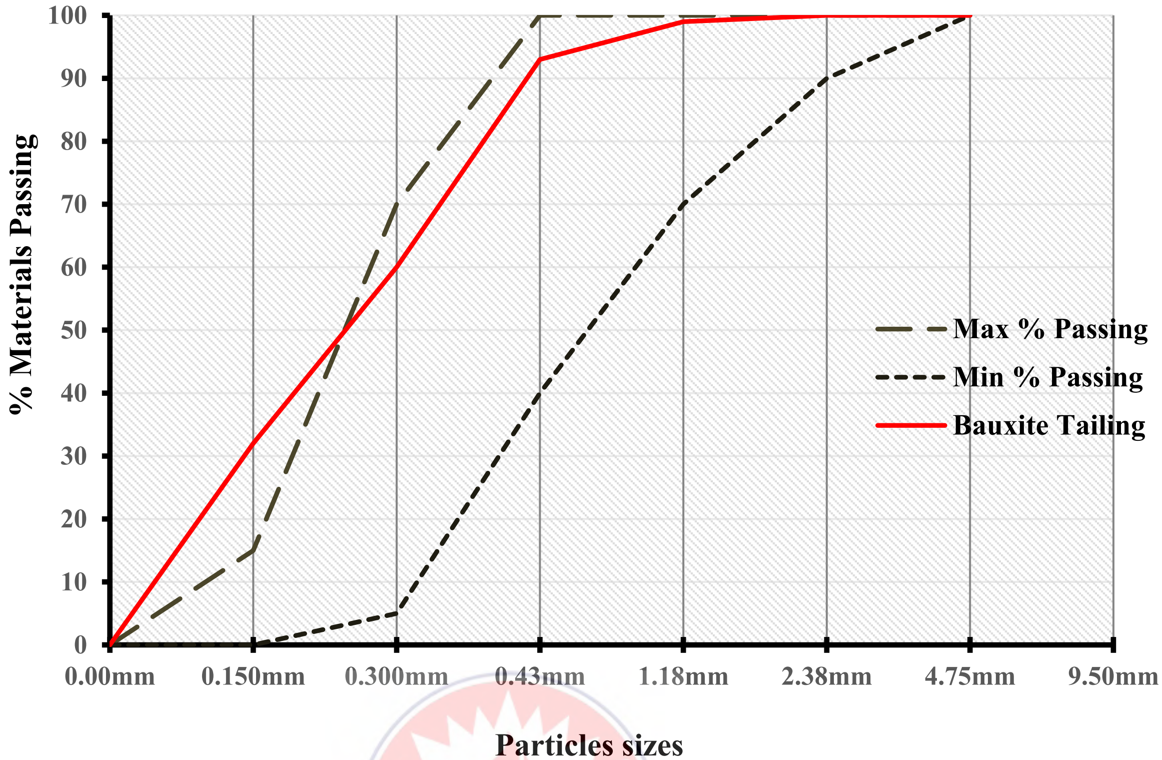

Figure 4.2: Grading curve for the Bauxite residue (Red mud) used

4.2.3 Natural Moisture Content

Climatic conditions of the soil samples are mostly having influence on the natural moisture content. The test was conducted to determine the water absorption capacity of the soil samples as it can negatively affect any of the materials used. Results obtained in Appendix C.3 & C.4 indicated that, the average water content in the bauxite residue and that of the sand was 6.8% and 8.8% respectively. These indicate that both soils have low water content and therefore can be recommended for blocks moulding.

4.2.4 Specific Gravity Test

Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature. The specific gravity of the sand and bauxite sample was determined as shown in Table 4.1 and presented in Appendix D i and D ii.

Table 4.1: Average Specific Gravity of Pit Sand and Bauxite Residue

Materials	Av. Specific Gravity	S.D
Pit Sand	2.64	0.176
Bauxite Residue	2.36	0.124

NB. See Appendix D1 & D2

The average specific gravity of pit sand and bauxite residue was 2.64 and 2.36, respectively which according to Maignien (1966), the recommended average specific gravity of lateritic soils range within 2.55 and 4.60. This means that the sand sample fell with in the range while the Bauxite fines deviated by 0.19 from the minimum in the range.

4.2.5 Silt Test

The silt test explained in Chapter 3 was used to determine the percentage content of clay and silt in the sand which Olanitori (2012) indicated that the percentage of silt/clay affects concrete and cement products. After conducting the test, the silt content was expressed in percentage and illustrated in Appendix D iii.

According to BS 882 (1992), the clay and silt content should not be more than 10%, indicating that the silt content obtained was within the allowable range and washing of sand before use was not necessary.

4.2.6 Compaction Characteristics of Bauxite Residue

Compaction in general placed the bauxite residue under heavier dense state resulting in a higher strength with decreasing water permeability. In carrying out the test, there was a systematic increase in the maximum dry densities of the bauxite residues as water content increased and the maximum dry densities start to decrease resulting in the attainment of the maximum dry density and its related optimum moisture content which was at 2751.98kg/m^3 and 13.22% respectively. This is illustrated in Figure 4.3.

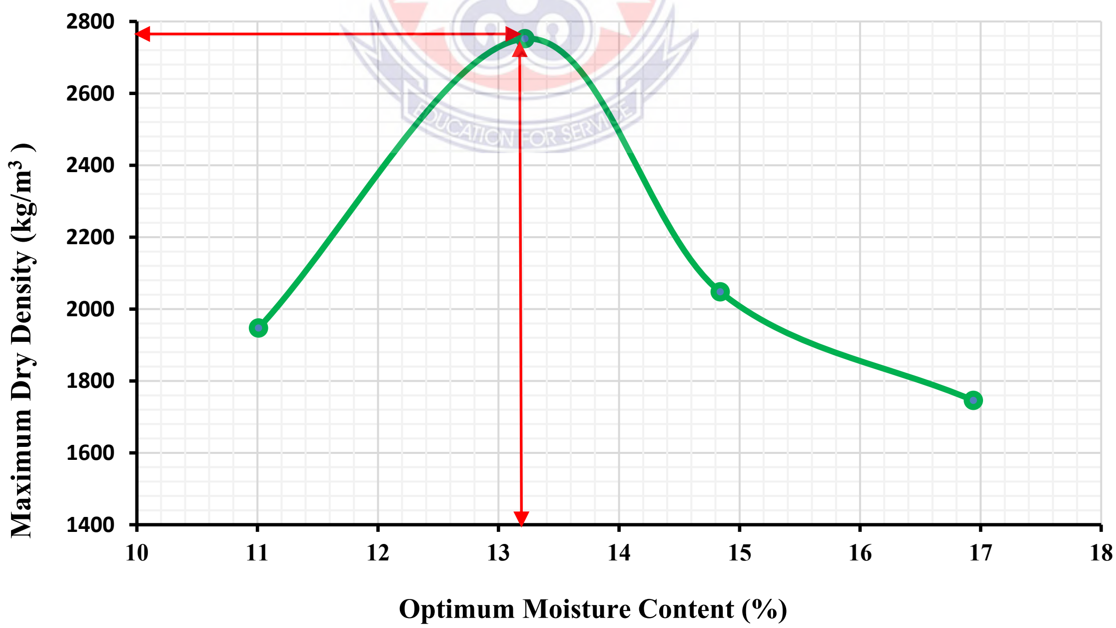

Figure 4.3: Compaction characteristics of Bauxite residue

4.3 Tests Results on Sand-Bauxite Cement Composite

This portion of the chapter talks about the various tests done on the composite cubes. The properties which were studied were density, compressive strength, abrasion and water absorption by total immersion for every batch after 28 days of curing. These were conducted to determine the effects of the bauxite residue on the cubes as compared to conventional sandcrete cubes (control group). The table 4.2 is the summary of the average results of the following tests; Density, Compressive Strength, Resistance to Abrasion and Water Absorption.

Table 4.2: Shows the tests results of sand-bauxite tailings blocks after 28 days curing age

Batches	Density (Kg/m3)	Comp. strength (N/mm3)	Abrasion loss (%)	Water absorbed (%)
B 0	2200.1	12.775	3.8	10.11
B 10	2147.4	13.750	1.8	8.03
B 20	2094.0	15.907	0.9	4.97
B 30	2049.1	11.910	4.9	5.11
B 40	2007.2	10.555	6.9	5.18
B 50	1888.6	8.427	9.1	5.23

4.3.1 Density of Composite

The weights and dimensions of the composite cubes were taken before testing them for their properties.

Based upon the result presented in Figure 4.4, and illustrated in Appendix E.1 there was a systematic fall in the average densities of the blocks as quantity of the bauxite tailings increased.

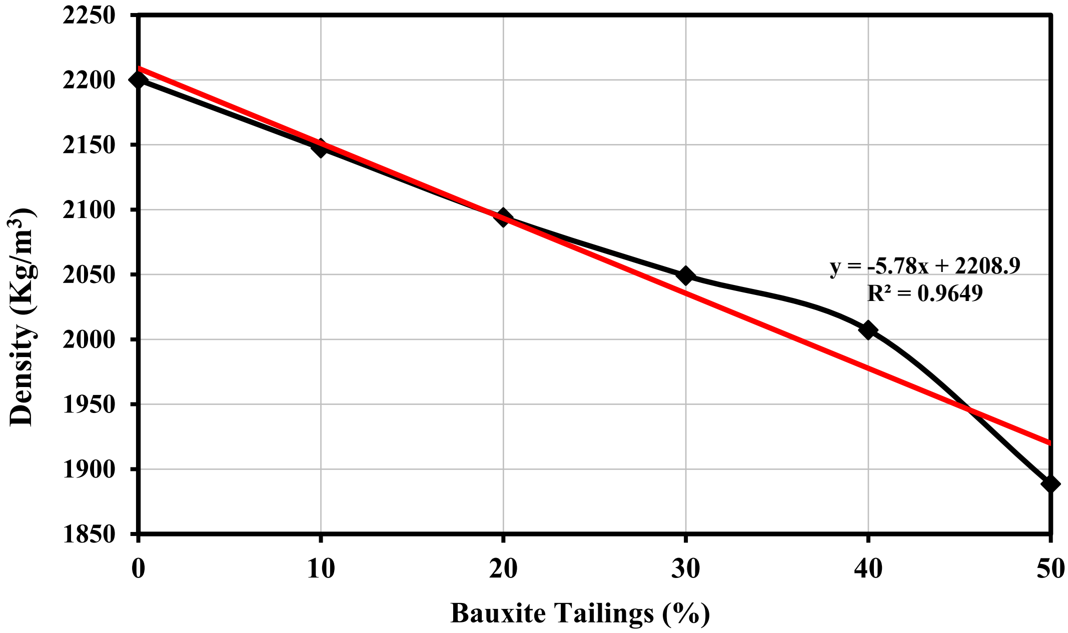

Figure 4.4: Relationship between Density and varying of the Bauxite tailings content

All the blocks used in the study had their densities within the range of 1500 kg/m^3-2400kg/m^3 as specified by BS 6073 for dense aggregates masonry units. Significantly, the control blocks had the highest average density of 2200.1kg/m^3. Composite bricks with 10% bauxite residues replacing the sand content recorded an average density of 2147.40kg/m^3 which was 2.4% less dense than blocks with no bauxite tailings. Furthermore, composite blocks with 20%, 30%, 40% and 50% of bauxite tailing replacing the sand on the other hand had average dry densities of 2094.0kg/m^3, 2049.1kg/m^3, 2007.kg/m^{3}and 1888.6kg/m^3 respectively which were found to be 4.82%, 6.86%, 8.77% and 14.16% less dense than the blocks with no bauxite tailings (control blocks).

These declining densities as the percentage of bauxite tailings increase could be attributed to the relative lower specific gravity of the bauxite tailings, thus reducing the overall density of the batch as the quantity added increased.

Statistically, there was a relatively strong relationship between the densities and the batches (varying bauxite content) as the correlation coefficient of -0.98 was deduced as illustrated in Table 4.3.

Table 4.3: Pearson Correlation between density and bauxite tailings

		Batch	Density
Batch	Pearson Correlation	1	- 0.980
	Sig. (2-Tailed)		0.000
	N	30	30
Density	Pearson Correlation	- 0.980	1
	Sig. (2-Tailed)	0.000	
	N	30	30

****. Correlation is significant at the 0.01 level (2-tailed).**

This relationship was confirmed after conducting a regression analysis. An equation of the model (Eq.1) which best describes the relationship between the density (y) and the bauxite tailings content (x) indicates that; if the tailings is increased by 1 unit, the density on average decreased by -5.78. And 2208.9 is the constant value for determined the density of the bauxite residues.

$$y = 2208.9 - 5.78x \ldots\ldots \text{Equation 1}$$

$$R^2 = 0.9649$$

This equation of the model was able to explain 96.49% of the variability in the mean density can be explained by the percentage of the bauxite tailings. This indicates that the bauxite tailings used in the study was responsible for 96.46% of the variations in the densities of the composite blocks.

Table 4.4: ANOVA summary of the Dry densities of Composite Cubes

Batches	Mean (kg/m^3)	SD	F-Value	P-Value
Sand + 0% Bauxite residue (Control)	2200.1*abcd*	38.49	22.048	0.000
Sand + 10% Bauxite residue	2147.4*ef*	40.62		
Sand + 20% Bauxite residue	2094.0*a*	13.08		
Sand + 30% Bauxite residue	2049.1*b*	9.78		
Sand + 40% Bauxite residue	2007.2*ce*	16.02		
Sand + 50% Bauxite residue	1888.6*df*	113.25		
Total	2064.4	112.76		

NB: MEAN VALUES WITH THE SAME LETTERS INDICATE THE SIGNIFICANT DIFFERENCE

One-way ANOVA test to a significance level of 5% was conducted and presented in Table 4.4. From Table 4.8, the F-value: $F(5, 24) = 22.048$; $p < 0.05$, obtained after the analysis indicated a high variability between the different batches than variability within each batch or group. This shows that the bauxite residue used in the study influences the dry densities of the composite cubes.

Post hoc analysis shown in Table 4.4 also revealed that the average dry density after 28days curing age of the conventional cubes (control group) of 2200.1kg/m^{3}was significantly different from that of the remaining composite cubes except cubes with 10% bauxite residue. Composite cubes with 50% of the sand replaced with bauxite residue was also found to be significantly different from the reminder of the cubes as it recorded the lowest dry density of 1888.6kg/m^3.

Furthermore, a correlation analysis showed a strong negative correlation of 0.890 existing between the bauxite residue and the average dry density of the sand-bauxite composite cubes indicating that as the amount of the bauxite residue increases the is decline in the dry densities of the composite cubes.

4.3.2 Compressive Strength of Composite Cubes

The compressive strength is one of the valuable properties of masonry products. The blocks were expected to achieve a 28-day compressive strength of not less than 7MPa for load-bearing concrete masonry units according to the requirement of BS 6073 (1981).

The compressive strength was determined after 28-days curing age and has been presented in Figure 4.5. Data for the graph in Appendix E.3 showed that; there is an increased in the compressive strengths of the sand-bauxite composite blocks when the bauxite tailings replacement level was up to 20%. The pattern changed as there was a subsequent decline in the compressive strengths as the block with bauxite tailings replacement level increased beyond 20%. Composite blocks with 20% bauxite tailing recorded the highest average compressive strength of 15.907N/mm^2 which was 24% higher than the control specimen. The composite blocks with 50% bauxite tailings had the least compressive strength of 8.427N/mm^2 which was found to be about 36% lower than the control specimen. Composite blocks with 10% bauxite tailings were found to be 7.5% higher than the control, while blocks replacing sand with 30% and 40% bauxite tailings resulted in reduced compressive strengths of about 7% and 17% below the control specimen. Nonetheless, none of the composite blocks had their average strength below the minimum 7.0 N/mm^{2}and 2.8N/mm^2 for bricks and blocks respectively as recommended by BS 6073:1981.

Data obtained showed quite a strong relationship between the compressive strengths (y) and the varying bauxite tailing contents (x) with a correlation coefficient of - 0.729 as presented in Table 4.5.

Table 4.5: Pearson Correlation between compressive strength and batches

		Batch	Compressive Strength
Batch	Pearson Correlation	1	- 0.729
	Sig. (2-Tailed)		0.000
	N	30	30
Compressive Strength	Pearson Correlation	- 0.729	1
	Sig. (2-Tailed)	0.000	
	N	30	30

****. Correlation is significant at the 0.01 level (2-tailed).**

This relationship is best described by the model equation (Equation .2) below as: if the bauxite tailing is increased by 1 unit, the compressive strength on average decreased by - 0.10092 and 14.7437 is the constant value for determine the compressive strength of the bauxite tailings.

$$y = -0.10092x + 14.7437 \text{ ......Equation 2}$$

$$R^2 = 0.5321$$

The R^2 statistic of 0.5321 shows that, 53.21% of the variability in the compressive strengths of the composite blocks could be explained by the percentage of the bauxite tailings used in the study was responsible for 53.21% of the variations in the compressive strengths of the composite blocks.

The declining compressive strength as the bauxite tailings increased beyond 20%, could be attributed to the very fine grained particles of the bauxite tailings which were too numerous, to ensure an effective bond in the cement matrix (Rai, et al. 2012). Appukutty & Murugesan (2009) also attributed this phenomenon to the fines which are below 150 microns which requires high affinity to water thereby creating high water demand. This is evidence of the water content for the mixing of the mortar which was determined during the compaction test. The higher water demand might have hampered effective hydration process resulting in a reduction in strength of the composite blocks especially as the bauxite tailings increased. As a result, larger quantity of cement is needed to ensure a more effective and stronger bond or could be removed by vacuum de-dusting system as it is done with quarry dust.

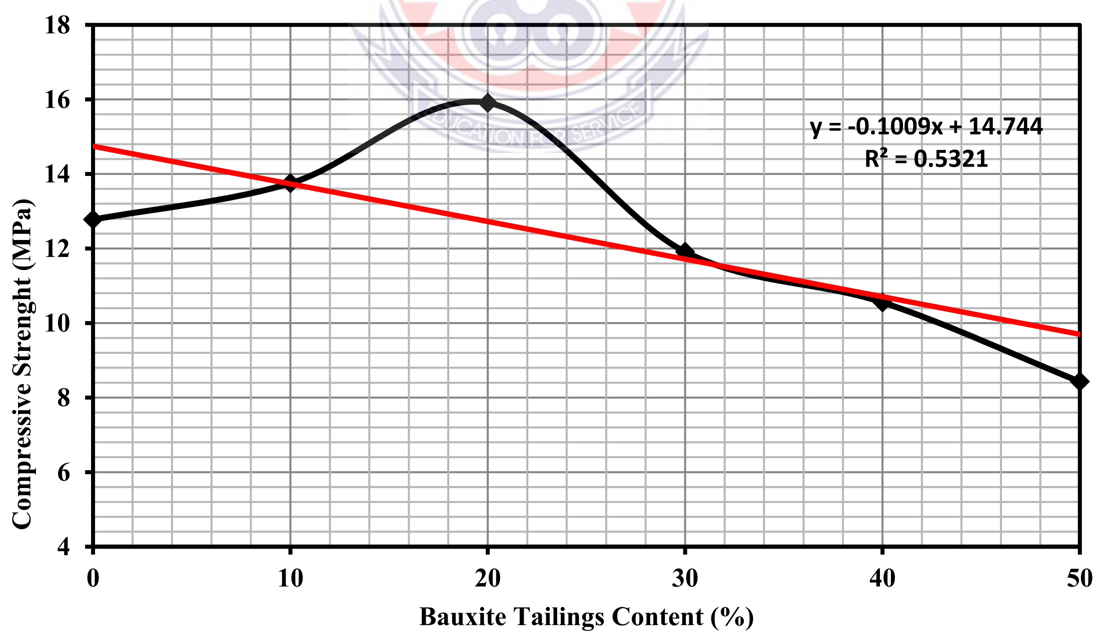

Figure 4.5: Relationship between Compressive strength and Bauxite tailings content

Table 4.6: ANOVA Summary of the Compressive strength of Composite cubes

Batches	Mean (N/mm^2)	SD	F-Value	P-Value
$B_{0\%}$	12.775*b*	0.167	63.170	0.000
$B_{10\%}$	13.750*af*	0.692		
$B_{20\%}$	15.907*abcde*	0.796		
$B_{30\%}$	11.910*cf*	0.366		
$B_{40\%}$	10.555*d*	0.558		
$B_{50\%}$	8.427*e*	1.264		
Total	**12.220**	**2.493**		

NB: MEAN VALUES WITH THE SAME LETTERS INDICATE THE SIGNIFICANT DIFFERENCE

The compressive strengths obtained after crushing the sand-bauxite composite cubes were analysed using one-factor ANOVA test at a confidence interval of 95% as shown in the Table 4.6 above. Statistically, there was a high variability between the individual batches than within the individual batches indicating that the bauxite residues influence the batches and not attributed to an error: $F (5, 24) = 63.170; p < 0.05$.

Deducing from the Post hoc analysis in Table 4.6, the 20% sand-bauxite composite produced the highest compressive strength being significantly different from the rest of the cubes as it had the highest average compressive strength of 15.907N/mm^2. Composite cubes with increasing bauxite residues showed a declining compressive strength which was buttressed by a relatively strong negative Pearson correlation of - 0.729 as shown in Table 4.6.

Using the Pearson correlation, the dry density of the composite cubes showed a strong negative correlation of: - 0.951. This shows that, as the dry density of the composite cube decreases, there is a corresponding decrease in the compressive strength beyond 20% of the sand-bauxite composite cubes thus 30%, 40% and 50% respectively.

4.3.3 Resistance to Abrasion of Composite Blocks

This property gives an idea of how masonry units disintegrate or degrade with time which can occur due to rubbing, scraping, skidding, or sliding on surfaces. In this study, the weight loss due to abrasion was the main parameter used in the analysis.

The loss in weight as a result of abrasion declined as the quantity of the bauxite tailings increased from 0% to 20%. Contrary to this observation, weight loss significantly increased as the quantity of bauxite tailings increased beyond 20% replacement in the composite blocks as illustrated in Figure 4.6. This was evident as blocks with 30%, 40% and 50% bauxite tailings content had an average weight loss of 4.93%, 6.894%, and 9.12% respectively. Composite blocks with 10% and 20% bauxite tailings had respective average weight loss of 1.75% and 0.89%.This weight loss pattern (in percentage)is believed to be as a result of the weak adhesion existing between the numerous fine grained particles in the composite blocks matrix and the cement paste which become easily displaced during the abrasion test.

Table 4.7: Pearson Correlation between Abrasion loss and batches

		Batch	**Abrasion loss**
Batch	Pearson Correlation	1	0.791
	Sig. (2-Tailed)		0.000
	N	30	30
Abrasion loss	Pearson Correlation	0.791	1
	Sig. (2-Tailed)	0.000	
	N	30	30

****. Correlation is significant at the 0.01 level (2-tailed).**

A relatively strong correlation coefficient (0.791) was found between the quantity abraded (in percentage) and the varying bauxite tailings replacing the sand as illustrated in the Table 4.7 above.

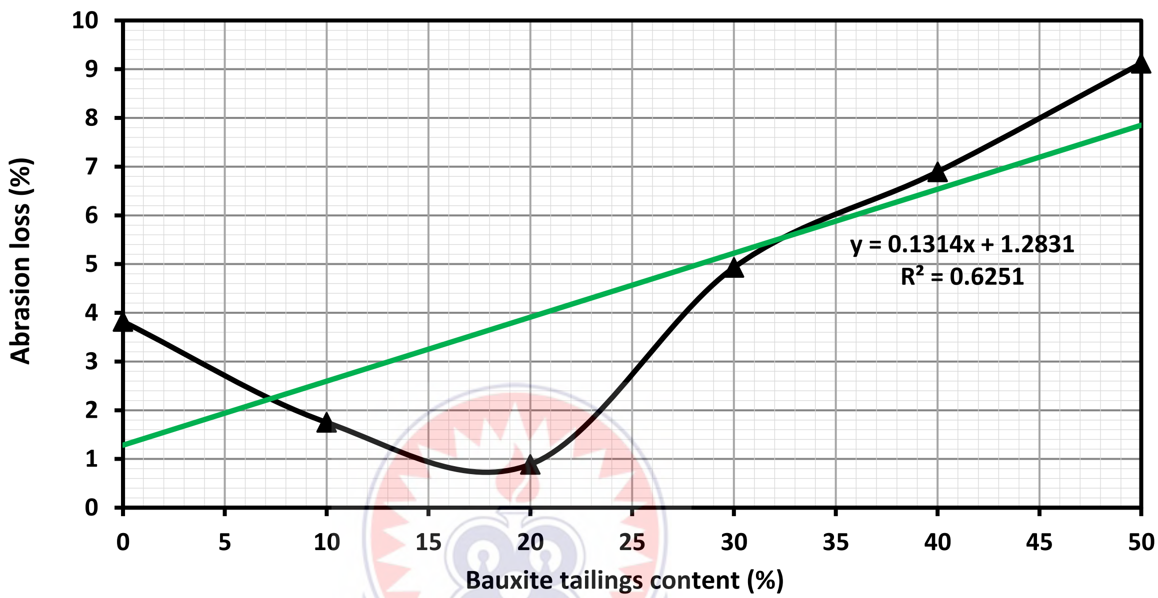

Figure 4.6: Relationship between bauxite tailing content and Abrasion resistance

The relationship between the abrasion loss (y) and the varying bauxite tailings (x) is given by:

$$y = 1.283 + 0.1314x \ldots\ldots \text{ Equation 3}$$

$$R^2 = 0.6251$$

Therefore, the equation of the model best explained that, if the bauxite residue is increased by 1 unit; the abrasion on average increased by 0.1314, and 1.283 is the constant value for determine the abrasion loss of the bauxite residue.

The R^2 statistics of 0.6251 indicates that 62.51% of the variability in the abrasion loss is explained by the percentage of bauxite tailings. In other words, the bauxite tailings used as a replacement for sand in the study accounted for 62.51% of the variations in the abrasion loss of composite blocks.

The relationship between the bauxite tailings content and weight loss due to abrasion has been illustrated by linear regression with a satisfactory correlation in Figure 4.6. From the graph, it could be deduced that the abrasion loss is inversely proportional to the compressive strength. In other words, as the loss to abrasion increases, there is a corresponding decline in the compressive strength. This phenomenon confirms earlier studies by Naik et al. (2002) that increasing compressive strength causes a decline in abrasion loss of cement products.

4.3.4 Water Absorption by Total Immersion

It was observed that the composite blocks showed a steady decline in the total quantity of water absorbed as the bauxite tailings increase in the batch. The presence of bauxite tailings replacement reduced substantially the absorptivity of the blocks from 5.0% for 0% bauxite content to 3.2% for 10% bauxite tailings. Composite blocks with 20% bauxite tailings recorded the lowest quantity of water absorbed with only 1.7% increase in weight. As the bauxite tailings content increased to 30%, the water absorbed slightly increased to 1.9% while 40% and 50% increase in the bauxite tailings content also increased the absorptivity of the blocks to 2.0% and 2.1% as illustrated in Figure 4.7

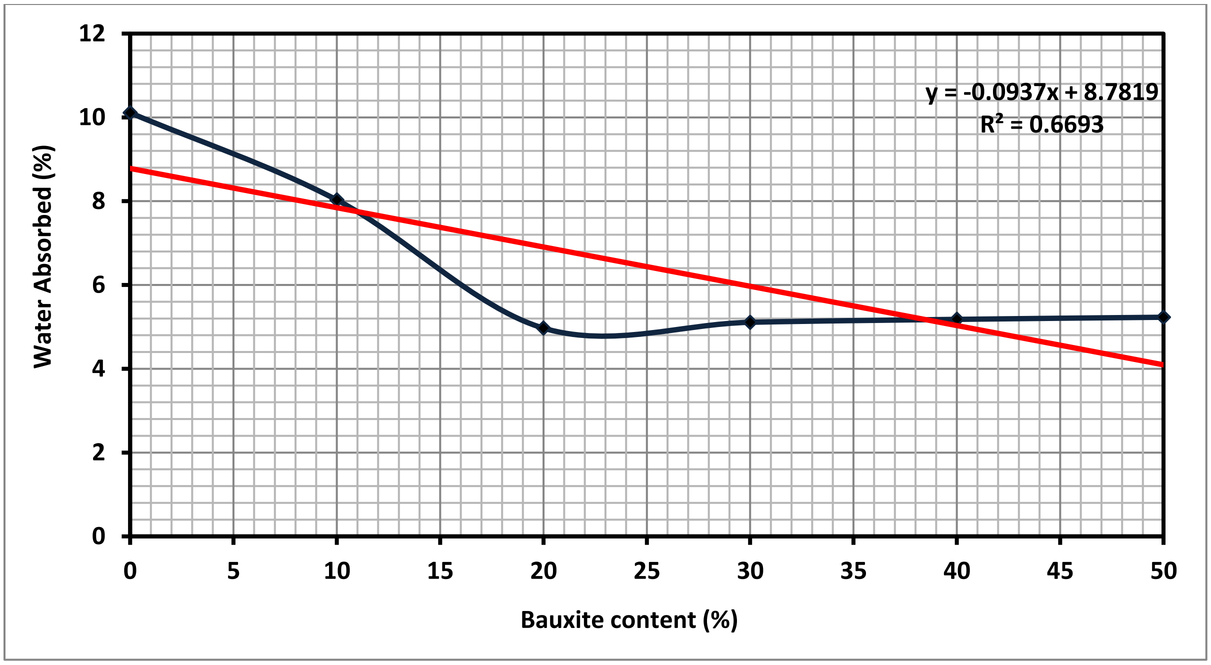

Figure 4.7: Water absorption characteristics of Sand-bauxite tailings composite cubes.

Statistically, there was a significantly strong relationship between the water absorbed (%) and the composite blocks with varying amount of bauxite tailings at the 95% confidence level indicated by a correlation coefficient of -0.818 as shown in Table 4.8

Table 4.8: Pearson Correlation between Water absorption and batches

		Batch	Water Absor.
Batch	Pearson Correlation	1	-0.818
	Sig. (2-Tailed)		0.000
	N	30	30
Water Absorption	Pearson Correlation	-0.818	1
	Sig. (2-Tailed)	0.000	
	N	30	30

****. Correlation is significant at the 0.01 level (2-tailed).**

From the regression analysis conducted, a linear model was used to describe the relationship between the water absorbed (Y %) and the bauxite tailings content (X %). The equation of the model which explained that; if the tailing is increased by 1 unit, the water absorption on average decreased by -0.0937; with 8.782 being the constant value for determined the rate of water absorption of the bauxite tailings.

R^2 indicates that, 66.93% of the variability in the total water absorbed (%) was best described by the percentage of the tailings. $R^2 = 0.6693$

$$y = 8.782 - 0.0937x \text{ …… Equation 4}$$

Generally, the addition of bauxite tailing content thus resulted in lower migration of water into the block (i e. lower permeability). This could be explained that the presence of the large bauxite tailing content eventually led to higher hydrated bauxite tailing and higher mortar content. The fine nature of bauxite tailing content makes the block with some amount of bauxite tailing less porous and more impermeable than the sand matrix probably by infilling the voids and displacing some of the sand with far less permeable bauxite tailing hydration products, thereby reducing paths for water ingression. Again increasing bauxite tailing content above 20% did not significantly improve the permeability of the blocks.

CHAPTER FIVE

DISCUSSIONS

5.1 Introduction

This chapter discusses the test results presented in chapter four on the utilization of neutralized bauxite waste as a partial replacement of sand in blocks to enhance its strength and durability properties. The purpose was to compare results in relation to other related studies, previous research findings, established standards in the literature.

5.2 Partial Replaced Bauxite Sand Block Production

Mix design and batching of sand-bauxite residue composite samples were moulded into cubes of dimensions 150mm×150mm×150mm. Each mix had the sand and bauxite residue samples thoroughly mixed with cement until there was a uniform colour before the required quantity of water 0.45ml by volume was added. Further mixing was done until a homogeneous mix was achieved before they were filled in the moulding machine. Mixing of the materials was done by hand in aluminium mixing pans with trowels and spatula. The tamping as shown in Figure 3.2 and Figure 3.3 in chapter 3 was done manually with a brick/block moulding machines after ensuring a uniform mix. In total, One Hundred and Twenty (120 No.) cubes were produced. This was enough for the four destructive tests (dry density, crushing or compressive strength, abrasion resistance and water absorption) investigated. The densities of the composite cubes were determined before performing the other destructives tests. For each test, five (5) cubes were randomly selected for the various batches (0%, 10%, 20%, 30%, 40% and 50%) respectively.

5.3 Dry Density

From the study conducted, the highest dry density of the blocks was recorded from the control blocks thus 2251.85kg/m^3 and gradually 50% sand bauxite composite also recorded the least density of 1717.82 kg/m$^{3.}$

From the results as presented in Appendix E.1 and illustrated in Figure 4.4, there was a systematic fall in the average densities of the blocks as quantity of the bauxite waste increased.

These declining densities as the bauxite fines increase could be attributed to the relative lower specific gravity of the bauxite tailings, thus reducing the overall density of the batch as the quantity added increased.

5.4 Compressive Strength

The compressive strength was determined after 28days curing and has been presented in Figure 4.5. Data from the study showed that; there is an increased in the compressive strengths of the sand-bauxite composite blocks when the bauxite fines replacement level was up to 20%. The composite block started reducing when the bauxite residue replacement level was beyond composite blocks with 20% bauxite fines recorded the highest average compressive strength of 15.907N/mm^2 which was 24% higher than the control specimen, While composite blocks with 50% bauxite fines had the least compressive strength of 8.427N/mm^2 which was found to be about 36% lower than the control specimen.

Nonetheless, none of the composite blocks had their average strength below the minimum 7.0 N/mm^{2}and 2.8N/mm^2 for bricks and blocks respectively as recommended by BS 6073:1981 and BS EN 771-3.

This declining compressive strength as the bauxite fines increased beyond 20%, could be attributed to the very fine grained particles of the bauxite tailings which were too numerous, to bond effectively in the cement matrix (Rai, et al. 2012). Appukutty & Murugesan (2009) also attributed this phenomenon to the fines which are below 150 microns and having high affinity to water thereby creating high water demand. This is evidence the water content for the mixing of the concrete which was determined during the compaction test. The higher water demand might have hampered effective hydration process resulting in a reduction in strength of the composite blocks especially as the bauxite fines increased. As a result, larger quantity of cement is needed to ensure a more effective and stronger bond or could be removed by vacuum de-dusting system as it is done with quarry dust.

5.5 Resistance to Abrasion

This property gives an idea of how masonry units disintegrate or degrade with time which can occur due to rubbing, scraping, skidding, or sliding on surfaces. In this study, the weight loss due to abrasion was the main parameter used in the analysis.

It was observed that weight loss significantly decreases as the quantity of bauxite tailings increase from 0%-20% .In contrast to this observation, weight loss significantly increased as the quantity of bauxite waste increased beyond 20% replacement in the composite blocks (shown in Figure 4.6).

This weight loss pattern might have been come about as a result of the weak adhesion existing between the numerous fine grained particles in the composite block matrix and the cement paste which are easily displaced during the abrasion test.

The relationship between the weight loss due to abrasion and the compressive strength has been illustrated by linear regression with a satisfactory correlation in Figure 4.6. From the graph, it could be deduced that the abrasion loss is inversely proportional to the compressive strength. In other words, as the loss to abrasion increases, there is a corresponding decline in the compressive strength. This phenomenon confirms earlier studies by Naik et al. (2002) that increasing compressive strength causes a decline in abrasion loss of cement products.

5.6 Water Absorption by Immersion

According to Amritphale and Patel (1987), bauxite residue pressed into blocks and calcined at high temperature (>1000C) have incredible compression strength suitable for high rise building construction with exceptional fire resistance, low water absorption and an appealing colour (Dimas et al., 2009). BS EN 771-3 recommended that, Water absorption in average is less than 7% after 24 hours.

Composite blocks from the various batches were tested for their absorption properties. This gave a fair idea of how the blocks would behave in water or determine the extent to which water would seep through the tiny pores when totally immersed in water as explained earlier.

Statistically, there was a significantly strong relationship between the water absorbed (%) and the composite blocks with varying amount of bauxite tailings at the 95% confidence level indicated by a correlation coefficient of -0.818.

Generally, the addition of bauxite tailing content thus resulted in lower migration of water into the block (i e. lower permeability).

This could be explained that the presence of bauxite fines content eventually led to higher hydrated bauxite fines and higher mortar content. The fine nature of bauxite residue content makes the block with some amount of bauxite tailing less porous and more impermeable than the sand matrix probably by infilling the voids and displacing some of the sand with far less permeable bauxite fines hydration products, thereby reducing paths for water ingression. Again increasing bauxite fines content above 20% did not improve the impermeability of the block.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter summaries the key findings of the study, draws conclusions and suggests recommendations. It also gives the indication on the areas of the study that could be replicated or further research.

6.2 Summary of Findings

- The study revealed that, partial replacement of bauxite residue has the significant effect on the density of the composite blocks. However, looking at individual densities, it was observed that there was a systematic fall in the average dry densities of the blocks as the quantity of bauxite residue was increased. Comparatively, the composite with B_{50} grade was 14.16% lesser dense than the control block.
- Data from the study showed that, there is an increase in the compressive strengths of the sand-bauxite composite blocks when the bauxite residue replacement level was up to 20%. The composite block started reducing when the bauxite residue replacement level was beyond 20%.
- Again, it was also observed that, none of the composite blocks had their average compressive strength below the minimum 7.0 N/mm^2 and 2.8 N/mm^2 for bricks and blocks respectively as recommended by BS 6073:1981 and BS EN 771-3.

- It was observed that weight loss significantly increases as the quantity of bauxite residues increases beyond 20% replacement in the composite blocks. This was evident as blocks with 30%, 40% and 50% bauxite tailings content had an average weight loss of about 4.93%, 6.89% and 9.12% respectively. While composite blocks with 0% - 20% bauxite residues had respective average weight loss as a result of abrasion declined as the quantity of the bauxite fines increased.
- The addition of bauxite tailing content thus resulted in lower migration of water into the block (i e. lower permeability). This could be observed that, the presence of bauxite tailing content eventually led to higher hydrated bauxite tailing and higher mortar content.
- It was also found that the composite with 20% replacement of sand-bauxite block composite recorded highest compressive strength of 15.907kg/m^3.

6.3 Conclusions

From the experimental investigations conducted, the following conclusions were drawn:

1. The bauxite tailings significantly influenced the properties of the blocks considered in this study.
2. It was found that the dry densities declined as the quantity of bauxite tailings increased.
3. Compressive strengths, abrasion loss and resistance to absorption of the blocks declined as the quantity of bauxite tailings increased beyond 20% replacement.
4. Sand-bauxite composite blocks give aesthetically pleasant appearances and are recommended for decorative or ornamental works.

5. Based on the results, the bauxite tailings used performed satisfactorily as a replacing material up to 20% for sand in the production of blocks for structural applications.
6. Other properties studied like abrasion loss and water permeability both saw a significant decline as the quantity of bauxite tailings increased to 20%. Further increase in the quantity of bauxite tailing beyond 20% replacement marginally affected these properties.

6.4 Recommendations

Based on the findings of the research conducted, some essential recommendations are drawn below:

From the study conducted, it was observed that, bauxite residue partially mixed with sand has significant effect on the strength and durability properties of blocks. However, blocks produced from partially replaced bauxite residue could be recommended to be used in below ground buildings because it absorbed less water. For the purpose of providing a low cost housing for the rural and urban poor in developing countries at a low-cost technique partially replaced bauxite fines are highly suitable and also recommended for single storey, two storey and high rise buildings.

The composite with the 20% replacement recorded the highest optimum compressive strength and as such recommended to be most appropriate even though all the replacement levels met the standard compressive strength, density, and abrasion coefficient and water absorption.

Finally, there should be for the developers and the local contractors in the Bibiani Anhwiaso Bekwai District should patronize partially replaced bauxite residue blocks because it is durable, low cost as well as environmentally friendly to be utilized for constructional purposes. Bauxite-sand blocks also give very nice appearance therefore it is recommended to be used for both internal and external works.

Also for future replication, it will be essential to look into the residue as the partial replacement in either mortar or concrete.

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APPENDIX (A)

SHOWS THE FIELD SURVEY CONDUCTED AT THE TAILINGS /RED MUD SITE

Plate (i) Disposal of the bauxite tailings from the pipe.

Plate (ii) pipe carrying the slurry from washing plant to the disposal point

Plate (iii): shows the Terrace Dam Ghana Bauxite Company-Awaso.

Plate (iv): shows the dry tailings dumped for some years

APPENDIX B

The plates illustrate production of partially replaced composite blocks (from batching, mixing, moulding, curing and crushing)

Plate 1 (A): shows the batching of materials

Plate1 (B): shows the dry mixing of materials

Plate 2: shows the mixing of materials

Plate 3. Removing of the composite from the mould box

Composite with 40% bauxite tailings replacement

Composite with 20% and 30% bauxite tailings replacement

28 day cube ready for crushing and other tests

APPENDIX C.1

Organic content determination

Readings	**Values (grams)**
Initial mass of dried sample (M_1)	65.5
Final mass of ignited sample (M_2)	65.2
Mass of organic matter (M_3) = (M_1- M_2)	0.3
Percentage of organic content M_3/M_1 = 0.3/ 65.5×100	**0.46%**

APPENDIX C.2

Grading envelope plotted as in BS 882 (1990) and Materials used in the study

Sieve size (mm)	**% Retained**	**% Passing**	**Min % Passing**	**Max % Passing**	**Pit Sand**	**Bauxite residue**
9.50mm	0.00	100	100	100	100	100
4.75mm	0.0	100	100	100	99	100
2.36mm	0.5	99.5	90	100	97	100
1.18mm	10.4	89.1	70	100	90	99
0.60mm	22.2	66.9	40	100	81	93
0.30mm	27.1	39.8	5	70	55	60
0.15mm	9.0	0.8	0	15	8	32
0.00mm	0.8	0.0	0	0	0	0

APPENDIX C.3

Results of natural moisture content determination (Bauxite residue)

Readings	mass (grams)
Mass of soil sample before oven dried (m_1)	125.8
Mass of soil samples after oven dried (M_2)	117.3
Change in mass	8.5
Natural moisture content (%) $= m_1 – m_2/ m_1 x\ 100$	**6.8%**

APPENDIX C.4

Natural moisture content determination (Sand)

Readings	mass (grams)
Mass of soil sample before oven dried (m_1)	149.3
Mass of soil samples after oven dried (M_2)	136.1
Change in mass	13.2
Natural moisture content (%) $= m_1 – m_2/ m_1 x\ 100$	**8.8%**

APPENDIX, D. I

Result of specific gravity of Pit sand

Readings	Sample 1	Sample 2	Sample 3	Sample 4
Weight of flask (W_1)	303.8g	303.5	303.7	303.4
Weight of Sand + flask (W_2)	361.0	362.5	383.7	381.6
Weight of flask +Water + sand (W_3)	585.6	587.5	600.0	602.5
Weight of flask +Water (W_4)	552.4	547.5	550.9	551.4
SP. Gravity = $\frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$	2.40	2.678	2.589	2.886
Average Specific Gravity		**2.64**		

APPENDIX D II

Result of specific gravity of Bauxite residue/tailings

Readings	Sample 1	Sample 2	Sample 3	Sample 4
Weight of flask (W_1)	303.3	303.9	303.9	303.9
Weight of tailings + flask (W_2)	359.3	365.5	372.0	375.4
Weight of flask + Water + tailings (W_3)	632.2	635.9	6639.8	640.9
Weight of flask +Water (W_4)	601.9	599.5	598.9	599.2
SP. Gravity = $\frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$	2.178	2.444	2.500	2.32
Average Specific Gravity		**2.36**		

APPENDIX D III

Results of the silt test

Composition	Sample 1	Sample 2	Average	S.D
Silt	5.1%	6.3%	**5.7%**	0.6
Sand	94.9%	93.7%	94.3%	0.6

APPENDIX E (THE MAIN EXPERIMENT)

APPENDIX E.1

Dry Densities of Composite Cubes

Batches	**Samples 1 ((kg/m^3)**	**Samp.2 (kg/m^3)**	**Samp.3 (kg/m^3)**	**Samp.4 (kg/m^3)**	**Samp.5 (kg/m^3)**	**Av. Density (kg/m^3)**
B_0(Control group)	2251.85	2222.22	2162.96	2162.96	2200.54	2200.1
B_{10}	2162.96	2162.96	2108.37	2199.21	2103.7	2147.4
B_{20}	2093.19	2103.7	2107.65	2091.5	2091.5	2094.0
B_{30}	2064.52	2052.15	2042.16	2040.07	2046.78	2049.1
B_{40}	2004.89	2024.44	2007.14	2017.54	1982.37	2007.2
B_{50}	1991.99	1830.0	1954.45	1949.21	1717.82	1888.6

APPENDIX E.2

Compressive strengths of composite cubes after curing for 28 days

Batches	Samples1 ((kg/m^3)	Samples2 ((kg/m^3)	Samples3 ((kg/m^3)	Samples4 ((kg/m^3)	Samples5 ((kg/m^3)	Av. (N/mm^2)
B_0	12.987	12.890	12.770	12.580	12.650	12.775
B_{10}	14.780	13.660	13.080	14.040	13.190	13.750
B_{20}	17.040	15.550	15.610	16.345	14.990	15.907
B_{30}	12.090	12.380	11.990	11.610	11.480	11.910
B_{40}	11.04	11.160	10.130	10.576	9.873	10.555
B_{50}	9.524	9.060	8.343	8.910	6.296	8.427

APPENDIX E.3

Abrasion results of Sand-bauxite residue composite cubes

Batches	Av.initial weight (grams)	Av.final weight (grams)	Amount Abraded (grams)	Percentage Abraded (%)
$B_{0\%}$	7160.0	6886.5	273.50	3.8
$B_{10\%}$	7242.4	7115.7	126.74	1.8
$B_{20\%}$	7357.6	7292.3	65.34	0.9
$B_{30\%}$	7123.2	6772.0	351.20	4.9
$B_{40\%}$	7077.5	6589.6	487.92	6.9
$B_{50\%}$	6756.7	6140.5	616.21	9.1

APPENDIX E.4

Weight of composite cubes after successive immersion in water

Batches	Initial Weight	Final Weight	Change in weight	Percentage Change in Weight
B_0	6.675	7.35	0.675	10.112
B_{10}	6.85	7.40	0.350	8.03
B_{20}	7.05	7.40	0.350	4.965
B_{30}	7.325	7.70	0.375	5.11
B_{40}	6.75	7.99	0.349	5.18
B_{50}	6.98	7.33	0.353	5.23