UNIVERSITY OF EDUCATION, WINNEBA

EFFECTS OF SAND ON THE CEMENT LATERITE INTERLOCKING BLOCKS

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DECLARATION

CANDIDATE'S DECLARATION

I, **Sampson Assiamah**, declare that, except for reference to other people's work, which has been duly acknowledged, this Dissertation consists of my own work produced from research undertaken under supervision and that, no part has been presented for any degree at the University of Education, Winneba or elsewhere.

SIGNATURE……………………………….

DATE……………………….................……

SUPERVISOR'S DECLARATION

I declare that, the preparation and presentation of this work were supervised in accordance with the guidelines for supervision of Dissertation laid down by the University of Education, Winneba.

DR. HUMPHREY DANSO

SIGNATURE……………………………….

DATE……………………….................……

DEDICATION

This thesis is dedicated to the almighty God for his guidance and protection and to my family for their encouragement, words of wisdom, prayers and moral support. I love you all!

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I sincerely appreciate the almighty God for this award that he has given me and the grace showered on me to complete my Master of Philosophy programme despite my imperfections and shortcoming, he has proven himself faithful and I return glory back to him. I wish to express my heartfelt appreciation to my family who supported me financially and morally to be able to finish this level of education. May the Almighty God grant them the divine wisdom and blessing in life.

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Finally, it is my deepest pleasure to thank for their love, support and spiritual guidance throughout my study. I would like to share the joy of graduating from my Master of Philosophy in Construction Technology with such awesome and wonderful people.

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ABSTRACT

In recent years, the attention of most researchers is shifting towards the optimization of building materials by using local contents, the use of indigenous materials, and local industrial by-products unique and abundant in certain localities. This study investigates the effect of sand utilised in cement–laterite interlocking block production in Ghana. Cement-laterite interlocking blocks were made with lateritic soil replacement with conventional fine aggregate from 0% to 25% by weight with Hydraform interlocking block moulding machine. Cement-laterite interlocking blocks without sand (0%) served as control. The blocks produced were tested to determine their density, compressive strength, tensile strength, water absorption, erosion and EDS/SEM properties. The average density of cement-laterite interlocking blocks indicated that as the curing days increase the density decreases alongside for each percentage of sand content decreases. The results of both the compressive and tensile strength were almost the same because only 5% sand replacement achieved the maximum strength above the 0% (control level) and the rest were below the control level or 0% from 7 days to 28 days curing period. Water absorption test results after 28 days curing period increased as the sand percentages increased. Erosion test result after 28 days curing period showed increase erodability as the sand percentages increased. The EDS results test indicated he chemical elements of the block such as O, Ca, Si, Al, and Fe. Lastly, the SEM images of the various percentages of sand showed some pores present in the cement–laterite interlocking blocks. Therefore, it can be concluded that the sand replacement interlocking laterite blocks have the potential of supporting the affordable housing concept in Ghana. The study recommends 5% sand replacement of laterite in producing cement–laterite interlocking blocks.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In the world today, there are some basic necessities one cannot live without such as food, clothing and shelter. However, the cost of shelter takes the most part of one's income. In recent years, homeownership for the middle and low-income earners of the society is turning to be a mirage as building materials, construction costs and other factors have constantly put housing development at a very high cost. In developed countries, accommodation and homeownership are easier as governments and financial institutions have planned effective housing policies and programmes to aid the citizenry in homeownership at affordable rates (Adebakin et al., 2012). In the developing world, especially in metropolitan African cities, scarcity of living accommodation has always been an issue. According to Adebakin et al. (2012), the available housing stock is diminishing by the day due to the high level of rural drift to urban centers. Checking scarcity and high cost of building materials and the need to drastically reduce critical housing shortages, especially in the urban areas (and developing modern housing setups in the rural areas), have encouraged the search for alternative, innovative and cost-effective building materials. Aside from concrete that is a major component of buildings and other engineering structures, sandcrete blocks form a major part to be recognized and put under consideration. One of such local materials that are being researched is lateritic soil. Lateritic soil has been one of the major building materials in Ghana for a long time. The main reason lies on the fact that it is readily available and the cost of procuring it is relatively low.

Lateritic soil possesses other advantages which make it potentially a very good and appropriate material for construction, especially for the construction of rural structures in the developing countries. These merits include little or no specialized skilled labour required for laterized sandcrete blocks production and for its use in other construction works; and laterized concrete structures have potentially sufficient strength compared with that of normal concrete (Lasisi & Ogunjimi, 1984). Lateritic soils are essentially the products of tropical weathering usually found in areas where natural drainage is impeded (Lasisi& Osunade, 1984). Lasisi and Ogunjimi (1984) assert that the degree of laterization is estimated by the silica sesquioxides ratio (SiO_2/ (Fe_2O_3 + Al_2O_3)). Silica-Sesquioxide (S-S) ratios less than 1.33 are indicative of laterites, those between 1.33 and 2.00 are lateritic soils and those greater than 2.00 are non-lateritic types.

According to Akintorinwa et al. (2012), lateritic soil abounds locally and its use is mainly limited to civil engineering works like road construction and land fill operations. It is less utilised in the building industry except in filling works. In lieu of the abundance of lateritic soils and its availability, its optimum use in building production could positively affect the cost of buildings leading to the production of more affordable housing units (Joshua &Lawal, 2011). Its use in the building production is not yet generally accepted because there are no sufficient technical data on it, hence limiting its wider application in building construction work (Udoeyo et al., 2006). Studies by Adepegba (1975) and Osunade (2002) used lateritic soil in concrete production where laterite was made to partly or wholly replace conventional fine aggregate in the production of concrete known as laterized concrete; and in the production of brick units such as Compressed Laterized Brick (CLB) usuallystabilised with cement. Presently, these applications are mostly limited to buildings in rural areas and low income housing projects which are mostly situated at satellite areas (outskirts) of Central Business Areas (CBA's).

Laterite is described as a product of in-situ weathering in igneous, sedimentary, and metamorphic rocks commonly found under unsaturated conditions (Rahardjo et al., 2004). Lateritic soil is one of the most important and common materials used in earthwork engineering construction in the tropics and subtropics where it is in abundance. The name laterite was coined by an English surgeon Francis Buchanan in 1807 in India from a Latin word "later" meaning brick in the 19^{th} century (Thomas, 1996). He coined the term laterite when he wrote "What I have called indurated clay is one of the most valuable materials for building. It is diffused in immense masses, without any appearance of stratification and is placed over the granite that forms the basis of Malayala (Thomas, 1996).It is believed that this work will contribute to the few existing studies on the use of lateritic soil in building production. Laterite, such as particle size, Atterberg's limits, moisture content, grain size among others which in turns affect the strength of laterized products. (Middendorfet al., 2003). Different methods have been used in laterite stabilization in recent years, mechanical and chemical stabilization being the two most popular methods in operation all over the world. Laterite stabilization using mechanical approach involves blending of different grades of soils to obtain a desired standard.

These properties can however be improved through stabilization in order to improve the characteristics and strength. O'Flaherty (2002), Villar-Cocina *et al*. (2003) and Amu *et al*. (2011) described soil stabilization as any treatment applied to a soil to improve its strength.

However, earth brick/brick buildings have been built for thousands of years, and there is a strong tradition of earthen structures on the African Continent. Traditional mud huts were the most common form of building before the advent of modern architecture and planning. Earth brick or brick buildings still shelter more than a third of the world's population. Recently there has been a worldwide resurgence of interest in earth building, especially in developing countries where local earth is the most accessible source of building material. However, most soils do not contain the mix of clay, silt and sand required for good earth building (Roux & Alexander, 2007).

1.2 Statement of the Problem

Recently, the attention of most researchers is shifting towards the optimization of building materials by using local contents; the use of indigenous materials; and local industrial by-products unique and abundant in certain localities. This study therefore explored ways in which sand could be utilised in cement–laterite interlocking block production in Ghana. One of the early works on laterite was by Adepegba (1975) who compared the strength properties of normal concrete with those of laterized concrete. He found that concrete with laterite and fine sand can be used as a structural material in place of normal concrete. Osunade (2002) studied theeffect of replacement of lateritic soils with granite fines onthe compressive and tensile strengths of laterized concrete.Lasisi and Osunade(1984) investigated the effect of grain size on the strength of cubes made from lateritic soils. They established that for lateritic soils to be of economical use in the industry, the range of particle sizes used in moulding blocks must tend towards the silt fraction. Joshua et al., (2014) also investigated the effects of partial replacement of sand with lateritic soil in sandcrete blocks. There is however a limited empirical literature on the use of sand as a partial replacement of laterite to produce salancrete interlocking blocks. This study therefore fills this gap by investigating the effect of sand on the properties of cement- laterite interlocking blocks.

1.3 Aim

The aim of the study is to determine the effects of sand on the properties of cement-laterite interlocking blocks.

1.4 Specific Objectives

In other to achieve the aim of the study, the specific objectives are:

- To determine the density of cement-laterite interlocking blocks produced from sand as partial replacement of laterite.
- To determine the compressive strength of cement-laterite interlocking blocks produced from sand as partial replacement of laterite.
- To determine the tensile strength of cement-laterite interlocking blocks produced from sand as partial replacement of laterite.
- To determine the water absorption of cement-laterite interlocking blocks produced from sand as partial replacement of laterite.
- To determine the erosion resistance of cement-laterite interlocking blocks produced from sand as partial replacement of laterite.
- To determine the Energy Dispersive X-Ray Spectroscopy (EDS) and Scanning Electron Microcopy (SEM) of cement-laterite interlocking blocks produced from sand as partial replacement of laterite

1.5 Research Questions

- What is the density of cement-laterite interlocking blocks produced from sand as partial replacement of laterite?
- What is the compressive strength of cement-laterite interlocking blocks produced from sand as partial replacement of laterite?
- What is the tensile strength of cement-laterite interlocking blocks produced from sand as partial replacement of laterite?
- What is the water absorption of cement-laterite interlocking blocks produced from sand as partial replacement of laterite?
- What is the erosion resistance of cement-laterite interlocking blocks produced from sand as partial replacement of laterite?
- How can the Energy Dispersive X-Ray Spectroscopy (EDS) and Scanning Electron Microcopy (SEM) of cement-laterite interlocking blocks produced from sand as partial replacement of laterite be determined?

1.6 Significance of the Study

This study on the properties of cement-laterite interlocking blocks produced from sand as partial replacement of laterite will help in policy decision making and offer insight into the positive effects of the overall development of the materials for building. The findings of the study will inform local craftsmen and contractors, developers and policymakers on the effects of using local materials in building houses in the communities. Also, the outcome of the study will enlighten the stakeholders in the building industry on the way forward in enhancing sustainable and environmental friendly building materials which can reduce the cost of using modern technology of building. The findings of the study equally hope to inculcate in the society the spirit of using local materials in building durable and sustainable houses.

1.7 Scope of the Study

The study was done in the Sunyani Municipality using resources available to the municipality. The samples were moulded on the Sunyani Technical University Campus and taken to the laboratory for testing.

1.8 Limitation of the research

The study focused on using sand as partial replacement of laterite in the production of cement-laterite interlocking blocks and conducted test to obtain the properties.The research was delayed due to time, money, resources available and logistical constraints. The research was based on comparing the strength development of interlocking blocks produced from sand as partial replacement of laterite.

1.9 Organization of the Thesis

The thesis covers six chapters.

- Chapter One describes the introduction, problem statement, aim and objectives, scope of the study, research methods, structure of the project.
- Chapter Two discusses the literature review of the topic. It deals with both theoretical and empirical study of the research.
- Chapter Three captures the overview of the methodology, materials and the Procedures for experimental investigations.
- Chapter Four presents the test results and analysis from the experimental works.
- Chapter Five presents the discussions of the results.
- Chapter Six presents the summary, conclusion and recommendations made from the research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter looks at what other authors have written on the study. It contains the definitions and explanations of relevant issues to the study. It also discusses earth as a building material, thermal and mechanical properties of earth and interlocking blocks structure.

2.2 Earth

Earth has been one of the most economical and user-friendly local building material and it is the oldest building material, which is most commonly used for making shelter. Dethier (1986) and Coffman et al. (1990) discussed that nearly 30% of the total population of the world still reside in mud houses. It is one of the most popularly used building construction materials in Europe. Singh and Singh (2007) discuss that 55% of houses in India are constructed with mud walls. Earth is the most preferred building material for providing shelter for people, especially in less economically developed countries as discussed by Danso et al. (2015). As for Gidigasu (1976), it was locally used by the natives as brick for building and hence he named it laterite from a Latin word "later", meaning brick.

The discussion on social, economic and environmental benefits associated with the use of earth reveals that when soil is used as raw material on site both the financial and environmental impact of the constructions are significantly reduced. Ease of use of earth and associated building techniques can help employ even the unskilled labor. This would enhance self-help technology among rural people eliminating the need for costly transportation of labor, material and equipment from other places.

This diverse use of earth depends upon climatic factors, topography and living requirements of inhabitants of the area. While the use of unbaked earth in shelter construction dates back to over a thousand years as discussed by Minke (2001). Research by Falceto et al. (2012) discusses worldwide durability tests in Spain regarding compressed earth blocks. The study discusses that different terminologies used in literature in this context like earth blocks as compressed earth blocks, cement stabilized earth blocks, compressed stabilized earth blocks, soil–cement blocks all refer to the use of the same product, that is earth blocks (without reinforcement). Similarly, document by CRATerre (CRATerre-EAGC, 1998) states that compressed earth blocks comprise different varieties with or without stabilization. AENOR (2008) discusses compressed earth blocks used for the construction of walls and partitions highlighting their benefits overuse of raw earth blocks as adobe. ASTM standards provide a set of guidelines for the design of buildings involving use of varied forms of earth (ASTM Standard guide, 2010).

2.2.1 Thermal and mechanical properties of earth

Galan et al., (2010); Ogunyeand Boussabaine (2002); Hall (2007); Ola (1990) and Walker (2004) involved in different experimental investigations give a comparative analysis of properties of earth products before and after modifications. Studies by Ogunye and Boussabaine (2002), Mbumbia and Tirlocq (2000), Ola (1990), Obonyo and Baskaran (2010), Donkor and Obonyo (2015), Villamizar et al. (2012), Prasad et al. (2012) andYetimoglu et al. (2005) all ascertain considerable improvement in mechanical and physical properties of soil after treatment. Given the advantages of thermal comfort (Taylor & Luther, 2004), heat and sound insulation (Binici et al., 2009;Acosta et al., 2010), local material availability, local employment criteria (Morel et al., 2001), minimal impact on environment (John et al., 2005) and easy repair and maintenance of adobe structures (Turanli & Erdogan, 1996), earth has remained a frequently used building and construction material. Research studies (Goodhew & Griffiths, 2005; Hall & Djerbib, 2004) have shown that thermal, acoustic and fire-resistant properties of earth materials are very high and the addition of fibrous material to adobe further enhances its thermal conductivity thereby increasing heat savings in the buildings. Research studies by Reddy (2012), Quagliarini et al. (2015) and Kinuthia (2015) discuss the energy efficiency and low embodied energy aspects of earth as building material. Considering all these advantages and popularity of earth material for construction of shelter many countries have framed legal regulations and codes dictating the use of earth in varied forms as discussed by Torgal and Jalali (2012). Research discusses at length codes and regulations of countries like New Zealand, Australia, Zimbabwe, New Mexico, Germany, Spain, Brazil, and France regarding the use of earth. These regulations also give design and planning guidelines involving the use of earth for various construction purposes for maximizing benefits from earth shelters.

2.2.2 Limitations in the use of earth

The use of earth suffers from certain drawbacks as well discussed by Heathcote (1995), Guettala et al. (2006) and Ren and Kagi (1995). These have been identified mainly as with less durability and low compressive strength of which low durability has been seen as a very prominent factor affecting the use of earth. Study by Degirmenci (2008) shows that adobe has poor mechanical properties in terms of compressive strength and durability in addition to poor resistance to moisture and water attack. Opposing climatic conditions produce deteriorating effects on mud shelters as reported by Bengtsson and Whitaker (1986) and Reman (2004). Rainwater erodes mud walls and the severity of rainfall even leads to their collapse. Frequent exposure of mud walls to water leads to the absorption of water in the walls which results in their swelling and upon evaporation during drying, shrinkage occurs. It produces structural and surface cracks in mud walls in addition to surface erosion as discussed by Heathcote (1995) and Frencham (1982).

2.3 Laterite

Laterite is described as a product of in-situ weathering in igneous, sedimentary, and metamorphic rocks commonly found under unsaturated conditions (Rahardjo et al., 2004). Lateritic soil is one of the most important and common materials used in earth work engineering construction in the tropics and subtropics where it is in abundance. The name laterite was coined by an English surgeon Francis Buchanan in 1807 in India from a Latin word "later" meaning brick in the 19^{th} century (Thomas, 1996). He coined the term laterite when he wrote "What I have called indurated clay is one of the most valuable materials for building. It is diffused in immense masses, without any appearance of stratification and is placed over the granite that forms the basis of Malayala. It is full of cavities and pores, and contains a very large quantity of iron in the form of yellow and red ochres" (Thomas, 1996). In the mass, while excluded from the air, it is so soft, that any iron instrument readily cuts it, and is dug up in square masses with a pick-axe, and immediately cut into the shape wanted with a trowel, or large knife. It very soon becomes as hard as brick, and resists the air and water much better as compare to other bricks. There is a tendency to apply the term to any red soil and rock in the tropics (Abebaw, 2005). Laterite soils are formed in situ from the intense weathering of parent material, whether primary or sedimentary, in the tropical and sub-tropical climate environment. This weathering process primarily involves the progressive chemical alteration of primary minerals, the release of iron and aluminum sesquioxides, increasing loss of silica and the increasing dominance of new clay materials (such as smectites, allophones, halloy site, and as weathering progresses, kaolinite)formed from dissolved materials (Northmore et al, 1992).

Tuncer and Lohnes (1977) described the genesis of laterite as the weathering process which involves leaching of silica, formation of colloidal sesquioxides, and precipitation of the oxides with increasing crystallinity and dehydration as the soil is weathered. The three major processes of weathering are the physical, chemical and biological processes. The physical weathering is pre-dominant in the dry climates while the extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature (Abebaw, 2005). As the disintegration of underlying rocks occurs, the primary elements are broken down by the processes of physical and chemical weathering to simple ionic form. The silica and bases in the weathered material such as sodium, potassium, calcium magnesium etc. are washed out by the percolated rain water (vadose water) and oxides and hydroxides of sesquioxides are accumulated thereby enriching the soil and giving the soil its typical red colour (Abebaw, 2005). This process is called laterization and it depends on the nature and extent of chemical weathering. Laterization is a gradual process which must be active for centuries. In tropical countries, the “vadose waters” are also at a higher temperature, than in the colder climates and they contain more carbonic acid, alkaline carbonates, organic matters, etc. These elements explain why rocks that are leached by the “vadose waters” in the tropics are more rapidly altered and also why laterite is much more commonly seen in tropical countries than in the colder ones (Abebaw, 2005). After weathering, dehydration occurs. Dehydration (either partial or complete) alters the composition and distribution of the sesquioxide rich materials in a manner which is generally not reversible over wetting (Abebaw, 2005). It leads to the formation of strongly cemented soils with a unique granular soils structure. The topography and drainage of an area also influences the rate of weathering because to some extent, it determines the amount of water available for laterization to occur and the rate at which it moves through the weathering zone. It controls the rate at which the weathered material is eroded. Deep weathering cannot occur on steep slopes. This is because the surface run-off on steep slopes is greater than the rate of infiltration thereby increasing the rate of erosion.

Hence, lateritic gravels tend to be found on slopes (sometimes locally termed ridge gravels), to a lesser extent on uplands and not in low poorly drained areas (Jiregna, 2008). The structure of Lateritic soil varies with the type of parent rock from which it was formed, the location (i.e. where it was formed), and also on the weathering process that lead to its formation. Studies in some lateritic soils show that they have a porous granular structure consisting of iron impregnated clayey material in minute spherical aggregation (Mahalinga-Iyer & Williams, 1997). The aggregation derives its strength from the thin film found within the micro-joints of the elementary clay particles, which in addition coats the particles (Gidigasu, 1988). Thus the thin film found within the micro joints of the elementary clay particles and as coatings over particles provides the strength of the aggregation.

Viewing carefully prepared thin sections of laterite under the optical microscope has shown that these soils contain rough materials with sizes tending from silt to fine sand spread throughout the soil with very finely-divided iron oxides, and a porous structure of peds or clayclusters which are usually not cemented by coatings of iron oxide but rather, they are weakly bonded. The surface of laterite soil initially exists as a gelatinous coating. After losing moisture, it becomes denser but retains its non-crystalline structure after which it crystalizes slowly into different forms, which gives them strongly cemented surfaces covered by iron oxides (Sergeyev et al., 1978). The structural development depends on the deposition of iron oxides at different stages of the weathering process (Malomo, 1989). Field and laboratory studies have shown that residual soils consist of different zones of weathering with differing morphological, physical, and geotechnical characteristics; and vary for different locations due to the heterogeneous nature and highly variable degree of weathering (Adekoya, 1987 and Rahardjo, 2004). The study of parent rock factor on the engineering properties of lateritic soils developed over different rock types can be determined by keeping other factors constant. These parent materials are of importance in the early stages of weathering since they supply the starting material (Bayewu et al., 2012).

Research has shown that laterite soils possess very favourable geotechnical properties, and this is evident in the widespread use of the materials in the construction industry (Ikiensinma 2005). The geotechnical properties of laterite are very much affected by compaction. Before using this soil for any construction purpose, the soil has to undergo some stabilization process so as to avoid failure or collapse or failure of the construction work. Unlike other soil types, the properties of laterite vary from region to region. The physical properties of residual soils, commonly known as the index properties, vary from region to region due to the heterogeneous nature and highly variable degree of weathering controlled by regional climatic and topographic conditions, and the nature of bedrock, (Nnadi, 1988). It also varies with the depth of the soil and can be determined by simple laboratory tests. Studies on the effect of weathering on the physical properties of laterite soil by Tuncer and Lohnes (1977) and Rahardjo et al., (2004) have revealed the following;

- Pore-size distribution varies with the degree of weathering.
- Higher pore volume and larger range of pore-size distribution indicates advancement in the weathering stage.
- Soil classification and Atterberg limits do not show any correlation to weathering.
- High specific gravity is a good indication of advanced degree of weathering.
- Soil aggregation increases with increasing weathering.

Lateritic soils are one of important soils and are widespread in tropical areas and subtropical climates. They are the most highly weathered soils in the classification system. Lateritic soils in Taiwan are mostly classified into ultisols and alfisols and cover about 25 percent of the cultivation lands. The significant features of the lateritic soils are their unique color, poor fertility, and high clay content and lower cation exchange capacity. In addition, lateritic soils possess a great amount of iron and aluminum oxides (Shaw, 2001). Iron oxides, existing mainly in the amorphous and crystalline inorganic forms, are one of major components in many soil orders. a series of soil samples including alfisol, inceptisol, entisol, and ultisol were used to test their H_2S removal efficiency from hot coal gas. Experimental results showed that the ultisols have the best removal efficiency among all soil samples. Additionally, the contents of total free iron have been confirmed as the major component to affect overall removal efficiency.

It is very important to understand the detailed properties of lateritic soils when they are going to be a commercial product for industrial application. Based on the previous study, it is believed that the Tamshui and Tungwei lateritic soils are the best candidates for industrial application because of the presence of magnetite and maghemite, which are two types of iron oxides that have excellent thermodynamic sulfurization compared to other iron oxides (Ko, 2008, Ko et al., 2006). Parent material is a key factor affecting the iron and mineral composition and distribution for lateritic soils. (Anda et al., (2008) reported a series of oxisols derived from serpentinite, basalt, and andesite and found that the content of iron oxides has an obvious different distribution. Approximately 19% of iron oxide was determined for the lateritic soils derived from serpentinite. Different parent materials also bring the different physical and chemical properties.

2.3.1 Chemical Composition of Laterite

However, Mbumbia, Wilmarsa, and Tirlocq, (2000) was the first to describe and named a laterite formation in southern India. He named it laterite from the Latin word “later”, which means a brick; this highly compacted and cemented soil can easily be cut into brick-shaped blocks for building. The word laterite has been used for variably cemented, sesquioxide-rich soil horizons. A sesquioxide is an oxide with three atoms of oxygen and two metal atoms. It has also been used for any reddish soil at or near the Earth's surface. The chemical composition of laterite can be shown in table 2.1.

Table 2.1: Chemical composition of Laterite

Soil Texture	% Sand	% Clay	% Silt
Loamy sand	70-85	0-15	0-30
Sandy loam	50-70	15-20	0-30
Sandy clay loam	50-70	20-30	0-30

Source: Vessely (2004)

Moreover, the word "laterite" has been derived from the Latin word "later" meaning brick (Gidigasu, 1976). Laterite is an unusual soil which is rich in iron and alumina. Laterite occurs in tropical humid regions within 30N and 30S of the Equator and these regions belong to less developed areas in economic and scientific terms. Laterite and laterite soils have been efficiently utilized in civil engineering applications like road base and low-cost housing (UN-HABITAT, 2009). Laterite cannot be placed in the triplet family of rocks, namely igneous, sedimentary or metamorphic. It is considered as metasomatic rock (Kasthurba & Santhanam, 2007). Additionally, metasomatism is a metamorphic process by which the chemical composition of a rock or rock portion is altered in a pervasive manner which involves the introduction and/or removal of chemical components as a result of the interaction of the rock with aqueous fluids (solutions). During metasomatism, the rock remains in a solid-state. They are usually found in heavy rainfall regions formed by intensive and long-lasting weathering. Silica in the clay is usually leached out over a long period of time leaving the residual soil rich in iron oxides, hydroxides and alumina.

When lateritic soils are exposed to atmosphere, the iron hydroxides lose the moisture quickly to form iron oxides, which develop a good bond with other particles in soil to form the laterite blocks. This process of irreversible surface hardening known as induration is due to oxidation as a result of exposure to the atmosphere. The progressive strengthening was due to mineral transformation from goethite to hematite which is a more stabilized form. Laterite covers are thick in the stable areas of the Western Ethiopian Shield, concretions of the South American Plate, and on the Australian Shield, (Tardy & Yves, 1997). Tardy and Yves (1997) added that laterites can either be soft or easily broken into smaller pieces, or firm and physically resistant. The basement rocks are buried under the thick weathered layer and rarely exposed.

Beside, Tardy and Yves (1997), from the French Institute National Polytechnique de Toulouse and the Centre National de la Recherche Scientifique, calculated that laterites cover about one-third of the Earth's continental land area. Lateritic soils are the subsoils of the equatorial forests, of the savannas of the humid tropical regions, and of the Sahelian steppes. They cover most of the land area between the tropics of Cancer and Capricorn in which Ghana is located. Additionally, areas not covered within these latitudes include the extreme western portion of South America, the southwestern portion of Africa, the desert regions of north-central Africa, the Arabian Peninsula and the interior of Australia.

Moreover, some of the oldest and most highly deformed ultramafic rocks which underwent lateralization are found in the complex Precambrian shields in Brazil and Australia. But smaller highly deformed Alpine-type intrusive have formed laterite profiles in Guatemala, Colombia, Central Europe, India and Burma, (Dalv et al., 2004). Laterites reflect past weathering conditions (Helgren et al., 1977). Laterites which are found in present-day non-tropical areas are products of former geological epochs when that area was near the equator. Present-day laterites occurring outside the humid tropics are considered to be indicators of climatic change, continental drift or a combination of both (Bourman, 1993).

According to Tardy and Yves (1997), ores are concentrated in metalliferous laterites; aluminum is found in bauxites, iron and manganese are found in iron-rich hard crusts, nickel and copper are found in disintegrated rocks, and gold is found in mottled clays.

However, formation of lateritic bauxites occurs world-wide in the 145- to 2-million-year-old Cretaceous and Tertiary coastal plains (Valeton, 1983). The bauxites form elongate belts, sometimes hundreds of kilometers long, parallel to Lower Tertiary shorelines in India and South America; their distribution is not related to a particular mineralogical composition of the parent rock (Valeton, 1983). The basaltic laterites of Northern Ireland were formed by extensive chemical weathering of basalts during a period of volcanic activity (Hill et al., 2000). Also, they reach a maximum thickness of 30m (100ft) and once provided a major source of iron and aluminum ore. Hill et al. (2000) added that, percolating water caused degradation of the parent basalt and preferential precipitation by acidic water through the lattice left the iron and aluminum ores *but* primary olivine, plagioclasefeldspar and augite were successively broken down and replaced by a mineral assemblage consisting of hematite, gibbsite, goethite, anatase, halloysite and kaolinite.

Moreover, laterite ores were the major source of early nickel and rich laterite deposits in New Caledonia were mined starting the end of the 19th century to produce white metal (Dalvi et al., 2004). Dalvi et al (2004) added that about 70% of the Earth's land-based nickel resources are contained in laterites; they currently account for about 40% of the world's nickel production. In 1950 laterite-source nickel was less than 10% of total production. In 2003 it accounted for 42%, and by 2012 the share of laterite-source nickel was expected to be 51%.The four main areas in the world with the largest nickel laterite resources are New Caledonia, with 21%; Australia, with 20%; the Philippines, with 17%; and Indonesia, with 12%, (Dalvi et al, 2004).

2.3.2 Physical Properties of Laterite

The colours can vary from ochre through red, brown, violet to black, depending largely on the concentration of iron oxides (Mbumbia, Wilmarsa, and Tirlocq, 2000). The darker the laterite, the harder, heavier and more resistant to moisture it is. Fresh laterites are generally reddish or orange in colour. Upon exposed to continuous weathering, changes of chemical compound of the laterite soil will then lead to colour change. A colour change indicates the degree of maturity and is due to the various degrees of iron, titanium and manganese hydration.

Laterite has specific gravity ranges from 2.9 to 4.4, which is greater than granite's specific gravity around 2.7. Laterite's absorption properties are around 3 to 9 % but granite absorption properties are less than 0.6 *%.* When comparing Aggregate Impact Value (AIV) of laterite and granite, granite has lower AIV in dry and wet state. The Aggregate Impact Value of laterite aggregate in wet condition is between 30 to 44% and in dry condition AIV is between *25* to 49 %. Moreover, the abrasion of granite is smaller than the abrasion of laterite which is between 3.5 to 20% (Mbumbia, Wilmarsa, and Tirlocq, 2000).

2.4 The Interlocking Block System

Interlocking blocks are different from conventional bricks since they do not require mortar to be laid. The blocks are just laid dry and locked into place. As a result of this characteristic, the process of building walls is faster and requires less skilled labour. Laying the first course in the mortar bed requires that care is taken to ensure that blocks are perfectly horizontal and in a straight line or at right angle corners. Once the base is properly laid, the blocks are stacked dry with the help of a wooden rubber hammer to knock the blocks gently in place (Nasly & Yasin, 2009).

According to a UN-HABITAT (2009) report titled interlocking Stabilized Soil Blocks: Appropriate Earth Technologies in Uganda, ISSB is a more cost effective, and quality block compared to the fired bricks. In addition, this technology can be said to be environmentally green, appropriate to a number of environments, and uses the locally available materials (UN-HABITAT, 2009).This technology uses soil as the major ingredient, with a little of cement as a stabilizer.

2.5 Compressed Earth Block-Interlocking Block

The interlocking dry-stack block system was tested by Pave (2007). A complete testing program achieved values for compressive strength and flexural strength for the interlocking blocks. Interlocking blocks are solid, compressed earth blocks that do allow for reinforcement parallel to the bed joint. The blocks form a shape that is pictured in Figure 2.1, where two edges of the blocks are lowered, to form a dry-stacked, interlocking pattern. The tested compressive strength of a single interlocking block, with 5% cement content was found to be 3.0 MPa. The masonry compressive strength, as determined by prism testing was found to be 1.1 MPa for blocks with 5% cement content.

Figure 2.1: Interlocking Blocks
Source: (Pave, 2007)

For the flexural strength tests, Pave (2007) decided to use composite beams made of reinforced concrete and dry stacked masonry. Multiple beams with 6 mm steel bar reinforcing were tested with different sizes and cross sections. Each beam was tested with loading perpendicular to the bed joints of the blocks, meaning the beams were tested across their minor axis (see Figure 2.1). The tests showed that the concrete-masonry beams were able to behave with composite action under flexural loading. A blocks was tested without concrete, as shown in Figure 2.1, and showed excessive deflections in the masonry. It should be noted that the interlocking block system does not have vertical grout holes or wide horizontal grout channels to resist this out-of-plane loading. Three out of the four beams tested did not meet the theoretical load capacity during experimentation. However, there were instances of shear cracks that could not be investigated completely at that time. Pave, (2007) recommended that the shear resistance of the dry-stack system should be heavily investigated.


Figure 2.2: Example of Cracking Pattern and Loading
Source: (Pave, 2007)

2.5.1 Benefits of Interlocking Stabilized Soil Blocks

The technology has helped millions of low income earners across the globe to own a decent house (UN-HABITAT, 2009) due to reduced labor costs and construction time. The technology has employed both semi-skilled and unskilled masons, and also supports the local small entrepreneurs. As green construction technology, it saves millions of trees, millions of tonnes of Carbon monoxide and reuses waste materials like quarry dust. The technology has been proven to produce neat, quality and aesthetically attractive block finishes says the UN-HABITAT (2009) report. The blocks are strong and several studies have proved that they are fire and bullet resistant UN-HABITAT (2009).

2.5.2 Towards Low-cost Housing

Interlocking soil-cement blocks allow for the quick and cost-efficient construction of housing units and other buildings. Tucker (2009), international sales manager at interlocking says that using interlocking blocks have numerous benefits, especially for companies operating on the African and Asia continents. One of the advantages of interlocking blocks is they are low in cost, interlocking block making machines only use three inputs, namely soil that can be sourced on-site, a small amount of cement that provides stability to blocks and water. As a result, the machines are ideal for sites where transport costs for cement and sand are high.

2.5.3 Wastes in Construction

A number of non-value adding activities are associated with design and construction processes resulting in waste generation. Majority of these wasteful activities consume time and effort without value generation to clients. As a result of this situation, managers of construction activities at the start of construction projects have to deal with many factors that may negatively affect construction processes producing different types of waste (Serpell et al., 1995). Waste here refers to both the incidence of material losses and the execution of unnecessary work that generates additional costs but does not add value to the construction product (Koskela, 1992).

In the construction and manufacturing industry, waste include among others, delay times, quality costs, lack of safety, rework, unnecessary transportation, long distances, improper choice of management, methods or equipment as well as poor constructability (Alarcon, 1993; Ishiwata,1997; Koskela, 1992 and Serpell et al., 1995). Formoso et al. (1999) went on to propose their main classification of waste in construction as overproduction, unwarranted substitution, waiting time, transportation, processing, inventories, movement and defective products.

Ohno (1988), who articulated the lean production philosophy and implemented it in Toyota's production system, classified sources of waste as follows: defects in products, over-production of goods not needed, inventories of goods awaiting further processing or consumption, unnecessary processing, unnecessary movement of people, unnecessary transport of goods, waiting by employees for process equipment to finish its work or for an upstream activity to complete. An eighth category of waste was added by Womack and Jones (1996) as the design of goods and services that fail to meet user's needs.

2.5.4 Workflow in Construction

The view of flow in production, proposed by Bertelsen, (2004) has in scientific terms, provided the basis for Just in Time (JIT) and lean production. In the concept of flow, production is viewed as a flow whereby in addition to transformation activities, there are no transformation activities like waiting, inspection and movement. Production management therefore involves reducing the share of non-transformation steps of production flow, especially by reducing variability. In this respect the flow model looks beyond transformation activities by taking non-transformation activities into account in order to improve flow efficiency (Bertelsen, 2004).

The concept of lean thinking in construction, apart from focusing on a systematic elimination of waste, also involves the implementation of the concepts of continuous flow and customer pull (Kotelnikov, 2007). Howell (1999) also identifies organising production as a continuous flow as one of the core concepts of lean production. Improving workflow reliability, according to Ballard (1999), is important for the productivity of linked production units, and consequently for project cost and duration. Continuous workflow ensures steady production rates that eliminate the chaos of fragmented stop-and-go production processes (Caldeira, 1999).

The nature of production in construction is assembly-type, in which case different material flows are connected to the end product. Koskela (2000) suggested three types of flows in construction. The first type is material flow which involves transportation of components to the site for installation. The second type is location flow whereby one particular trade goes through the different parts of the building or construction site to get work done. The third type is assembly flow involving the sequence of works of assembly and installation.

2.5.5 Speed of Wall Construction

Speedy delivery of value is very important in ensuring a lean project delivery of construction products. "Lean" is doing more with less: less time among others (Kotelnikov, 2007). The delivery of construction products on time, apart from contributing to a reduction in the cost of construction, also enhances value to clients. The results of the study indicate that the pace of wall construction using the interlocking blocks is far more than using the sandcrete block. The elimination of non-value steps like spreading mortar, leveling, vertical mortar jointing and dressing of joints significantly reduces the cycle time of bonding blocks thus increasing the speed of wall construction.

Much time is devoted to the interlocking block system for the construction of the first course to ensure near-perfect alignment and proper coordination of block units in subsequent courses. Once the first course is properly laid, the building of the subsequent courses simply involves packing the blocks to interlock. This eliminates the chaos of disjointed stop-and-go production processes associated with the sandcrete blocks and rather focuses on fast cycle times to ensure reliable and continuous workflow. Generally, less than half the time that is used to erect a wall using the sandcrete block is required to erect a similar wall using the interlocking block (Zoya et al., 2012).Although the majority of the experiences of their use in construction is as a target in fired clay materials (UN-HABITAT, 2009) other authors have demonstrated the possibility of using them in the production of pozzolanic materials (Cyr et al., 2007; Liu et al., 2011).

2.5.6 Why Interlocking Blocks?

Tucker (2009) says that using interlocking blocks have numerous benefits, especially for companies operating on the African continent.

- One of the advantages of interlocking blocks is that they can be dry-stacked with no mortar. “This greatly increases the speed of construction,” he says.
- It has been extensively tested for structural strength and durability, as well as for fire, rain and sound resistance.
- Interlocking Block making machines only use three inputs, namely soil that can be sourced on-site, a small amount of cement that provides stability to the blocks, and water. As a result, the machines are ideal for sites where transport costs for cement and sand are high. They are also an eco-friendly, cost-saving alternative to conventional vibration machines. Interlocking machines are available in diesel or electrical options. Depending on the model, the machines have the capacity to produce between 1,500 and 3,000 blocks per eight-hour shift.
- The machines are relatively labour intensive, requiring about six operators. Tucker (2009) says that for most companies and governments this is an advantage because it creates employment opportunities and allows for skills transfer.

- According to Tucker (2009), the company's technology is particularly popular in Africa's mining industry, where entire communities often have to be relocated to make way for new mines.
- Hydraform also provides full training on using its machines as well as building techniques for interlocking blocks. "We offer training programmes both here in South Africa and on-site across the continent. Our technicians would give workers training on operating the machines as well as maintenance. The machines are relatively easy to use and people normally learn quite quickly (Tucker 2009)."
- Tucker notes that although Africa is currently the company's biggest market, its machines are being used extensively throughout the world, including South America, Central America, the US, Eastern Europe and India. Hydraform also has French-speaking sales and training staff.
- Interlocking blocks – a cost-effective building solution for Africa
- Interlocking soil-cement blocks allow for the quick and cost-efficient construction of housing units and other buildings. South Africa-based interlocking block making Machines are currently being used across Africa by property developers, entrepreneurs, governments and NGOs.
- A building constructed using interlocking blocks.
- One company that is benefitting from interlocking blocks technology is Malawi's Hydra Homes Ltd. Formed in 2009 by a British Chartered Civil Engineer; the company has over 200 employees engaged in construction projects around Malawi.

- An engineering team that can offer simple advice on projects or develop full technical drawings for developments for planning and construction (Bansal, 2010).

The interlocking building system replaces conventional bricks and mortar through the use of interlocking blocks, which are interlocking and can be dry-stacked. The other components of the conventional building system remain unchanged. These blocks can be made on the construction sites or at block yard using interlocking block making machines. Today the interlocking building system and the machines are used in over 50 countries worldwide. These blocks – bricks can be made with local soil and cement or Fly ash (burnt coal ash) and cement. Hydraform has a range of interlocking block making machines, mixers to suit client requirements. Machines can also make conventional brick and other block sizes to suit requirement by changing the moulds. Technical assistance and training is available (Zoya et al., 2012). The following are advantages of using interlocking blocks.

1. High-Quality Product
2. Environment-Friendly – No burning of bricks required
3. Option to Use Waste materials/Fly Ash/Marble Slurry/Concrete mix with chips up to 6mm
4. Minimum mortar required
5. Independence to make at site of construction
6. Training and technical support
7. International proven product used in more than 50 countries
8. Can be used without plastering
9. Lighter than conventional masonry
10. Suitable for earthquake-resistant construction

11. Local/Unskilled labour can be constructed Conduits/Plumbing possible (Hydraform India, 2008).

2.6 The Material Composition of Interlocking Blocks

2.6.1 Laterite

Different kinds of materials are used for the design and construction of walls in buildings including sand, laterite, timber, glass, plastic etc. in Ghana. Laterite forms a greater percentage of the land surface or soil composition in the country and hence is more available and less expensive than any of the above-mentioned building materials. It is estimated that about seventy percent of the land surface of Ghana is covered by laterite (Gidigasu; 2005).

Irrespective of this abundance of laterite soils, Darko (2007) confirms an earlier research by Andam (2004) saying that 90% of urban housing is built with sandcrete blocks derived mainly from sand and cement. Sand is also used for several other critical activities in the housing construction process including concreting, plastering of walls, laying of blocks in walls and floor screeding, activities which cannot be achieved without the use of sand.

Despite the widespread application of sand in the process of housing construction sandcrete block continues to be the most dominant material used as a building unit for the formation of walls in urban housing delivery in Ghana. The excessive use of sand in the construction industry has led to land degradation in the few areas where sand deposites occur since identifiable deposits are usually completely exhausted before moving on to locate new ones. This usually leads to the creation of pools of stagnant water serve as bleeding places for malaria and other water-borne diseases. Sand resources in environment therefore face an imminent depletion as a result of over-exploitation construction activities.

With regard to materials used in producing walling units for buildings, laterite may be more economical and accessible material in Ghana than any other material, yet it has not received the needed attention in the modern building industry. It has generically been applied as a material for hardcore filling for building foundations as well as base and sub-base material for road construction due to its good natural cementitious properties which make it set quite naturally (Fales, 1991).

The use of laterite as a material for walling in the building industry has been limited to the production of landcrete blocks (laterite plus cement), adobe blocks, atakpami and wattle-and-daub (earth walls for laterite without cement) technologies, all for rural housing. Landcrete building block, although could be as suitable as sandcrete block if treated professionally, has been relegated to the background since people associate it with rural housing as a result of its reddish colouration which likens it to adobe blocks (Gooding & Thomas, 1995). Earth walls also exhibit low cohesion with sand-cement plaster, as the plaster usually peels-off from a wall produced from them over a long period as a result of the differential thermal properties of the rather soft material as against the hard sand-cement plaster (Gidigasu, 2005). These perceptions have rendered laterite an unattractive material for walling production.

However, due to its abundance, unique engineering properties and relatively low cost compared to sand, the material has the potential of becoming a very significant input in affordable housing delivery for urban dwellers. This potential could be unraveled if further research is carried on it, especially by blending it with sand to produce a hybrid material for building block manufacture.

This prospect is affirmed by the good performance of interlocking blocks, a South-Africa technology that uses a mixture of laterite, marginal amount of sand and cement to produce building block units for affordable and durable housing for both rural and urban dwellers. The technology produces high-strength building block units of compressive strength in the order of 5 to 10N/mm^2 using 5 to 10% cement content (Hydraform India, 2008) in contrast with the relatively low-compressive-strength sandcrete blocks of the order 0.3-1N/mm^2 normally applied in the building industry of Ghana (Andam, 2004). Gidigasu (2005) has also indicated that depending on the plasticity of lateritic soil, an amount of sand stabilization could be done to improve the grading of the soil to achieve high strength blocks with a minimum amount of binder content when producing landcrete blocks for low-cost housing.

The difficulty of transporting sand over long distances for building purposes, the excessive exploitation and depletion of sand deposits in Ghana as well as the exorbitant cost of sandcrete blocks as a result of the relative high cost of sand indicate that lateritic materials should be employed in the building industry to produce affordable and sustainable construction in Ghana.

2.6.2 Sand

Sand is a granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e., a soil containing more than 85 percent sand-sized particles by mass. The composition of sand varies, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO_2), usually in the form of quartz. The second most common type of sand is calcium carbonate, for example, aragonite, which has mostly been created, over the past half billion years, by various forms of life, like coral and shellfish. For example, it is the primary form of sand apparent in areas where reefs have dominated the ecosystem for millions of years like the Caribbean. Sand is a non-renewable resource over human timescales, and sand suitable for making concrete is in high demand. Desert sand, although plentiful, is not suitable for concrete and 50 billion tons of beach sand and fossil sand is needed each year for construction (Madhav, 2017).

2.6.3 Cement

As a stabilising material cement is well researched, well understood and its properties clearly defined, (Akroyd, 2018; Popovics, 1998; United Nations, 1972). Portland cement is readily available in most urban areas, and usually available in semi-urban areas, it is one of the major components for any building construction. Earlier studies have shown that cement is a suitable stabilizer for use with soil in the production of CSSB, (International labour Office, 1987). 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 C_3S and C_2S in the cement literature (Akroyd, 2018; Lea, 1970; Neville, 1995). The chemical reaction eventually generates a matrix of interlocking crystals that cover any inert filler i.e. (aggregates) and provide a high compressive strength and stability. The basic mechanism is friction of point contacts between the particles taking place at a microscopic level. The duration time for this reaction to take place is not precisely defined. There is however the definition of the 'critical time'' after which further working of the mix causes breaking of the crystals that have formed but before the total matrix has gained strength.

2.6.4 Water

Water must be clean and should not contain any harmful quantities of acid, alkalis, salts, sugar or any other organic or chemical material. Any organic material in water will prevent the cement from setting. Chemicals and impurities could also affect the strength of the end product. Potable water is normally satisfactory.

2.7 Comparisons with Interlocking Blocks

Interlocking blocks are different from conventional bricks since they do not require mortar to be laid. The blocks are just laid dry and locked into place. As a result of this characteristic, the process of building walls is faster and requires less skilled labour. Laying the first course in the mortar bed requires that care is taken to ensure that blocks are perfectly horizontal and in a straight line or at right angle corners. Once the base is properly laid, the blocks are stacked dry with the help of a wooden rubber hammer to knock the blocks gently in place (Nasly & Yasin, 2009).

The interlocking block masonry is one building system which almost fulfils all such requirements of sustainability masonry as use of locally available resources (materials and labour), cost-effectiveness, eco-friendly, easy to adopt, faster to build and energy efficient. Interlocking dry stacked interlocking block system enables aesthetic affordable buildings as well as speedy construction of high quality walls in stretcher bond (Bansal, 2010). The interlocking stabilised soil block technology is affordable, environmentally sound, user friendly, versatile in use among others (UN-HABITAT, 2009).

Almost any type of building can be constructed with interlocking blocks. The main design constraints according to Nasly and Yassin (2009) are however that the plan should be rectangular and all wall dimensions and openings must be multiples of the width of the block used. All other principles of design and construction such as dimensioning of foundations, protection against rain and ground moisture, ceiling and roof construction and the like, are the same as for other standard building types.

The concept of inter locking blocks is based on the following principles:

i. The blocks are shaped with protruding parts which fit exactly into recess parts in the blocks placed above such that they are automatically aligned horizontally and vertically (Figures 2.3 and 2.4). This makes brick laying possible without specialised skills.
ii. Since blocks can be laid dry, no mortar is required and a considerable amount of cement is saved.

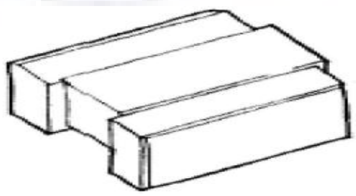

Figure 2.3: Interlocking Block (Bansal, 2010)

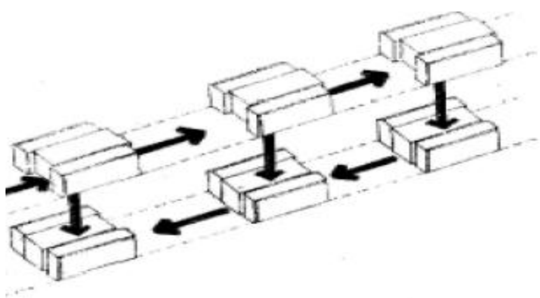

Figure 2.4: Placing of Interlocking Block (Bansal, 2010)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The materials and method employed in the production and testing of the cement-laterite interlocking blocks are discussed below.

3.2 Materials

3.2.1 Sand

The sand was obtained from Chiraa in Sunyani, and was prepared according to the standards specified by British Standard Institution (BS EN 12620:2002+A1:2008). After procurement, the sand was first of all air dried to constant weight in theBuilding Department Workshop at Sunyani Technical University, as illustrated in Figure 3.1.

Figure 3.1: Sand which was used for moulding interlocking blocks

3.2.2 Cement

As a binding material cement is well researched, well accepted and its properties clearly defined (Gooding and Thomas 1995). Portland cement is readily available in almost all Urban and Semi-urban areas, it is one of the major components for any building construction. Earlier studies have shown that cement is a suitable stabilizer for use with soil in the production of Cement Stabilized Soil Block (CSSB) (Raheem et al,.2010). The cement used is ordinary Portland cement manufactured by Dangote Cement Company. The Cement with grade 42.5R is a fine mineral powder manufactured with very precise processes. Mixed with water, this powder converts into a paste that binds and hardens when submerged in water. Because the composition and greatness of the powder may vary, cement has different properties depending upon its composition. The ordinary Portland cement (OPC) was purchased from the open market and used for the specimen preparation and can be observed in Figure 3.2.

Figure 3.2: Dangote Cement was used as the binding agent

3.2.3 Laterite

Laterite used to mould the interlocking blocks was obtained from Koutokrom in Sunyani. The large lumps were crushed and sieved through ASTM sieveNo.8 (aperture2.36mm).The lateritic samples were reddish in colour as shown in Figure 3.3. The general properties of the laterite were determined by laboratory tests. These tests were conducted in accordance with British Standard specifications (BS1377-9:1990). Wet sieving and sedimentation were carried out to determine the grain-size distribution of the laterite with different sizes of sieves in the Sunyani Highways Authority Workshop. The common properties of the soils are shown in Table 3.1, Figures 3.4 and 3.5.

Figure 3.3: Laterite used for moulding interlocking blocks was sieved.

Table 3.1: Properties of the soil samples

Laterite Type	Grain Sizes (%)		Compaction		Atterberg Limits (%)	
	Gravel (>2 mm)	19	Optimum moisture content OMC (%)	14.40	Liquid limit(wL)	46.70
Red	Sand (2 - 0.063 mm)	46				
	Silt (0.063 - 0.002 mm)	15			Plastic limit(wP)	23.44
	Clay (<0.002 mm)	20	Maximum dry density MDD(kg/m³)	18.74	Plasticity index(PI)	23.26

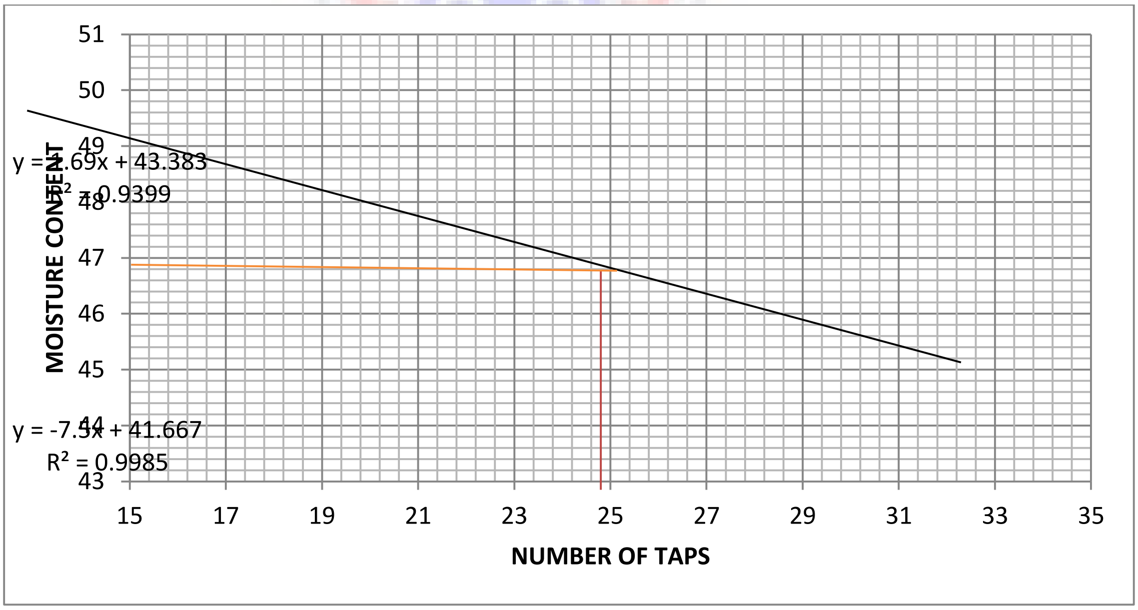

Figure 3.4: Moisture Content Determinations Graph

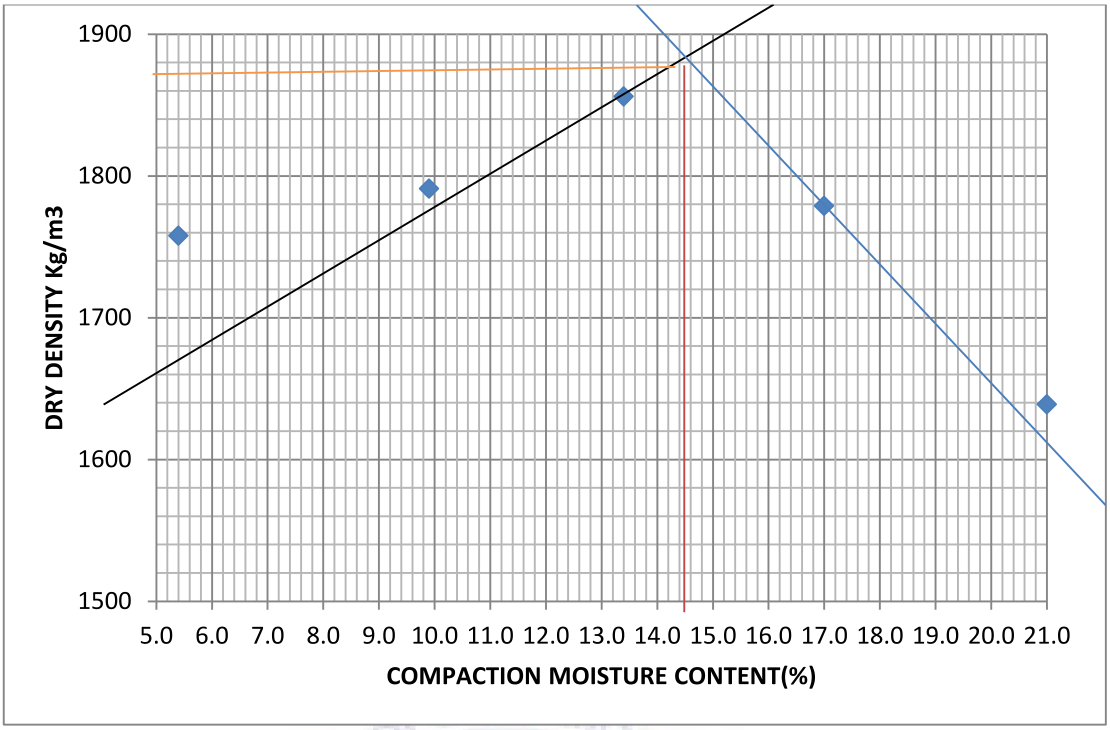

Figure 3.5: Minimum and Maximum Dry Density graph

3.2.4 Water

The water used for this study was clean and did not contain any dangerous quantities of acid, alkalis, salts, sugar or any other organic or chemical material. Because any organic material in water would have prevented the cement from setting. Chemicals and impurities could also have affected the strength of the end product and this was used for the mixing of the materials for the normal pavement brick as controlled specimens. However, the water used was of the same quality standard. It is obtained from free flowing tap, supplied by Ghana Water Company limited was used in the study.

3.3 Production of Cement-laterite Interlocking Blocks

A mix proportion of 1:6 of cement: laterite by weight was used in the work. The sand replacement of proportion 0, 5,10,15,20 and 25% to the weight of laterite in the mix as illustrated in Figure 3.6. The mixing was done by the use of shovel and hand to provide a very plastic and easily worked paste. The laterite samples were mixed with cement and water-cement ratio of 0.7 was used as control sample. For the experimental blocks, the laterite, cement and sand replacement percentage ranging from 5%-25% were mixed to desired consistency. The mixture was then loaded into the block mould for the interlocking blocks of size 220x185x120mm to be hydraulically mouldedat a constant pressure of 10 MPa as shown in Figure 3.7 and cured for 28 days.

Figure 3.6: batching of the various percentages of the materials.

Figure 3.7: Hydraform interlocking blocks machine with single mould and blocks

Thirty-nine (39) blocks at each percentage (5%, 10%, 15%, 20% and 25%) substitution of the laterite aggregate with the sand content were produced, cured, weighed and tested on7 days, 14 days, 21 days and 28 days for compressive strength, tensile strength, water absorption and 28 days for erosion range values taken as actual parameters as shown in Table 3.2.

For control, Thirty-nine (39) interlocking blocks were moulded without substitution which is with 100% laterite which can be seen in Table 3.2 and total number of blocks produced for the test which was two hundred and thirty-four (234).

Table 3.2: Types of Test and Number of the interlocking blocks moulded

	Interlocking Blocks Moulded (%)					
Test	**Experiment**	**7-Days Curing**	**14-Days Curing**	**21-Days Curing**	**28-Days Curing**	**Total**
Compressive Test	0%	3	3	3	3	12
	5%	3	3	3	3	12
	10%	3	3	3	3	12
	15%	3	3	3	3	12
	20%	3	3	3	3	12
	25%	3	3	3	3	12
Tensile Test	0%	3	3	3	3	12
	5%	3	3	3	3	12
	10%	3	3	3	3	12
	15%	3	3	3	3	12
	20%	3	3	3	3	12
	25%	3	3	3	3	12
Water Absorption Test	0%	3	3	3	3	12
	5%	3	3	3	3	12
	10%	3	3	3	3	12
	15%	3	3	3	3	12
	20%	3	3	3	3	12
	25%	3	3	3	3	12
Erosion Test	0%	5%	10%	15%	20%	25%
	3	3	3	3	3	3
	Total					**18**

3.4 Curing of Lateritic Interlocking Blocks

The blocks were first allowed to air dry under a shade made with polythene sheet for 24 hours. Thereafter, curing was continued by sprinkling water morning and evening and covering the blocks with polythene sheet to prevent rapid drying out of the blocks which could lead to shrinkage cracking. The blocks were afterward stacked in rows and columns with maximum of five blocks in a column until they were ready for testing (Figure 3.8).

Figure 3.8: Curing of the specimen with water and polythene sheets, for 28days

3.5 Tests Conducted on the Blocks

The various experimental tests carried out are densities, compressive strength, tensile strength, water absorption testing. In addition, erosion test was conducted to evaluate the specimen’s tolerance to continuous rainfall as well as SEM and EDS.

3.5.1 Density

The specimen density was determined as per BS EN 771-1:2011+A1:2015). The blocks were selected and their dimensions measured by tape measure. They were oven dried at a temperature of 105°C after each curing age until a reliable mass was documented, indicating a normal dried block. The dried blocks were weighed and the density determined.

3.5.2 Compressive Strength

Compressive strength testing was carried out with Universal Testing Machine (Model: 50_C34A2, serial no: 0294910) to determine the compressive strength of blocks. The blocks that have reached the ripe ages of curing of 7,14,21 and 28 days were taken from the stacking area to the laboratory, two hours before the test was conducted, to regulate the temperature and to make the block relatively dry or free from moisture. The weight of each block was taken before being placed on the compression testing machine. A 25mm thick rectangular timber platen having the same template of the interlocking blocks both top and down (220mmx185mm) for easy crushing because the top and the down part of the block is not flat which the machine can attach it well. On top and down this platen were attached to the loading structure by means of a 294mm diameter stiff steel cylinder of the Universal testing machine. The dimensions of the platen fulfill the recommendations of Atkinson (1991). Figure 3.9 illustrates the test set up. The blocks were then crushed and the matching failure load recorded. The crushing force was divided by the cross sectional area of the block to determine at the compressive strength.

Figure 3.9: Compressive Strength test set up

3.5.2.1 Stress-strain Relationship of the various blocks

Stress-strain testing was carried out with Universal Testing Machine (Model: 50_C34A2, serial no: 0294910) to determine the higher stress and higher strain (deformation) under compressive strength test of blocks. And the same procedure of testing the compressive strength was used.

Figure 3.9.1: Stress-strain test set up.

3.5.3 Tensile Strength

The splitting tensile strength test was performed in accordance with BS EN 12390-6 (2009). This was carried out with the testing machine (CONTROLS 50-C46G2) and splitting jigs were positioned centrally above and below the block. The loading was done constantly at a study rate of 0.05 N/mm^2/s until the breakdown of the block. The maximum load applied at which each of the blocks failed were recorded and splitting tensile strength determined and this gives the formula T= load being applied by the cross sectional area of the specimen, as shown in Figure 3.10.

Figure 3.10: Tensile Strength Test

3.5.4 Water Absorption

The water absorption was performed by randomly selecting three (3) blocks from each group at the specified age, and weighing them on a balance. These blocks were then immersed partially in water for 20 minutes (basic requirements), after which they were removed and weighed again. The percentages of water absorbed by the blocks were estimated as follows:

Wa = Ws –Wd divided by Wd x 100%

where: Wa = percentage moisture absorption Ws = weight of partially drenched block Wd =weight of dry block.

For the water absorption test, the blocks were positioned in a metal plate carrying water of 20 mm high on level pieces of one inch thickness of plywood. Afterwards the blocks were then placed on this plywood and permitted them partially into the water for 10 min and the blocks started to absorb water through capillary action and weighed after the 10 min. Figure 3.11illustrates the test set up.

Figure 3.11: Water Absorption Test Procedure

3.5.5 Erosion Test

The erosion test was conducted to determine the confrontation of the specimen to continuous rainfall condition. The test is an experimental one developed by Commonwealth, Scientific and Industrial Research Organisation (CSIRO) according to Australian Standard (2002) to replicate rain action. The purpose of performing this test was to determine the ability of the blocks to resist erosion which may be caused by constant rainfall as seen in Figure 3.12. The test was made in accordance with Section D of New Zealand Standard (1998). This test was established with shield board positioned in the plastic bath and the pressure spray nozzle set on the bath at a distance of 470 mm from the shield as shown in Figure 3.12. Each block was mounted behind a thin shield and was exposed to send out through a 100 mm diameter hole. The shield ensured that only limited area of the block face was subjected to water spray. Tap water was linked to the pressure spray nozzle and then opened at pressure 50 kPa through the nozzle onto the block. The water was sprayed onto the block uncovered surface and run out through the opening of the plastic bath and the spray was broken up at every 15 minutes to permit for measurement for a total of 60 min. The penetration of erosion was then measured using a 10 mm diameter flat ended rod and recorded. Three blocks were used for each test (Danso, 2017).

Figure 3.12: Erosion Test set Procedure

3.5.6 EDS and SEM

The Energy Dispersive X-Ray Spectroscopy (EDS) And Scanning Electron Microcopy (SEM) test was also conducted to determine the microscopic details and the chemical elements as well as the oxides in the blocks. Each of the specimens (0%-25%) was sent to University of Ghana laboratory in Accra and used the SEM machine to scan them for microscopic details after the 28 days curing. However, each of the specimens was placed in the EDS machine one after the other also to determine the elements and oxides after 28 days curing.

CHAPTER FOUR

RESULTS

4.1 Introduction

The results obtained from the various tests conducted are presented and discussed in the following sections.

4.2 Density of Sand-cement-laterite Interlocking Blocks

The average density of the sand-cement-laterite interlocking blocks at various days of curing is shown in Table 4.1.

Table 4.1: Density of sand-cement-laterite interlocking blocks

Curing Day	Sand content of interlocking blocks (kg/m^3)					
	0%	**5%**	**10%**	**15%**	**20%**	**25%**
7	1937	1853	1863	1873	1941	1932
14	1864	1843	1852	1859	1893	1862
21	1795	1780	1785	1788	1799	1790
28	1784	1757	1774	1780	1790	1782

Table 4.1 shows the summary of the average density of cement-laterite interlocking blocks which explains as the curing days increases the density decreases alongside for each percentage of sand content decrease. This is because the drying of the blocks also means the blocks are losing their moisture contents gradually at the period at in order to gain their strength so as the days are increasing the blocks also lose their weight at the drying stage (Danso et al., 2017). In these results, the minimum density in day 7 was 1853kg/m^3 (5% sand) whereas the maximum density recorded 1941 kg/m^3(20% sand), the minimum density in day 14 was 1843kg/m^3(5% sand)whereas the maximum density recorded 1893 kg/m^3(20% sand), the minimum density in day 21 was 1780kg/m^3(5% sand) whereas the maximum density recorded 1799 kg/m^3(20% sand),

the minimum density in day 28 was 1757kg/m^3(5% sand)whereas the maximum density recorded 1790 kg/m^3(20% sand).

4.3 Compressive Strength of Sand-cement-laterite Interlocking Blocks

The results of the compressive strength tests of the sand-cement-laterite interlocking blocks are shown in Figure 4.1.

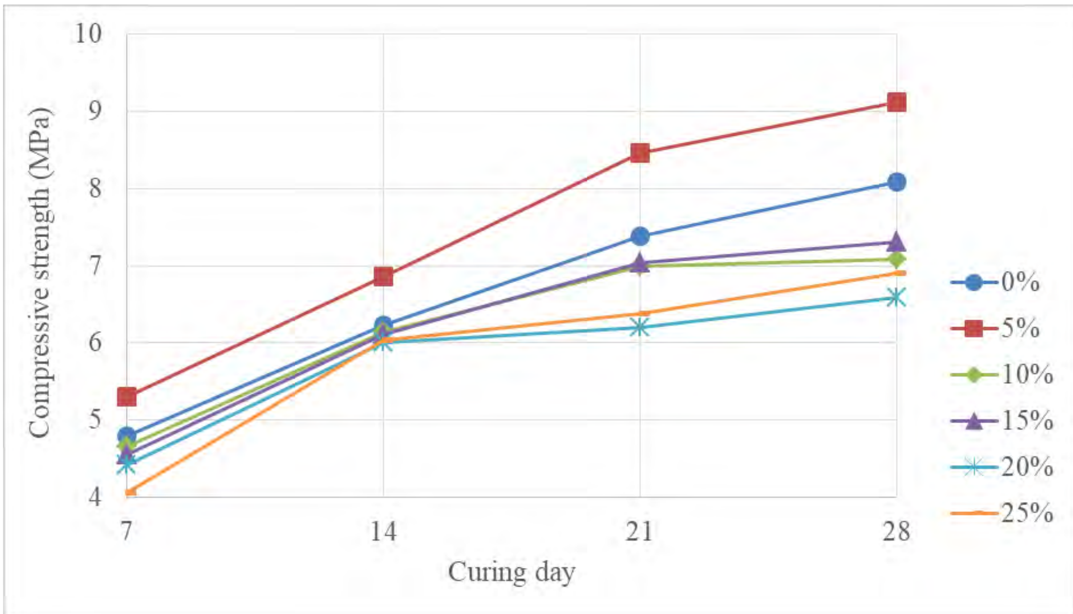

Figure 4.1: Compressive strength tests Results

The results of the compressive strength of the cement laterite interlocking blocks show that the compressive strengths increased at 5% only above the 0% at an increasing rate and the rest were below the control level or 0% from 7 days to 28 days curing period. Therefore, it is seen from Figure 4.1 that for the control specimen, the compressive strength increased from 4.803 N/mm^2 at 7 days to 8.089 N/mm^2 at 28 days (i.e. about 68% increment). The strength of the 5% replacement by sand showed increase in compressive strength from 5.305 N/mm^2 at 7 days to 8.451 N/mm^2 at 28 days (59.3% increment). The strength of the 10% replacement by sand showed increase in compressive strength from 4.659 N/mm^2 at 7 days to 7.378 N/mm^2 at 28 days (58%

increment). The strength of the 15% replacement by sand showed increase in compressive strength from 4.553 N/mm^2 at 7 days to 7.044 N/mm ^{2} at 28 days (34% increment). The strength of the 20% replacement by sand showed increase in compressive strength from 4.424 N/mm^2 at 7 days to 6.197 N/mm ^{2} at 28 days (40% increment). The strength of the 25% replacement by sand showed increase in compressive strength from 4.006 N/mm^2 at 7 days to 6.376 N/mm ^{2} at 28 days (59% increment).

4.4 Stress-strain Relationship of the various Blocks

Figure 4.2 show s stress-strain results of various percentages of blocks after 28-day curing.

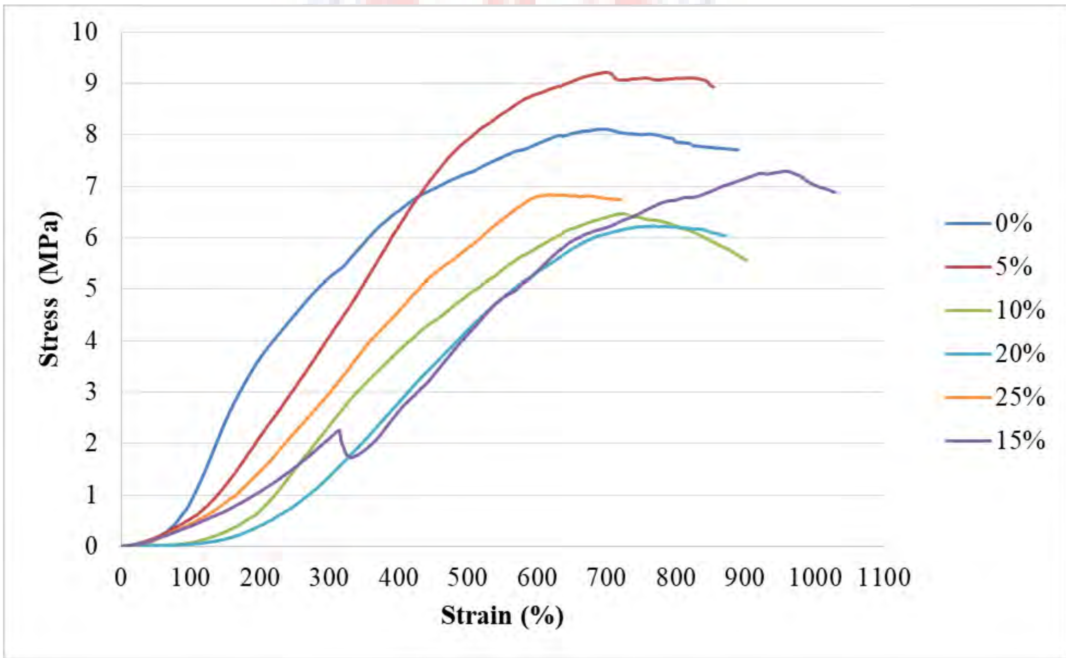

Figure 4.2: Stress-strain graphs of the various percentages of blocks (28-day curing)

The graphs show the stress-strain diagram up to peak load for sand replacement of cement-laterite interlocking blocks obtained in the experimental study. In the stress-strain curves, only 5% sand replacement achieved the highest stress above the control level of 0% and the rest of the percentages of sand were below the control level or the

0%. However, 10% and 15% sand replacement were subjected to higher strain (deformation) above the control level of 0% and the rest of the percentages of sand replacements are below the control level or the 0%.

4.5 Tensile Strength of sand-cement-laterite Interlocking Blocks

The results of the tensile strength tests on sand-cement-laterite interlocking blocks are shown in Figure 4.3.

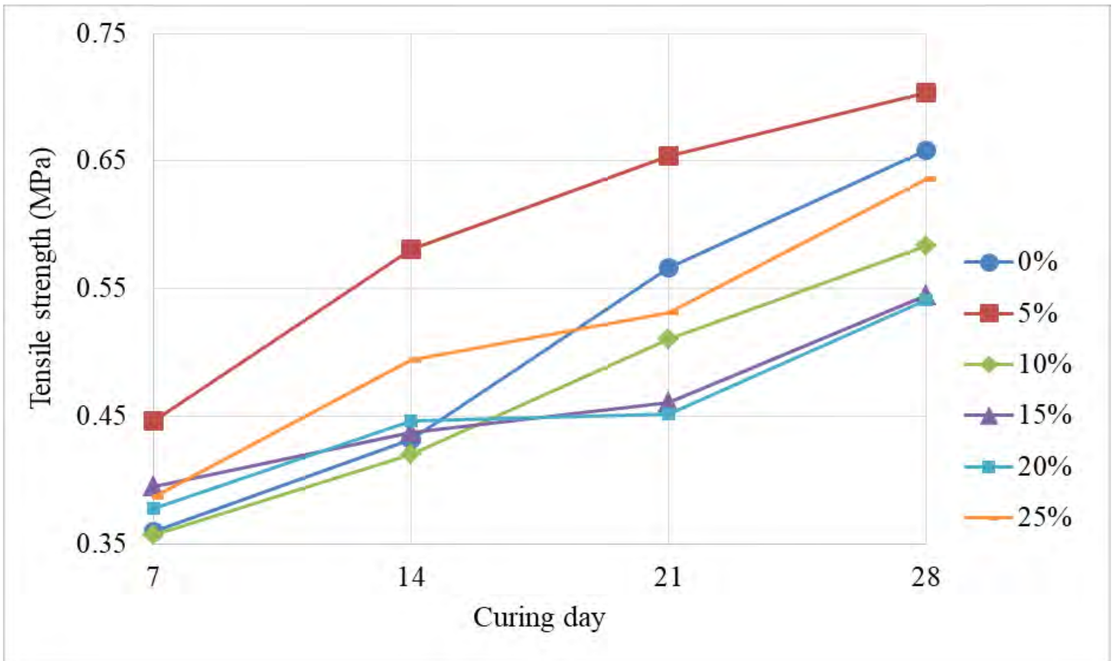

Figure 4.3: Effect of Sand content on Tensile Strength Test Results

The results of the tensile strength of the cement laterite interlocking blocks show that the tensile strengths increased as the percentage sand replacement also increased from 7 days to 14 days curing period and were lower as compared to 0% at an increasing rate from 21 days to 28 days curing period apart from 5% of sand replacement which obtained the highest values from 0.446 N/mm^2 at 7 days to 0.704 N/mm^2 at 28 days curing period. It can also be seen from Figure 4.3 that for the control specimen, the tensile strength increased from 0.360 N/mm^2 at 7 days to 0.676 N/mm^2 at 28 days (i.e. about 88% increment). The strength of the 5% replacement by sand showed increase in tensile strength from 0.446 N/mm^2 at 7 days to 0.704 N/mm^2 at 28 days (58% increment). The strength of the 10% replacement by sand showed increase in tensile strength from 0.357 N/mm^2 at 7 days to 0.585N/mm^2 at 28 days (64% increment). The strength of the 15% replacement by sand showed increase in tensile strength from 0.395 N/mm^2 at 7 days to 0.545 N/mm ^{2} at 28 days (38% increment). The strength of the 20% replacement by sand showed increase in tensile strength from 0.378N/mm^2 at 7 days to 0.539 N/mm ^{2} at 28 days (43% increment). The strength of the 25% replacement by sand showed increase in tensile strength from 0.387 N/mm^2 at 7 days to 0.637 N/mm ^{2} at 28 days (68% increment).

4.6 Water Absorption Results

Figure 4.4 below shows water absorption test results for Cement-laterite interlocking blocks after 28 days curing period for all the sand percentages.

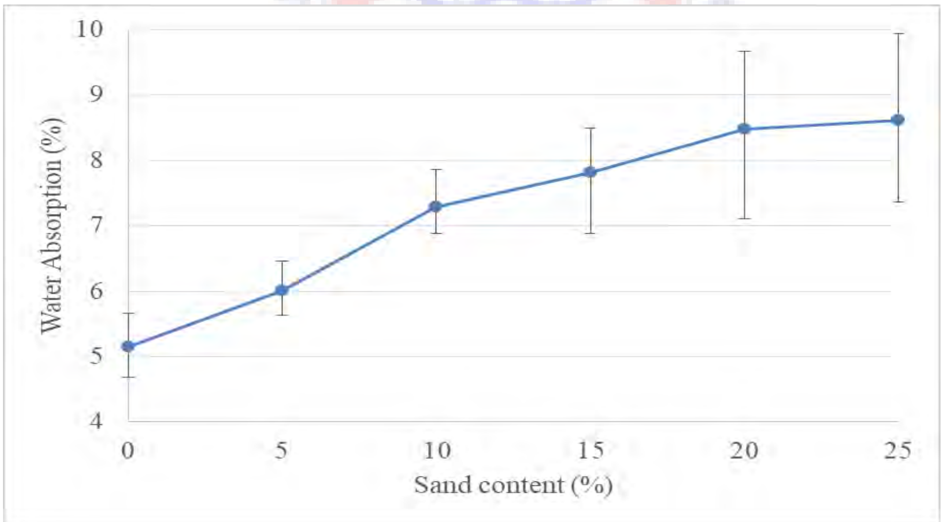

Figure 4.4: Water absorption Test Results

For 28 days, the mean water absorption of 0% was 5.156%, 5% was 6.013%, 10% was 7.808%, 15% of sand was 7.989%, 20% of sand was 8.471% and lastly 25% of sand was 8.608%. The results indicate that water absorption increases as sand replacement increases for all the cement-laterite interlocking blocks. It can also be seen that 0% sand recorded minimum water absorption and the rest were above the control specimen respectively which is in line with Raheem et al., (2010).

4.7 Erosion Result

Figure 4.5 shows erosion test results for sand cement-laterite interlocking blocks after 28 days curing period for all the sand percentages.

With 25% sand

20% sand

15% sand

10% sand

0% sand

5% sand

Figure 4.5: Erosions created on the various percentages of blocks

Figure 4.5 indicates the erosion mode of the various percentages of sand cement-laterite interlocking blocks. This explains as the front surface of the specimens got direct contact with water, some of the specimens were gradually damaging and others were gradually resisting the erosion for the entire 60 minutes water spraying. All the six specimens (0%, 5%10%, 15%, and 20% and 25% sand contents) tested survived the 60 min water spray test but these four (10%, 15%, and 20% and 25%) specimens eroded deeply from between 14mm to 16.5 mm for the specimens tested. However, the 0% and 5% specimens also survived the 60 min water spray test but eroded shallowly from between 9mm to 13mm mm for the specimens tested. This result suggests the sand replacement from 0% to 5% interlocking blocks have better resistance to erosion than from 10% to 25% interlocking blocks, hence there is the need for using 0% to 5% in order to improve strength and also resist erosion and water absorption and relative good density properly(Danso, 2017).

Table 4.2: Erosion Results of blocks Specimen in sand Percentage

Specimen with sand Percentage	Depth of erosion (mm)	
	30 MIN	60 MIN
0%	6 mm	9 mm
5%	8 mm	13 mm
10%	9 mm	14 mm
15%	9.5 mm	15 mm
20%	10 mm	16 mm
25%	10 mm	16.5 mm

The results of the erosion test of the cement laterite interlocking blocks in Table 4.2 show that the depth of eroded surface increased as the percentage sand increased at the 28 days curing period Therefore it is seen from Table 4.2 that for the control specimen, the eroded surface increased from 6mm at 30 min to 9 mm at 60 min. The erosion of the 5% replacement by sand showed the eroded surface increased from 8 mm at 30 min to 13 mm at 60 min. The erosion of the 10% replacement by sand showed the eroded surface increased from 9mm at 30 min to14 mm at 60 min. The erosion of the 15% replacement by sand showed the eroded surface increased from 9.5mm at 30 min to 15 mm at 60 min. The erosion of the 20% replacement by sand showed the eroded surface increased from 10 mm at 30 min to16 mm at 60 min. The erosion of the 25% replacement by sand showed the eroded surface increased from 10 mm at 30 min to16.5 mm at 60 min. This means that the amount of erosion in the compressed earth blocks was reducing through the period of testing, means that the intensity of the erosion occurred at the beginning, slowed down gradually to the end. This means from the outer surface of the blocks, the speed of the erosion was high, but as the water reaches the internal of the blocks, the intensity of the erosion subsides (Danso, et al. 2015).

4.8 Energy Dispersive X-Ray Spectroscopy (EDS) Result

The results of EDS test on cement-laterite interlocking blocks are shown in Figure 4.3.

Table 4.3: Energy Dispersive X-Ray Spectroscopy (EDS) test results of the blocks

Element Symbol	Atomic Conc. (%)	Weight Conc. (%)	Oxide Symbol	Stoich. wt Conc. (%)
O	76.43	60.29		
Ca	9.95	19.66	Ca	49.50
Si	6.96	9.64	Si	24.28
Al	5.56	7.40	Al	18.64
Fe	1.09	3.01	Fe	7.58

The EDS test results indicate the chemical elements of the block, namely O, Ca, Si, Al, and Fe. The Oxygen (O) in the blocks recorded an atomic concentration of 76.43% and weight concentration 60.29% respectively, Calcium (C) in the blocks recorded an atomic concentration of 9.95% and weight concentration 19.66%, Silica (S) in the blocks recorded an atomic concentration of 6.96% and weight concentration 9.64% respectively, Aluminum (A) in the blocks recorded an atomic concentration of 5.56% and weight concentration 7.40% respectively and Iron (Fe) in the blocks recorded an atomic concentration of 1.09% and weight concentration 3.01 respectively. However, for oxide Oxygen (O) in the blocks recorded no value for stoichiometric weight concentration, Calcium (C) in the blocks recorded 49.50%, Silica (S) in the blocks recorded 24.28%, Aluminum (A) in the blocks recorded 18.64%, Iron (Fe) in the blocks recorded stoichiometric concentration of 7.58%.

4.9 Scanning Electron Microcopy (SEM) Result

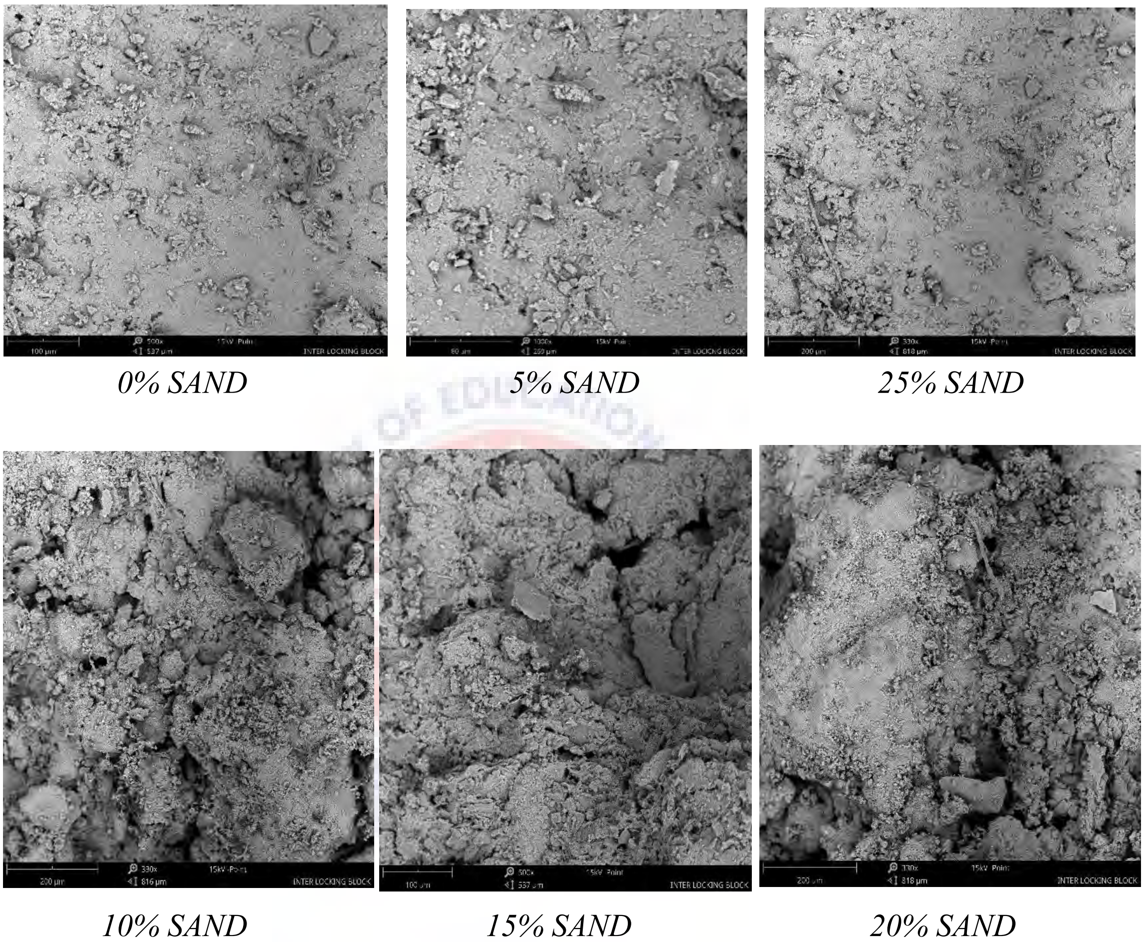

Figure 4.6: SEM images of the various percentages of sand

Figure 4.6 shows the SEM images of the various percentages of sand and how the blocks were compacted or compressed after the moulding from the machine for 28 days. The first image is 0% sand with smooth texture which leads to good compaction and the same happens to 5% sand respectively. However, 10% sand which can be seen to be rough surface and the same thing to 15%, 20% and 25% sand. It can also be observed that there are pores in the images especially with the blocks with high sand percentages.

This is the result of the sand added to the cement-laterite matrix which causes hydration reaction in the composite, hence some of the pores observed in the blocks can be sealed in order to improve strength and also resist erosion and water absorption and relative good density properly (Danso, 2020; Danso & Manu, 2020).

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter entails the discussion of the results and the analysis of the findings.

5.2 Density of Sand-cement-laterite Interlocking Blocks

It was observed in Table 4.1 that as the curing days increase the density decreases alongside for each percentage of sand content decrease. This is because the drying of the blocks leads to the blocks losing their moisture contents gradually at the period and as such the blocks also lose their weight at the drying stage which is in line with Danso et al., (2017) results. In this results, the highest density in day 7 was recorded 1941 kg/m^3(20% sand), the highest density in day 14 was recorded 1893 kg/m^3(20% sand), the highest density in day 21 recorded 1799 kg/m^3(20% sand) and lastly, the highest density in day 28 was recorded 1790 kg/m^3(20% sand). Hence, it is clearly shown in table 4.1 that, 20% replacement of sand recorded the highest density from day 7 to day 28 above the control level (0%) and started reducing at 25% replacement of sand, which means 20% was the peak level for sand replacement of this experimental study. It means the sand replacement has exceeded its limit and doesn't need any sand replacement above 20%.

5.3 Compressive Strength of Sand-cement-laterite Interlocking Blocks

The effect of curing ages on the compressive strength of sand replacement of laterite presented in Figure 4.1 indicates that all the percentage of sand replacements show continuous increase with increased curing age. However, only 5% sand replacement yielded higher strength above the control specimen (0%) and the rest were all below the control specimen (0%) this is because the sand content in the laterite were about 95% and does not need any sand replacement exceeding 5%. The result at 7 days indicated a lower in strength from 4.803 N/mm^2 for control (0%) to 4.006 N/mm^2 for 25% sand replacement. Same thing was observed at 14 days as shown in figure 4.1. However, these results show that blocks containing sand above 5% slowly gained strength at early curing age. This is in line with previous findings that blocks containing sand content at high quantities gained strength slowly at early curing ages (Hossain, 2005; Adesanya & Raheem, 2009a). At 28 days, there was continuous increase in compressive strength for all the percentages of blocks with values ranging from 8.089 $N/mm^2$for the control, to 6.197 N/mm for 20% sand replacement (Raheem, 2006). It means 5% still has the highest compressive strength at this age which can be concluded that 5% sand substitution is adequate to obtain maximum benefit of strength gain.

5.4 Stress-strain Graphs of the various Percentages of Block

In the stress-strain curves in Figure 4.2, 5% sand replacement yielded the highest stress above the control level of 0% and the rest of the percentages of sand replacement were below the control. This is due to the fact that there was enough sand content in the laterite so in this case it was only sand content from 0% to 5% which were needed for optimum strength. However, it is observed that the 5% sand replacement and the 0% which reached the correct peak value and these could be good for this block specimen. Similar findings are also shown in a previous study (Fatemeh et al., (2012). However, 10% and 15% sand replacement are subjected to higher deformation above the control level of 0% and the rest of the percentages of sand replacements are below the control level or the 0%.

5.5 Tensile Strength of Sand-cement-laterite Interlocking Blocks

The results in Figure 4.3 indicate that all the percentage of sand replacements show continuous increase with increased curing age but 5% sand percentage achieved the higher strength above the control specimen (0%) and the rest were all below the 0%. However, it is observed that all the sand replacements from 10% to 25% strength were below the control specimen (0%) which could be due to the fact that the sand content in lateritic soil were high and does not need additional sand content exceeding 5% else the blocks specimen will create more pores. In this case the blocks specimen does not need enough sand above 5% to gain its strength. Studies by Bahar et al. (2004) and Morel (2001) and Medjo Eko et al. (2012) with cement as stabilizer in soil blocks recorded similar trend.

5.6 Water Absorption

It was observed in Figure 4.4 that the water absorption increases as the percentage replacement of Sand. The cement-laterite interlocking blocks with 25% sand replacement is the most porous with the absorption rate of 8.6%. The reason for increase in absorption may be as a result of trapped air bubbles due to porosity of the sand. Only the control with 0% sand content satisfied the minimum requirement as stated above. It can also be seen that 0% sand recorded minimum water absorption and the rest were above the control specimen (Raheem, et al., 2010).

5.7 Erosion Result

Figure 4.5 indicates the erosion mode of the various percentages of cement-laterite interlocking blocks. The front surface got direct contact with water and the specimens were gradually damaging and were gradually resisting the erosion for the entire 60 min water spraying which means all the specimens tested could not fail at the 60 minutes (Danso, 2017).

This means that the amount of erosion in the compressed earth blocks was reducing through the period of testing, meaning that the intensity of the erosion occurred at the beginning, slowed down gradually. This means from the outer surface of the blocks, the speed of the erosion was high, but as the water reaches the internal of the blocks, the intensity of the erosion subsides (Danso *et al.*, 2015).

5.7.1 Failure Mode

Figure 4.5 shows the failure mode of the compressed earth blocks (specimens). The front surface that had direct contact with the spraying water started deforming the block thickness. This is expected as the front surface always has direct contact with water/rainfall, and therefore is prone to excessive damage though it was able to resist the erosion for the entire 60 min water spraying. All the six specimens tested passed between all the 60 minutes. However, the 0% specimens also survived the 60 min water spray test but eroded narrowly at the 60 minutes. This result suggests that with sand replacement from 10% to 25% compressed earth blocks have poor resistance to erosion hence the need for higher cement (stabilizer) content to improve its durability property and this in line with the previous findings in (Danso, 2017).

5.8 Energy Dispersive X-Ray Spectroscopy (EDS) and Scanning Electron Microcopy (SEM) Result

The EDS test results in Table 4.6 indicated the chemical elements of the block, namely O, Ca, Si, Al, and Fe and they all amount to 100% indicating that it is good pozzolanic material in accordance with the requirement in ASTM C 618(1991). These chemical elements are good for strength improvement and water absorption and relative good density properties (Danso, 2020).

5.9 Scanning Electron Microcopy (SEM) Result

The results of Figure 4.6 showed that the SEM images of 0% and 5% have smooth surface for good compaction and improving strength properties of the specimen. The rest (10%, 15%, 20% and 25%) have rough surface with ability to bond with the cement matrix. The result is in line with previous study by Danso (2015). Some of the pores can be sealed in order to improve strength and also resist erosion and water absorption and relative good density properly.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents a summary, conclusions and recommendations based on the observed test results. The conclusive goal of this study was to determine the effects of sand on the properties of cement- laterite interlocking blocks for the building industry in Ghana.

The research aimed to investigate the use of sand as a partial replacement for cement in the production of interlocking blocks in order to improve strength and also resist erosion and water absorption and relative good density properly.

6.2 Summary of Findings

- It was observed that the measured density for cement laterite interlocking blocks produced from sand at 20% were always higher than the calculated density at 0%, 5%, 10% and 15% but as the sand content increased beyond 20%, the measured density dropped significantly.
- The effect of sand content on compressive strength and tensile strength of the specimen were positive. It was observed in the compressive strength and tensile strength of the cement laterite interlocking blocks that, both strengths increased at 5% only above the 0% at an increasing rate and the rest were below the control level or 0% from 7 days to 28 days curing period.
- Again, it was observed in the stress- strain behaviuor that, only 5% sand replacement yielded the higher stress above the 0% and the rest of the percentage replacements were below the control level where as 15% also recorded the higher deformation.

- It was also observed in the water absorption results that cement-laterite interlocking blocks with 25% sand replacement is the most porous with the absorption rate of 8.6%. Only the control with 0% sand content satisfied the minimum requirement as stated above.
- Moreover, it was observed in the erosion test that, the front surface which got direct contact with water was gradually damaging and was gradually resisting the erosion for the entire 60 minutes water spraying which means all the six specimens tested passed between all the 60 minutes.
- It was observed in the EDS results that, the chemical elements were good for strength improvement and have proper resistance to erosion and water absorption and relative good density properties.
- Lastly, it was observed in the SEM results that, the non-porous surface specimens (0% and 5%) were for good compaction and improving strength properties of the specimen and the rest (10%, 15%, 20% and 25%) with rough surface also having ability to bond with the cement matrix.

6.3 Conclusions

The construction industry plays a vital role in meeting the needs of society and enhancing quality of life. The use of sand replacement in cement laterite interlocking blocks production works resulted in strength improvement and fair resistance to erosion, water absorption and relative good density properties.

In this experimental study, cement laterite interlocking blocks modified with sand were produced and underwent various tests (density test, compressive strength test, tensile strength test, water absorption, erosion, EDS and SEM test). Specimen containing 5%, of sand replacement performed better than those prepared with 10%, 15, and 20% and

25% of sand replacement. In fact, the higher sand percentage (10%, 15, and 20% and 25%) reduced compressive strength and tensile strength of blocks specimen although exhibits the lowest density. The low sand replacement (5%) was useful for good compressive strengths. Again, all the sand replacements specimens tested passed between all the 60 minutes and the chemical elements were good for strength improvement and have proper resistance to erosion and water absorption and relative good density properties.

On the basis of the above, the cement laterite interlocking blocks provide smooth surface for good compaction and improving strength properties of the specimen and also rough surface for having ability to bond with the cement matrix. Therefore, it can be concluded that the sand replacement interlocking laterite blocks have the potential of supporting the affordable housing concept in Ghana. Cement laterite interlocking blocks construction is likely to support sustainable construction concept since it uses materials that are abundant and possesses good strength, fair resistance to erosion and water absorption and relative good density properties.

6.4 Recommendations

The following recommendations were made at the end of the study:

- The use of cement laterite interlocking blocks produced from 5% sand should be recommended to clients for use in constructing houses because they have ability for good compaction and improving strength properties of the specimen and also have ability to bond with the cement matrix in the construction industry in Ghana.

- The government should encourage estate developers to use cement laterite interlocking blocks produced from sand for building walls.
- The government should organize a national housing forum to discuss sand replacement of laterite for the production of cement laterite interlocking blocks on large scale to make it available in the Ghanaian market.
- Further investigation on the use of cement laterite interlocking blocks should be made with emphasis on the effect of addition of sand on the strength of the blocks.

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APPENDIX I

28 DAYS -COMPRESSIVE STRENGTH RESULTS

SampleID	TestDate	Operator	Type	Size mm	Area mm2	Max.force KN	Max. strength MPa
Assiamah Laterite block	2/21/2020	1	Flat	185*120	22200.00	136.70	6.158
Assiamah Laterite block	2/24/2020	2	Flat	185*120	22200.00	180.10	8.113
Average							**7.135**
Assiamah Laterite block 5%	2/24/2020	1	Flat	185*120	22200.00	202.55	9.124
Assiamah Laterite block 5%	2/24/2020	2	Flat	185*120	22200.00	204.60	9.216
Average							**9.170**
Assiamah Laterite block 10%	2/24/2020	1	Flat	185*120	22200.00	143.60	6.468
Assiamah Laterite block 10%	2/24/2020	3	Flat	185*120	22200.00	123.40	5.559
Average							**6.014**
Assiamah Laterite block 15%	2/24/2020	1	Flat	185*120	22200.00	161.95	7.295
Assiamah Laterite block 15%	2/24/2020	2	Flat	185*120	22200.00	152.90	6.887
Average							**7.091**
Assiamah Laterite block 20%	2/24/2020	1	Flat	185*120	22200.00	143.45	6.462
Assiamah Laterite block 20%	2/24/2020	2	Flat	185*120	22200.00	138.25	6.227
Average							**6.345**
Assiamah Laterite block 25%	2/24/2020	1	Flat	185*120	22200.00	146.30	6.590
Assiamah Laterite block 25%	2/24/2020	2	Flat	185*120	22200.00	151.75	6.836
Average							**6.713**

*Control (0%)*7.135	
5%	9.170
10%	6.014
15%	7.091
20%	6.345
25%	*6.345*

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	*CASAGRANDE CUP LIQUID LIMIT*			*B.S CONE LIQUID LIMIT*			*PLASTIC LIMIT*	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
No. Blows-cone penetration	34	27	19					
Container No.	263	482	496				67	418
Mass of wet soil + Container	27.43	30.27	33.39				15.27	15.44
Mass of dry soil + Container	20.55	22.39	24.29				13.39	13.53
Mass of Container	5.37	5.36	5.40				5.39	5.36
Mass of water	6.88	7.88	9.08				1.88	1.91
Mass of dry soil	15.18	17.03	18.89				8.00	8.17
Moisture Content	45.32	46.27	48.07				23.50	23.38

MOISTURE-DENSITY RELATIONSHIP

MINUS 19mm FRACTION

	Mass minus 19mm:	**Mass plus 19mm:**			**Total Mass:**	
ROW	Parameter	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
1	Percentage water added (%)	4 (%)	8 (%)	12 (%)	16 (%)	20 (%)
2	Estimated air DRY M.C (%)					
3	**Est. Compaction MC. (%) (1) + (2)**					
4	Mould no.	A	A	A	A	A
5	Mould factor	0.4753	0.4753	0.4753	0.4753	0.4753
6	Mass of mould(g)	4187	4187	4187	4187	4187
7	Mass of mould Wet sample (g)	8086	8327	8616	8568	8360
8	Mass of wet sample (g)(7)-(6)	3899	4140	4429	4381	4173
9	**WET DENSITY (Kg/cu.m)(8)*(5)**	1853	1968	2105	2082	1983
MOISTURE CONTENT DETERMINATION						
11	Oven-pan no.	B4	D4	D13	D12	T02
12	Mass of oven-pan (g)	102	104	103	104	103
13	Mass oven-pan+ wet soil (g))	375	404	332	345	339
14	Mass oven-pan + dry soil (g)	361	377	305	310	298
15	Mass of water (g)(13)-(14)	14	27	27	35	41
16	Mass of dry soil (g)(14-12)	259	273	202	206	195
17	**MOISTURE CONT.(%)(15)/(16)*100**	5.4	9.9	13.4	17.0	21.0
18	**Back calc. Air-dry MC.(%)(17)-(1)**	1758	1791	1856	1779	1639

APPENDIX II


Interlocking blocks ESTATES Housing

Laying of Interlocking blocks by the artisan.

How tensile (left) and compresasive (right) tests were done in the laboratory

How water absorption (left) density (middle) and erosion (right) tests were conducted