ASSESSMENT OF THE COMPRESSIVE STRENGTH OF SOIL CEMENT BLOCK EXPOSED TO NPK FERTILIZER

BY

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DECLARATION

I declare that the work in the thesis entitled 'an assessment of the compressive strength of soil cement block exposed to NPK fertilizer' has been performed by me in the Department of Building. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project thesis was previously presented for another degree or diploma at any University.

Mohammed Mustapha Ibrahim	______________________	____________________
Name of Student	Signature	Date

CERTIFICATION

This thesis entitled 'AN ASSESSMENT OF THE COMPRESSIVE STRENGTH OF SOIL CEMENT BLOCK EXPOSED TO NPK FERTILIZER' by MOHAMMED MUSTAPHA IBRAHIM, meets the regulations governing the award of the degree of Master of Science (M.Sc. Construction Technology) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The large number of farmers, especially the rural farmers, make use of NPK fertilizer for farming. These farmers lack adequate storage facilities for storing farm products. This study is aimed at determining the compressive strength of soil cement blocks (SCB) in contact with NPK fertilizer with a view to study the chemical reaction and ascertaining the suitability of the SCB in the construction of ware houses for the storage of NPK. The SCBs were obtained from a Hydraform block firm constructing an estate in Kuje, LGA Abuja. A total of 150 samples of the SCB, the soil used to produce the SCB, obtained from the site in Kuje LGA. The properties of the soil that determines the cement content and properties of the blocks were investigated in accordance with BS EN 771-1:2011 and BS EN 772-1:2011 respectively. The shrinkage has a value of 5.8% and sieve analysis (clay and silt 0.95%) indicates that the cement content can be increased to improve the strength of the SCB. The wet compressive strength (1.8N/mm^2) was 78% of the dry compressive strength (2.3N/mm^2) and less than 80% as recommended by BS EN 772-1:2011. Chemical analysis of the cement, soil and NPK were carried out, a saturated solution of NPK was determined to produce different concentrations. The solutions were prepared and three blocks selected at random were immersed for 7days, 14days, 21days, 28days, 56days and 90days respectively to ensure adequate exposure to the NPK solution. The compressive strength tests shows that the behaviour of the control differs from those in the solution. It was observed that the control experienced leaching of calcium hydroxide from the cement paste with low compressive strength of 1.64N/mm^2. Whereas, the compressive strength of the SCBs in NPK solution was higher at 7days (1.7N/mm^2, 1.74 N/mm^2, 2.12N/mm^2, 2.13N/mm^2, 2.11N/mm^2). After 56 days and 90 days, a white layer was observed to form within the SCB exposed to high concentrations of NPK. This was related to the likely ions exchange reaction with calcium hydroxide. The SCB were found to be suitable for use in the construction of ware houses to store NPK fertilizer as long

as the selection of the soil and block production was based on standard code and the structure is kept dry from moisture.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Earth as a construction material has been used for thousands of years by civilisations all over the world. Many different techniques have been developed, the methods used vary according to the local climate and environment as well as local traditions and customs. As a modest estimate it is thought that as many as 30% of the world's population live in a home constructed in earth (Houben & Guillaud, 1994).

Despite these very significant figures, earth construction in many parts of the world particularly in developing countries, is considered to be a construction material for the poor and hence undesirable. Loss of traditional knowledge resulting in deterioration in the quality of recent earth constructions has, in many cases, compounded these beliefs.

In recent years, however, the potential for earth as a valuable and desirable construction material is being rediscovered. Methods derived from the traditional techniques are being developed to improve the quality of earth construction and broaden the potential for its application.

Earth construction is very cost effective, energy efficient (excellent thermal properties and low energy input required for production), environmentally friendly, and safe, qualities that are particularly relevant and important with the ever-growing need for increased awareness to reduce energy consumption worldwide (Adam and Agib, 2001).

Specific research in the production of building blocks over the years has revealed certain features of the material. Generally un- rendered low-cement (<6%) and low-density (<1800kg/m^3) Soil

Cement Blocks (SCB) exhibit an unacceptably low tolerance to humid conditions and will deteriorate during less than 10 years. This deterioration is typically in the form of spalling of the exterior surface. By increasing the cement content, and/or the density, the stability of the material is greatly enhanced and becomes more acceptable for use in humid areas (Montgomery 2002).

The hydrated cement, a component of the SCB, is most vulnerable to the effects of the environment. Moskvin (1983), identified three principal forms of deterioration of concrete based on the prevalent signs of destruction as; the first form is the decomposition of concrete by action of liquids (aqueous solutions) able to dissolve the ingredients (calcium hydroxide) of the hardened cement known as leaching. The second embraces exchange reactions, i.e. chemical interaction between the hardened cement constituents and a solution, including cation exchange; easily soluble reaction products are removed from the internal structure by diffusion or percolation. This form of deterioration is represented by processes occurring in concrete attacked by solutions of acids (Carbonic Acids) and certain salts (Magnesium sulfate and chloride). The last form involves the accumulation, crystallization, and polymerization of reaction products which increase the volume of the solid phase within the pore structure of concrete Crystallization and other secondary processes occurring in concrete create internal stresses which may lead to the structural failure of concrete (attack by sulfates). The effect of the aggressive environment can occur in different forms, aggressive solids, liquids and gases. Aggressive liquids begin decomposition in a solid or gaseous medium and progresses only in a liquid phase (Moskvin, 1983). Aggressive Gases affect concrete at a certain temperature and humidity, while aggressive solids such as dry saline soils, various loose chemicals (fertilizers) will affect concrete in a liquid phase at normal temperature.

Zuckerman (2003), defined Fertilizers as “chemical compounds applied to promote plant and fruit growth”. Fertilizers are usually applied either through the soil (for uptake by plant roots) or, by foliar feeding (for uptake through leaves).Fertilizers can be placed into the categories of organic fertilizers (composed of decayed plant/animal matter), or inorganic fertilizers (composed of simple chemicals and minerals). Organic fertilizers are 'naturally' occurring compounds, such as peat, manufactured through natural processes (such as composting), or naturally occurring mineral deposits; inorganic fertilizers are manufactured through chemical processes (such as the Haber process), also using naturally occurring deposits, while chemically altering them (e.g. concentrated triple superphosphate). Properly applied, organic fertilizers can improve the health and productivity of soil and plants, as they provide different essential nutrients to encourage plant growth. Organic nutrients increase the abundance of soil organisms by providing organic matter and micronutrients for organisms such as fungal mycorrhiza, which aid plants in absorbing nutrients. Chemical fertilizers may have long-term adverse impact on the organisms living in soil and a detrimental long term effect on soil productivity of the soil. Fertilizers typically provide, in varying proportions, the three major plant nutrients: nitrogen, phosphorus, potassium known shorthand as N-P-K; the secondary plant nutrients (calcium, sulfur, magnesium) and sometimes trace elements (or micronutrients) with a role in plant or animal nutrition: boron, chlorine, manganese, iron, zinc, copper, molybdenum and (in some countries) selenium (Zuckerman, 2003). The Synthesized materials are also called artificial, where the product predominantly contains the three primary ingredients of nitrogen (N) from Amonium nitrate [NH_4 NO_3 (AN)], phosphorus (P) from phosphorous pentoxide [P_2O_5], and potassium (K) from potassium chloride or potassium sulfate [KCl or K_2 SO_4] respectively, (known as N-P-K fertilizers or compound fertilizers when elements are mixed intentionally) (Zuckerman, 2003).

1.2 Statement of the Research Problem

The majority of developing countries are today faced with an ever increasing problem of providing adequate yet affordable housing in sufficient numbers. In the last few decades, resources have remained scarce, housing demand has risen and the urgency to provide immediate practical solutions has become more acute (Kerali, 2001).

The present high cost of building materials and the exorbitant cost of residential houses in Nigeria have necessitated an intensification in the search for low cost building materials and of simple and cheap construction techniques to be developed so as to make the ownership of living accommodation be within the reach of a large majority of the citizens. Especially those living in the rural areas that constitute over 60% of the population (Uche, 2003).

Several sources have indicated that SCB has been identified as a more environmentally and socially acceptable alternative, if its production and use is carefully controlled (Montgomery, 2002). Therefore, literature has shown that SCB have been researched using different materials and methods to improve the strength and permeability of the blocks. The researches were carried out using different techniques and have proven successful for the construction of buildings from a single storey up to four storey depending on the compressive strength of the blocks, 2.5 N/mm^2 for non-load bearing walls to 7 N/mm^2 for load bearing walls (Rama and Purna, 2015).

Various studies have been carried out on the durability of SCB such as abrasion resistance, stabilization techniques, use of admixtures and coating surfaces with chemicals by Al-Sakkaf (2009), Asmamaw (2007), Ipinge, (2012), Kerrali, (2001). Alternative ways of improving the permeability and strength of the SCB. Previous study on the suitability of Hydraform block produced by the same manufacturer used for this study suggests that the block is fit for use in construction (Samuel, 2012). As a result of the acceptability of SCB in walling construction, the durability (abraision resistance, stabilization techniques, use of admixtures and coating surfaces with chemicals) of SCB have been studied but not in a chemically aggressive environment. According to Orji, (2015), over 75% of rural dwellers in Nigeria are full time farmers who live in poverty and they also lack storage facilities. Ebewore and Achoja (2013), and Ogba (2013) stated that the major methods of storage used by local farmers were barns, underground pits, grasses, shades, leaves etc. Which, have not been adequate in the preservation of farm products and chemicals. With this research, the study of the chemical reaction of NPK with SCB can provide a useful information for the suitability of SCB in constructing warehouses for NPK storage. With the large agricultural farming in Nigeria, local farmers will need adequate and alternative storage facility to store agricultural chemicals such as; fertilizers, insecticides, herbicides, fungicides and other chemical materials. The aggressiveness of these chemicals on the SCB is influenced by the relative humidity, moisture content and temperature of the environment (Moskvin, 1983).

1.3 Justification For The Study

SCB have shown to be a useful material in the construction of buildings. Therefore, there is the need to study its suitability for use in the construction of warehouses, for the storage of NPK fertilizer. The NPK fertilizer was chosen for this study because it is the most commonly used fertilizer suitable for many plants. It contains the primary nutrients (Nitrogen, Phosphorus and Potassium) needed for plant growth. These elements are sourced from different compounds; Amonium nitrate [NH_4NO_3], phosphorous pentoxide [P_2O_5], potassium chloride or potassium sulfate [KCl or K_2SO_4], and each of these sources contain chemicals that are harmful to cement.

The characteristics of SCB exposed to the NPK fertilizer will provide manufacturers with an idea of how the block behaves under such environments. It will also provide local farmers with an alternative cheap material to construct storage facilities to store NPK fertilizers. The SCB will also be an alternative building material for the storage of NPK fertilizer especially with the current problems associated with storing large amount of NPK fertilizer such as swelling and caking.

1.4 Aim And Objectives

1.4.1 Aim

The aim of this research is to determine the compressive strength of SCB in contact with NPK fertilizer with a view to determine its suitability for construction of warehouses for storage of NPK fertilizer.

1.4.2 Objectives

1. To determine the physical and chemical properties of the soil used for casting SCB.
2. To establish the chemical composition of the NPK fertilizer.
3. To study the possible deleterious effect of NPK in cement stabilized blocks.
4. To determine the impact of exposure of SCB to NPK environment on the compressive strength.

1.5 Scope And Limitation

1.5.1 Scope

The study is focused on the physical properties of SCB such as linear shrinkage, sieve analysis, moisture absorption, wet and dry compressive strengths test, and chemical test of the composition of NPK, cement and laterite soil. However, other aspects of durability such as abraision resistance, stabilization techniques, use of admixtures and coating surfaces with chemicals and the deleterious effect of other aggressive chemicals were not included. The cost implications was not established in this work.

1.5.2 Limitations

1. The Mini pal X-ray spectrometer cannot detect all elements and elements with less than 0.02% concentration.
2. The equipment used to carry out shrinkage test was locally made.
3. Chemistry Department Laboratory was not involved in the chemical analysis test due to the restriction involved with NPK fertilizer. Therefore, there was no further test of the elements present in the block samples after immersion and crushing.
4. The minimum number of samples to be tested by the BS EN 771-1: 2011 and BS EN 772-2:2011 were not obtained from the block manufacturer. The Hydraform blocks were not for sale and thus the available quantity limited quantity was used to conduct the experiments.

CHAPTER TWO

LITERATURE REVIEW

2.1 History of Earth Materials and Traditional Clay Buildings

From literature, earth has been regarded as one of the oldest building material used in construction. Legget, (as cited in Al-Sakkaf, 2009), stated that earth has been the most widely known and used building material in construction and probably the most important of all building materials. According to Middendorf (as cited in Kerali, 2001), recorded cases of the use of earth bricks dates back to Mesopotamia "around 8000 BC". some researches shows that, about half of the world's populations are still living in earth buildings. All urban housing units worldwide, there are about 25 % that does not conform to building regulations while, 18 % are considered nonpermanent structures. Clay pure or mixed with sand is a universally existing material due to different geographic, climatic and cultural conditions, regional building techniques were developed throughout the world. At a point in time, the use of earth declined due to the presence of concrete and is making a comeback. The Third-World nations are not the only ones using earth for buildings, ecological and economic problems of the industrial nations are leading to a return to earth as well.

2.2 Traditional Methods of Earth Construction

The traditional methods of earth construction involves the use of locally available materials independently or mixed. These include, clay, sand, straws, wood and water. One or more of the materials are mixed to form; adobe blocks, wattle and daub, cob etc.

2.2.1 Adobe Blocks

This is made by mixing clay, sand and sometimes straw or manure, poured or pressed into forms, which are removed either immediately or after the brick has partially dried. The sun-dried mud ricks stacked with a mud mortar to create thick-walled structures. The use of adobe dates back centuries in traditional earth-building areas such as North Africa, the Middle East, South America and the United States Southwest. In some areas this building method is in decline, whereas still in widespread use in others. Dramatic examples of vaulted and domed structures built entirely of earth bricks still stand after centuries in the Middle East, testament to adobe's timeless beauty and structural integrity. In developing countries its use is mostly confined to those too poor to have access to other building materials, while in the Southwest U.S., adobe is often used by the very rich, illustrating its wide appeal. Adobe is appropriate in areas which are labor-rich and capital-poor, because it is labor intensive, using local materials and simple tools (Kennedy, 1997).

2.2.2 Cob

The process of building with cob entails mixing local subsoil with sand and/or clay (depending on the composition of the base earth) and straw or other fibrous materials to create a stiff mud which is formed into small loaves (cobs). These cobs can be tossed to the builder on the wall who mashes them together to form a monolithic wall on top of a stone or concrete foundation. Cob is an ancient technique of building monolithic walls using moist earth and straw that has similar thermal properties to adobe. It is being rediscovered as a multifaceted building material applicable to a number of conditions. Cob has been used mostly in informal or experimental buildings in the U.S. while code-testing procedures are investigated, but now several isolated projects are receiving permits. Traditional cob construction is undergoing a revival in England as well, where proponents are rediscovering five hundred year old houses in perfect condition, and new projects are reinvigorated this nearly-lost craft (Kennedy, 1997).

2.3 Modern Methods of Earth Construction

According to Montgomery 2002, modern earth construction uses the locally available materials i.e. soil/or clay with an added advantage of wet compressive strength. Improvement in strength is achieved through one or two of the methods of stabilization. The two methods are the application of mechanical pressure to reduce the voids, increase density, increase strength and reduce permeability or moisture absorption of the blocks. (Houben & Guillaud, 1994). The other method includes the addition of a chemical stabiliser the binds particles together. Cement, lime and bitumen are additives generally available and their application to soil popular.

2.3.1 Compressed Earth Blocks

Compressed earth blocks are similar to adobes, with the main differences being they are not fully saturated with water, are denser than adobe blocks, and are usually significantly more uniform. These blocks are created using a variety of machines. Some, like the Cinva-Ram were invented for compressing earth blocks (Plate I), use human labor and are relatively inexpensive. The earth-compressed blocks became widely used around the world in the last 30 years or more, not only in third world countries, but also in developed countries like the USA, France, Canada and Australia. Especially in developing countries in Africa, South America and Asia (Houben &Guillaud, 1994). The compressed earth block is one of the most important "modern building materials" which has enough production flexibility to let it be integrated into both formal and informal sectors of structural activities. Some hydraulic machines were developed to get blocks similar to concrete blocks.

Plate I: The CINVA-Ram hydraulic compressed machine

Source: Al-Sakkaf (2009)

2.3.2 Stabilised Soil

Stabilization is defined by Adam and Agib (2001) as the modification of soil properties through the addition of stabilisers. Stabilisation is necessary to achieve a lasting structure from local soil. The local material properties determine the appropriate stabilization method (Montgomery, 2002). Stabilisation can be broken down into three categories, (Houben & Guillaud, 1994).

1. Mechanical stabilisation: compacting the soil and changing its density, compressibility, permeability and porosity e.g. compressed earth blocks.
2. Physical stabilisation: changing the texture properties of the soil. It can be done by controlling the mixture of different grain fractions, drying or freezing, heat treatment and electrical treatment.
3. Chemical stabilisation: changing the properties of the soil by adding other chemicals or additives. This happens either by creating a matrix, which binds or coats the grains or by a physico-chemical reaction between the grains and the additive materials (Montgomery & Thomas, 1995).

The compressive strength of the soil can be improved by using the right stabilization method. This will also improve the durability by increasing its resistance to erosion and water damage. Stabilization techniques used in developing countries are Portland cement, lime, bitumen, gypsum and pozzolanas (Adam and Agib, 2001). The various type of blocks produced by this method include; extruded clay bricks, SUMATEC compressed earth block lime technology, Hydraform blocks etc.

2.4 Stabilisation Techniques

The different methods used to stabilize soil in other to improve the quality of material and construction are classified below (Adam and Agib, 2001):

2.4.1 Mechanical Stabilisation

This is compacting soil by using heavy weight in reducing the air and void volume, thereby increasing the density of the soil. The purpose of compaction is to increase strength and reduce permeability. The type of soil, moisture content and compression effort applied affects the degree of compaction.

2.4.2 Cement Stabilisation

Cement as a stabilising material is well researched and understood and its properties are clearly defined. From different types of cement, Portland cement is readily available in most urban areas and usually available in semi-urban areas, as it is one of the major components for any building construction. Earlier studies have shown that cement is a suitable stabiliser for use with soil in the production of compressed stabilised soil block. 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 (Neville, 1996). 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 of 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 (Montgomery, 2002).

Cement is usually mixed with an aggregate to form concrete. The aggregate is usually inert filler that makes up the bulk of the material, and the cement coats the aggregate in the gaps (Neville, 1996). The concrete industry has recognized that the achieved strength of concrete is highly dependent on the quantity of voids present in the mixture before curing. The presence of 5% air voids will reduce the strength of a concrete mix by about 30% and even 2% voids can result in a drop of strength of more than 10% compared to a sample with 0% voids present (Neville, 1996). To aid the particle intimacy, different aggregate grades are mixed together giving a spectrum of particle sizes that reduces the quantity of air voids in the material. The water used to mix the concrete plays an important role both in placing the material and in achieving strength. The quantity of water used is typically calculated using an appropriate water-cement ratio. Very low water-cement ratios yield a highly unworkable mixture and more water has to be added to form the mixture into the desired shape. Additional water is called the free-water content and is calculated from the Slump or Vebe test. This water does not form part of the chemical reaction and will eventually evaporate from the concrete leaving voids of air throughout the material (Neville, 1996). In order to keep the free-water as low as possible concrete can be compacted or vibrated to aid workability and consolidation.

Portland cement hydrates when water is added; the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates; calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementation process results in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel. Penetration of the gel throughout the soil hydration process is dependent on time, temperature and cement type.

The lime released during hydration of the cement reacts further with the clay fraction forming additional cementations bonds. Soil-cement mixes should be compacted immediately after mixing in order not to break down the newly created gel and therefore reduce strengthening. The basic function of cementation is to make the soil water-resistant by reducing swelling and increasing its compressive strength. With respect to the general processes of cementation, penetration and binding mentioned above, many factors must be considered. Processes may also vary between different types of soils. Cement is considered a good stabiliser for granular soils but unsatisfactory for clays. Generally cement can be used with any soil type, but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilisation is between 3% and 18% by weight according to soil type (Houben & Guillaud, 1994). Findings have shown that there is a relationship between linear shrinkage and cement content needed for stabilisation. Table 2.1 shows that the cement to soil ratio ranges between 5.56% and 8.33% for measured shrinkage variations of between15mm to 60mm (Houben & Guillaud, 1994).

Table 2.1: Cement to soil ratio

Measured shrinkage (mm)	Cement to soil ratio
Under 15	1:18 parts (5.56%)
15 – 30	1:16 parts (6.25%)
30 – 45	1:14 parts (7.14%)
45 – 60	1:12 parts (8.33%)

Source Houben & Guillaud, (1994)

It may be noted that for a given shrinkage the cement to soil ratio is a function of the compaction effort exerted. For example, a CINVA RAM machine exerts a compaction pressure of about $2N/mm^2$ by increasing this pressure to about $10N/mm^2$ the cement content can be reduced to between 4% and 6% for soil with shrinkage of up to 25mm. Over this shrinkage value, 6% - 8% cement would need to be used for effective stabilization.

2.4.3 Lime Stabilisation

One major alternative binder to cement is lime. By adding lime to the soil for stabilisation, four basic reactions are believed to occur: Cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions (Adam & Agib, 2001).

The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals to form a variety of cementitious compounds, which bind the soil particles together. Lime can also reduce the degree, to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability. Lime is a suitable stabiliser for clay soils. Lime is cheaply available than Portland cement in Ethiopia and is produced locally in traditional kilns. However, some improvements still need to be made in its production and processing.

It is estimated that up to 40% of cement used in building construction in masonry mortars could be saved through the use of lime and other lime associated binders. The advantages that lime has over Portland cement are that it requires less fuel to manufacture and requires relatively simple equipment to make. It is therefore more suitable for village scale production and use (Adam & Agib, 2001).When lime is used as a stabiliser instead of cement, the quantity of stabiliser required has been increased. However, research at the United Kingdom Building Research Establishment shows that such increment is not necessary if a sufficiently high compacting effort is applied on a high clay content soil. The reduction in the volume of air voids brings the lime and soil particles into closer contact and the stabilising reactions can take place more easily. Tests show that wet compressive strengths of between $3N/mm^2$ and $3.5N/mm^2$ may be achieved with compacting efforts in the range of 8 - $14N/mm^2$ (Adam & Agib, 2001).

2.4.4 Bitumen Stabilisation

There are two ways whereby bitumen can stabilise soil. The first way is a binding process that increases soil strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength. The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilisation are sandy soils. Clays need large amounts for good results (Adam & Agib, 2001).

The main disadvantages of bituminous materials as stabilisers are:

1. They are not a traditional building material in most developing countries,
2. Bituminous materials are expensive to import,

3. Preparation costs are high (heating, storing and mixing),

4. Heat can have an adverse effect on their binding properties, particularly in hot countries.

2.4.5 Gypsum Stabilisation

Gypsum is a traditional material found in many Mediterranean and Middle Eastern countries. The earliest civilizations used gypsum for building purposes, mainly for plasters and mortars. The advantage that gypsum has over Portland cement and lime is that it requires a low calcinations temperature (about 1/7 of that needed for cement and 1/5 of that needed for lime). Besides its agricultural and chemical uses, the main use of gypsum is in the production of Portland cement where it retards the setting of the cement. Gypsum is a good stabiliser for sandy soils.

2.4.6 Pozzolanas Stabilisation

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilisation and construction needs. Pozzolanas are found in their natural state as volcanic ash or pumice or it can be manmade (Neville 1996).

2.4.7 Other Stabilisers

Traditionally, many stabilisers such as animal dung, ant hill materials, bird droppings, plant extracts and animal blood, have been used for the manufacture of compressed stablised earth building blocks. These waste materials generally consist of nitrogenous organic compounds, which help bind together soil grains. Chopped straw, grasses and natural organic fibers, although not active stabilisers, they are used as reinforcement materials to reduce linear shrinkage problems, which occur with soil that has high clay content

2.5 Hydraform Blocks

The block used in this study is the Hydraform block, therefore the production, selection of materials, properties of the materials (soil, clay and cement) and blocks will be that of the Hydraform block. According to Ipinge 2012, Hydraform dry-stack interlocking CSEB was developed by 'Hydraform Africa Ltd in 1988, where Hydraform blocks are produced by stabilising local available soils with small amounts of Ordinary cement and mixed with small amounts of water". The mix is compressed by a mechanically operated Hydraform block making machine under a compressive pressure of up to 10N/mm^2. Various forms of Hydraform block making machines are available. They include the mechanical, electrical and diesel power generated machines. Figure 2.3 shows a typical mobile diesel powered block making machine (Hydraform Manual, 2004).

Plate II: M7 Hydraform Block Making Machine

Source: Hydraform Manual (2004)

Hydraform is the simplest type of interlocking block (Plate III) in shape, when interlocked it makes a tongue and grooved joint at the sides, top, bottom and free to slide along the course horizontally, it can be pushed along to achieve tighter vertical joints.

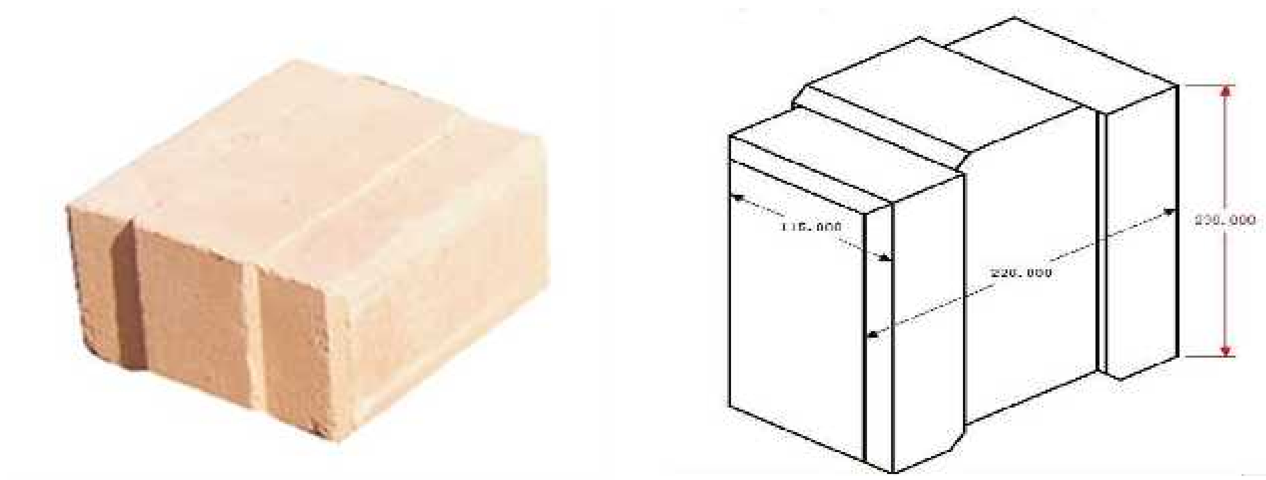

Plate III: Hydraform block

Source:Asmamaw (2007)

Hydraform block is moulded by pressing along its length from the ends. It is a solid block, slightly shorter, wider and thicker in size (240 x 220 x 115mm) Plate III. The stability of the wall built from the Hydraform blocks is not provided by the blocking mechanism but by the width and weight (massiveness) of the block. In producing the SCB, they require considerable power to mould (compress) due to their large volume, 30% more soil is used. Moreover, the compression must be sufficient to allow a fresh block to withstand the squeezing forces occurring when it is manually moved from machine to the curing area. A powerful (moulding pressure 4N/mm^2 to 10N/mm^2) and expensive motorised machine (Hydraform Manual, 2004) is required to compact such a volume of soil.

2.5.1 Suitable Soil for Soil Cement Block

A suitable soil should not contain organic material or excessive soluble salts, which would interfere with the setting of the cement. Its sand fraction should be well graded to provide a densely packed load-bearing skeleton for the block and its largest size particle should be small enough to give a smooth surface finish. The fine fraction should be just sufficient to provide enough cohesion to the fresh block to prevent damage on ejection and transportation from the mould. Too large fines content will either require large cement content for adequate stabilisation or will reduce the durability and wet strength of the final cured block. The cohesion of the fresh block will depend on the compaction pressure used and the type as well as the quantity of clay present in the fines. From the above it should now be possible to see the role that each of the soil's component fractions plays in a soil-cement block and the importance of selecting a suitable soil. If the soil available on site appears unsuitable, it should be remembered that natural soil exists in distinct strata with differing compositions. If the different strata are adequately tested then it is a comparatively simple operation to mix suitable masses of two or more strata to produce an acceptable soil (Montgomery, 2002).

2.5.2 Tests for Soils

Field tests can divide the soils in to two categories. These categories are suitable and unsuitable and if suitable, can be grouped into potential high and low cement classes (Montgomery, 2002). Laboratory tests can be used to characterize the soils by particle size distribution, plasticity or other numerical measures for relation to the selection criteria and enable simple soil modification by blending (Montgomery, 2002).

Most small- scale manufacturers of blocks, especially those producing blocks at a rural building site, have little or no access to laboratory facilities and in particular accurate mass measurement to 0.01g. For these block makers, judicious use of the field tests, the shrinkage test, production trials and past experience has to suffice.

The laboratory tests are appropriate where medium or large- scale production is planned, where minimizing cement content is especially important or when soil cement block making is moving into a new area.

2.5.2.1 Field Tests

Field tests are for preliminary site surveying to identify if the soils are most likely suitable and so restrict the number of soils to be more rigorously assessed by laboratory tests or trial production. The tests will provide a rough idea of a soil's grading and plasticity and also indicate whether a soil contains significant organic matter (reject outright), a large quantity of gravel, sand or fines. They may also be able to distinguish whether silt or clay is a more significant fraction of the fines. They are generally fairly easy to perform and often require little or no experimental equipment, making them very simple to implement.

Simple field tests which are performed to get an indication of the composition of the soil sample includes: smell test, nibble test, touch test, sedimentation test, adhesion test, washing test, linear shrinkage test, dry strength test, water retention test, consistency test and cohesion test (Adam & Agib, 2001).

2.5.2.2 Laboratory Tests

The laboratory tests establish numerical values for certain soil parameters, primarily the percentage distribution of the different sizes of soil particles present and the plasticity limits.

These values are subsequently used to determine the best available soil or domination of soils. All of these tests rely on accurate weighing and or some form of laboratory equipment scales with a resolution higher than one thousandth of the chosen sample weights is desirable. There are four main types of tests: The sieving test, sedimentation test, Atterburg limit test and compaction test.

The sieving tests separate the different size fractions of the soil in to discrete parts thereby indicating the soil's particle grading. The silt and clay fraction are too small to particle grading. The silt and clay fractions are too small to be easily separated by sieving and as such are normally reported as a combined fraction. The larger particles may be separated into a number of size fractions, depending on the number of sieve seizes available (Adam & Agib, 2001).

2.6 Compressive Strength of Hydraform Blocks

Literature show that the unconfined compressive strength of masonry units is usually directly related to other durability properties such as resistance to abrasion and water absorption. Thus the unit of measuring the quality of a masonry unit is usually specified as the characteristic unconfined compressive strength. For the above reason, codes (ASTM, BS) specify grades or classes of masonry units synonymous with the compressive strength and quality of units. Different grades of masonry units have different applications, for example a grade 1 masonry unit can be used for non-load bearing masonry walls only. A grade 2 unit can be used for non-load bearing including load bearing masonry walls and a grade 3 unit can be used for both the above where units are susceptible to the action of freeze-thaw. Although masonry standards specify classes for conventional regular shaped masonry, the general problem with interlocking CSEB's is that the blocks are usually irregular in shape, with each specific type block having its unique particular shape. In addition each unique shaped block employs a unique method of interlocking, be it with or without mortar, where international masonry standards describe and standardise construction methods for regular mortar bonded masonry units. This makes it difficult to standardise each unique blocks construction technique, making it all the more harder to develop a unified code of practise for irregular shaped interlocking blocks.

Looking at the characteristic strength of individual masonry units only and not the blocks' construction techniques', BS EN 772-1, 2011 code of practice recommend that irregular shaped masonry units either be capped with mortar to even out irregular surfaces or that irregular surfaces be evenly saw cut. This is done to facilitate testing between flat parallel compressive strength testing platens. Appendix I shows adopted methods, the loading arrangement and the methods' respective failure patterns (Pave, 2007). The different methods are discussed as follows:

2.6.1 Method 1

This method entails loading the block across the full width and breadth of the block. Special steel plates were manufactured to be placed within the grooves of the blocks. This type of loading method is set to simulate the behaviour of blocks in practice, where blocks are laid in an interlocking tongue and groove manner and all voids are filled with mortar. Failure is recorded at first sign of block crushing. Cracks that develop on tested blocks are approximately parallel to the direction of applied load.

2.6.2 Method 2

This method simulates the behaviour of blocks laid in practice with no mortar between blocks. When blocks are laid in practise in this manner it is found that there is a small interface between groove and tongue of block above and below, respectively. If blocks are loaded by means of this given loading arrangement, the shoulders fail with the remainder of the block remaining intact.

2.6.3 Method 3

This method simulates the behaviour of loading a block centrally between two platens, with voids remaining between the top platen and tongue, the bottom platen and underside groove area (Plate V). It is expected that the block fail in shear because of loading method restrains bottom two sides of block whilst top platen pushes tongue area only. This method has shown the lowest compressive strength with a normalized strength factor value of 0.6 (Hydraform Manual 2004).

Plate IV: Loading of Hydraform Block across the Tongue

Source: Laboratory Work (2013)

2.6.4 Method 4

Standard concrete testing procedure requires cubes of 100 x 100 mm to be cast and tested in order to estimate the strength of concrete. Four cubes were cube from each block, two blocks from the top half and two from the bottom half of the block. The part extruded first from the machine is known as the top side whilst the part nearest the bottom rammer is known as the bottom. The cubes are then tested in a dry state under a uniformly applied load.

2.7 Moisture Movement

Building materials with high porosity when used for wall construction may expand slightly in wet and dry conditions. Such movements may result in cracking and other defects to the building. Expansion of S C B may vary according to the properties of the soil; some soils expand or shrink more than others.

The addition of a stabiliser will reduce this expansion. However, there may be greater movement in structures built with compressed stabilised earth blocks than those using alternative construction materials (Asmamaw, 2007). Proper block manufacture and construction methods, however, will reduce such movement.

Moisture movement is denoted in terms of linear percentage. It is worth mentioning that moisture movement becomes especially important when two materials with different movement properties are used in a building. Differential movement results in stress, which may break the bond between the materials, or cause other damage. For example, cement renderings often peel off earth walls or poorly compressed stabilised earth blocks because of their different expansion properties.

2.8 Chemical Analysis of Soil Cement Blocks

Soil on its own can be used for construction, but unless it is protected from water the resulting building will not be very durable in any but the driest climates, as has been described above. Cementitious stabilisation in combination with densification gives soil both wet strength and erosion resistance. Densification or compaction reduces the soils permeability and enhances the secondary cementitious bonding mechanism. Portland cement is the most commonly used stabiliser and at present usually the cheapest. Lime and lime pozzolan stabilisation are growing in popularity because, unlike cement, lime may be produced economically by small scale batching kilns. However at present the quality of lime produced by such small-scale kilns are highly variable and liable to change from one batch to another.

SCB is produced by dry mixing a suitable soil with a small quantity of cement and remixing the product with a specific quantity of water (the criteria for suitable soil is discussed above but it should be noted that two or more unsuitable soils may be combined by simple mixing to produce one more successful soil). The resulting damp soil is normally compressed in a mould, ejected and subsequently wet cured for three to four days then damp cured for twenty-eight days before incorporation in a building. In many ways SCB may be seen as a simpler version of Sand Cement Block, not requiring the sand to be first separated from other soil constituents. Sand Cement Block is widely used, though variable in quality as a result of poor curing (Montgomery, 2002).

SCBs' produced with compression are in general denser and hence less porous than Sand Cement Blocks. The resultant reduction of moisture loss during curing leads to a greater consistency in quality for soil cement.

The minimum amount of cement required to stabilise a block depends on the type of soil, the degree of compression and the final application for the blocks. Generally the interest is to minimize the cement content to below 10%. Given suitable conditions, blocks cement contents as low as 3% are possible (Houben & Guillaud, 1994).

In the presence of damp soil these components hydrate to form mono and dicalcium silicate hydrate gels (CSH and C_2SH, see equation (i) and (ii)). These gels then slowly crystallise into an insoluble interlocking matrix throughout the soil voids binding the soil particles together. As the matrix is insoluble it gives a strength mechanism that works to restrain the softening and swelling of the unaffected soil, thereby dramatically reducing the weakening effect of water. The interlocking calcium silicate fibers may be seen when a cured soil cement sample is examined under an electron microscope (Montgomery, 2002).

Making the approximate assumption that $C_3S_2H_3$ (Calcium silicate hydrate) binding gel, is the final product of the hydration of both C_3S and C_2S, the reactions of hydration can be written (as a guide, although not as exact stoichiometeric equation) (Neville, 1996) and results in the release of free lime (CaOH) according to the reaction:

$$6CaO.2SiO_2 + 6H_2O = 3CaO.2SiO_2.3H_2O + 3Ca\,(OH)_2 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_} \quad (i)$$

$$4CaO.SiO_2 + 4H_2O = 3CaO.2SiO_2.3H_2O + Ca\,(OH)_2 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_} \quad (ii)$$

The free lime then reacts further with the clay fraction (pozzolanic reaction) by the removal of silica from the clay minerals and subsequently forms more calcium silicate gel that also gradually crystallises.

2.9 Durability of Hydraform Blocks

According to Shetty (2005), durability is defined 'as the ability of cement concrete to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality and serviceability when exposed to its environment’.

Deterioration has been defined by several authors as 'the time-related loss of quality of a material, usually under the influence of environmental agents' (Moskvin, 1983). Premature deterioration has also been defined as a failure to achieve the predicted service life. Due to deterioration however, the durability of a block is unlikely to remain constant. It may in fact change considerably. The implication is that durability of a block and its deterioration are likely to influence each other mutually but negatively. As can be expected, the more a block deteriorates, the less durable it is likely to become over time. For example bulk properties of a block such as water absorption and permeability are related to the type of microstructure and density of the block (Kerali, 2001). However, the microstructure and density of a block may alter appreciably due to weathering (deterioration). This alteration can in turn increase the water absorption and permeability of the block. Such increases are likely to accelerate the rate of deterioration due to softening and dissolution of any unbound soil particles in the block. Further loss of performance can then be expected. The limit at which the loss of performance can be considered unacceptable is not yet well defined in SCBs. Unfortunately, even if it was, the limit may not be easily applicable without further qualification. This is because depending on the constituent materials used in a block, and on the quality of the processing methods used, no two blocks might be easy to compare. Unacceptable deterioration will therefore vary from block to block, and from property to property. Block properties that diminish over time reflect the past history of the block, both during and after manufacture (Kerali, 2001).

2.10 Deterioration Mechanisms in SCB

As is the case with most other building materials, deterioration mechanisms in CSBs are varied and complex. From the literature and experience gained through the use of the material, laboratory tests, building inspection records and the exposure condition surveys, three main deterioration modes can be identified, namely: water related deterioration, temperature related deterioration, chemical based deterioration.

2.10.1 Water Related Deterioration in SCB

Water serves as a common denominator for other deterioration mechanisms occurring in blocks. The main sources of water linked to such deterioration mechanisms are rain, rising damp and condensation. The action of water in causing deterioration in blocks can occur in any one or all of the following ways: solvent action, abrasive action, swelling action and catalytic action.

2.10.1.1 The Solvent Action

This is one of the most common deterioration mechanisms occurring in many building materials. The ability of a block surface to easily get wet, and the capacity of the block to absorb and retain water for sufficiently long periods of time, are two properties likely to leave the material vulnerable to the solvent action of water. The composition of a block fabric itself might also contribute to its vulnerability. Over 90% of the block bulk consists of soil, with the other 10% or less consisting of cement. In a stabilised block matrix, the process of cement stabilisation is known not to affect all the constituents in the block (Houben & Guillaud, 1994). Moreover, the hydration reaction between Ordinary Portland Cement (OPC) and water which is responsible for the binding action in the block also produces soluble by-products such as calcium hydroxide. The microstructure of a block consists of materials which are juxtaposed with capillary pores. The block is therefore able to attract water and retain it. As water permeates the block, any unstabilised soil fraction present, together with the freed calcium hydroxide from the hydration reaction of cement, can be expected to dissolve. Dispersal and subsequent leaching out of these substances can then follow. Repeated action of this nature over the years can lead to overall softening of a block fabric. Such action can also have the effect of weakening and altering the microstructure of the hardened cement matrix in a block. The microstructure of a block is therefore likely to continue evolving throughout its service lifetime. This is a detrimental trend since the softening and leaching action is irreversible. The severity of the action can be expected to increase during the rainy seasons, and to depend on the proportions of materials present in the block which are vulnerable to dissolution and softening. Unfortunately, as this form of deterioration progresses, it has the adverse potential of making the block more vulnerable to other forms of deterioration such as the erosive action of rainwater droplets (Kerali, 2001).

2.10.1.1 Surface Erosion

This only occurs in areas prone to frequent and intense rainfall such as is obtained in the humid tropics. The mechanism of surface erosion in blocks might not yet be well understood but the phenomenon is thought to proceed as follows. When rainwater strikes an exposed block surface, it will directly impact on it, with part of it turning into a spray. While the effect of the impact can be likened to the removal of loose particles, the effect of the spray is more likely to first wet the block surface. It has been estimated that up to 75% of the energy of a raindrop is dissipated on impact. The erosion capacity of raindrops depend on the state of bonding of the block surface, and on the characteristics of the rain (Kerali, 2001).

2.10.2 Temperature-Related Deterioration in SCBS

As SCBs form the exterior part of buildings, they will inevitably experience regular temperature variations. High ambient temperatures are common in tropical and sub-tropical regions of the world Temperature variations of such magnitude can cause both reversible and irreversible changes in the physical and chemical properties of blocks. These changes are likely to influence the durability of blocks in three main ways, namely: expansion and contraction of the block fabric, shrinkage and drying (of clay and hardened cement paste), catalytic action (for chemical reactions) (Kerali, 2001).

2.10.3 Chemical-Related Deterioration

The deterioration of SCBs can also be linked to the effects of chemical activity. According to literature sources, mechanisms associated with chemical action in SCBs remain the least investigated (Houben & Guillaud, 1994). Yet sources of potentially reactive chemicals in a block are soil and cement. Soils which constitute most of the bulk of a block contain minerals as well as contaminants. Some of these substances can remain dormant and stable when not in active contact with environmental elements (rainwater, high temperatures, relative humidity, gasses). OPC as the main binder in blocks also contains potentially unstable chemical constituents even in the hardened cement paste phase. Contact with environmental agents can catalyse chemical reactions in cement hydrates (Kerali, 2001).

The precondition for chemical reaction to start in most cement based materials is the presence of moisture (Moskvin 1983). Due to seasonal moisture variations from heavy rainstorms and humid conditions in the tropics, chemical reactions can be expected to occur within a block during its service lifetime. Environmental conditions found in the humid tropics therefore provide the best possible setting for chemical activity to occur in a block. Based on the nature of their action and resulting effects, deleterious mechanisms of chemical action can be broadly categorised into three groups, namely:

1. leaching out effect (clay and calcium hydroxide)
2. expanded product formation (internal stress generation)
3. direct decomposition (of the cement binder)

2.10.3.1: Leaching Out Effect

This is a phenomenon that involves the washing out of soluble substances from a material. There are two key sources of soluble substances in blocks: the calcium hydroxide found in the hardened cement paste, and the clay fraction likely to be found in residual unstabilised or partially stabilised matrix of a block (Houben & Guillaud, 1994).Calcium hydroxide [$Ca(OH)_2$] is known to easily dissolve in water (Neville, 1996). The dissolution process is irreversible once started, and is known to be facilitated by high temperatures, and the presence of carbon dioxide. Moreover, block properties such as water absorption and permeability, are likely to ensure that adequate moisture is absorbed and circulated within a block. Dissolved calcium hydroxide can be removed out of a block in either of two ways. It may simply be washed out of a block through surface flow on saturation during rainstorms, or it may be expelled onto the block surface by evaporation due to high temperatures. The phenomenon of leaching out of calcium hydroxide is also widely reported in concrete literature. There is no justifiable reason to expect that similar occurrences would not occur in CSBs. Residues of unstabilised soil (usually clay) have been found in a stabilised block fabric (Houben & Guillaud, 1994). Even within the recommended limit of less than 30% by weight of a block which is generally tolerated, the presence of clay is a potential source of problems. Owing to its fineness and high specific surface area, not only can clay grains obstruct the stabilisation process, but they are also likely to compete for the mix-water required for the hydration of cement. Clay can also coat the surfaces of coarse soil fractions (fine gravel and sand). Such coatings can inhibit the binding effect of cement on these particles. During rainy seasons, a block can rapidly absorb rainwater. The attraction of water by clay minerals has been explained by various mechanisms but ion exchange appears to remain the dominant mechanism (Moskvin, 1983). The amount and type of clay in a block can affect the degree of dispersion or flocculation. Kaolinite clays whose structure comprises platelets at a fixed distance are more stable in water, but are still capable of being disrupted. Ilite and montmorolinite clays on the other hand, which mostly contain interlayer potassium favour hydration in their dispersal (Houben & Guillaud, 1994). The swelling of clay lattice is known to assist in the mechanism of dispersal. Dispersed clay in a block fabric can easily be washed out as moisture permeates and circulates within it during rainy seasons.

The combined effect of leaching out of both calcium hydroxide and dispersed clays from a block is likely to be more severe in CSBs than in concrete. Extensive leaching is known to increase the porosity of a material (Neville, 1996). This can cause a block to become progressively weaker, and more permeable. A weakened block surface is more vulnerable to the direct abrasive action associated with driving rains. Since these mechanisms are likely to occur for the duration of the service lifetime of a block, deterioration over time can be expected. The effects of leaching can however be minimised in blocks if certain preventive measures are taken early enough. These include the following:

1 The use of pozolans and lime in combination with OPC during stabilisation. Pozolans and lime have the ability to fix both the calcium hydroxide present in hydrated cement paste and in any excess clay respectively.

2 Use of denser and more homogenous blocks of low permeability (less than 1.10^{-5} mm/sec) and of low water absorption capacity (less than 15%).

3 Careful soil selection that avoids use of soil with excessive clay content (<30% when OPC is used as the sole stabiliser).

4 Adequate curing of blocks.

2.10.3.2 Expanded Product Formation

Certain categories of chemical activity that can influence the durability of CSBs are associated with the formation of expanded products within a block. These expanded products can occupy a greater volume within the block than the compounds which they replaced. By forcibly trying to occupy space that is not readily available, internal stresses can be generated within a block. Reactions of this category are well documented in concrete literature (Neville, 1996). Apart from the occasional mention of the harmful effects of organic matter and other soil contaminants, no similar documentation of this phenomenon is covered in CSB literature. Yet the potential for such effects may be even greater in CSBs. The three main categories of reactions likely to affect the durability of CSBs through expanded product formation include:

1 Sulfate attack (on cement hydrates)

2 Alkali-aggregate reactions (involving silica and carbonates)

3 Soluble salts crystallisation (within the voids in a block).

Sulfates Attack: This occur widely in natural soils in most parts of the world. The type of sulfates vary greatly. But the common ones in soil are calcium, sodium and magnesium sulfates. These are mostly found in clayey soils rather than in sandy soils. The inclusion of significant amounts of sulfates in SCBs cannot be ruled out since no tests have so far been devised for their detection during soil selection. In the presence of sufficient amounts of moisture, sulfates present in soil can readily dissolve in water and react with certain hydrated cement products namely, calcium hydroxide and calcium aluminate (Neville, 1996). The dissolution of sulfates in water can create a sulfate solution within a SCB fabric. The sulfate solution might then react with both the $Ca(OH)_2$ and the hydrated C_3A to form calcium sulfate (gypsum), and calcium sulphoaluminates compounds (ettringite) respectively (Neville, 1996). The volume of these two by-products is much greater than that of the original substrates in the block. As these products expand in order to occupy more space within a block, and when this expansion is restrained by adjacent particles and phases within the core of the block, significant internal stresses are generated. The generated stresses are capable of disrupting bonding within the block. This can in turn result in a weakened block of lower strength, rigidity and hardness. The reactions are irreversible and their deleterious effects are noticeable within only a few years of their occurrence. The damage in blocks is commonly presented as defective edges and corners. These can also be followed by spalling and cracking of the block surface. The severity of sulfate attack on CSBs depends on a number of factors. They include: type and amount of sulfates present in the soil, type of cement used, and the bulk properties of a block.

Alkali-Aggregate Reactions (AAR): can also be expected to occur in SCBs. According to literature sources, the reaction is essentially an inter-constituent material reaction also with the potential to form expanded products in a block. The reaction can occur between the active silica and carbonate containing soils and the alkalis (Na_2O and K_2O) present in minute quantities in OPC (Neville, 1996). Alkalis may also be present in remote amounts in most soils. Two kinds of alkali- aggregate reactions, both potentially harmful to blocks, are distinguished: Alkali-silica reactions (ASR) and Alkali-carbonate reactions (ACR). These phenomena and the mechanisms involved are also widely reported in concrete (Neville, 1996).

Defects on blocks resulting from AAR reactions will most likely appear as map cracking and spalling, occurring mainly on the surface of the block. Cracking of the star shaped pattern is the most common, but not necessarily the only type. Factors likely to influence AAR reactions in SCBs include the following:

1 Availability of moisture

2 High temperature environments (10^0C - 40^0C)

3 Concentration of alkalis in cement and soil

4 Concentration of active silica and carbonates in soil

5 Porosity and permeability of the block.

From the above factors, the main preventive measures for AAR in SCBs should involve procedures that attempt to lower the alkali content in the cement while it is still in the plastic state. The addition of pozolans to the soil-cement-water mix at the time of stabilisation could be helpful. The main reason for using pozolans is that they easily combine with the alkali content of the cement and soil, thus effectively lowering the alkali content. AAR can therefore be avoided in SCBs by using low alkali cements, non-reactive soils and pozolans blended with OPC (Neville, 1996).

Soluble Salts Crystallisation (SSC): This can occur within the pores and voids spaces of a block. According to literature source, the crystallisation of salts results in expanded product formation (Neville, 1996). As before, such products have the potential to generate significant internal stresses within the pores and void spaces in a block. The phenomenon is widely reported in concrete literature. Soluble salts are commonly found in most soils especially sandy soils. Sandy soils won from rivers can also contain appreciable amounts of soluble salts. Amounts as little as 6% of the mass of the sand are enough to trigger off such reactions (Neville, 1996). The most common salts are usually sulfates and chlorides (Neville, 1996). Although these salts could easily be removed by washing of sand, the procedure is rarely followed in most developing countries. Sand is normally imported from various sources to improve the particle grading of soils needed for stabilisation. The soluble salts are however not reactive in the solid form in which they are normally present in the sand. They will only become reactive in solution. The alternate wetting and drying of block surfaces provides an ideal setting for such reactions. The mechanism of SSC is thought to be as follows.

When soluble salts in solution are present in a block fabric, they are likely to permeate into its capillary pores. Due to high temperatures leading to evaporation, moisture is driven off from the solution causing the salts to crystallise within the pores and voids spaces of the block. The volume of the crystals increase as the pore spaces get filled. But any further increase can be resisted by the rigid block fabric. This leads to the creation of significant stresses within the pores in the block. The induced stresses can cause cracking and disintegration at the surface of the block. Progressive deterioration of the block surface can then take place as moisture and temperature variations occur over the service lifetime of the block. The deterioration mechanism is known to be unaffected by the type of cement used. Limits on the soluble salts content of soil (especially its sand component) should therefore be specified during soil selection for SCB production.

Due to the threat from SSC, use of SCBs below the foundation level is still prohibited. Moreover, even blocks used at short distances above ground level in the lower courses of a wall may also be vulnerable to deterioration from SSC. The lower layers of a wall can be plastered to minimise such incidences.

2.10.3.3 Direct Decomposition of the Cement Binder

Direct decomposition of cement within a CSB can occur due to attack from acidic conditions. No OPC is known to be resistant to acid attack (Neville, 1996). The direct decomposition of OPC can lead to the progressive breakup of the bonds that hold the CSB fabric together and progress towards the interior. The phenomenon is widely reported in concrete literature.

CHAPTER THREE

EXPERIMENTAL PROCEDURE

3.1 Introduction

The materials used for this research were procured from the same source. The specimens were prepared and tested in accordance with the relevant code of practice. The experiments were carried out in the concrete laboratory of the Department of Building, A.B. U, Zaria. The chemical analysis for the fertilizer, cement and soil were carried out at the Center for Energy Research and Training, A. B. U Zaria and the Institute for Agricultural Research (I. A. R), A. B. U Zaria respectively.

3.1 Materials

The materials used for this study included; Hydraform blocks, soil samples from which the blocks were cast, cement and NPK fertilizer. The cement (Dangote Ordinary Portland) which conform to BS standards, was obtained from a local dealer at Samaru market, Zaria. The hydraform blocks and soil samples were obtained from the site, at Kuje L.G.A Abuja. The fertilizer was NPK (Golden 15-15-15) obtained from a local dealer at Samara market, Zaria.

3.1.1 Properties of Soil

The physical properties of the soil were determined in accordance with the appropriate section of BS codes. The relevant codes used for this tests are BS EN 771-1:2011 and BS EN 772-1:2011.

3.1.2 Shrinkage Test

A semi-cylindrical trough of internal dimensions 600mm long and 4mm diameter with razed on square ends, mixing container, hand scoop, water, measuring ruler, lubricant (used engine oil) were used to carry out the shrinkage test.. The internal length of the semi-cylindrical trough was measured and recorded. The internal mould faces was smeared with the lubricant to reduce the tendency of the soil to adhere to the rim of the mould.

The soil was then thoroughly mixed with water until it had a wet pudding consistency. The mould was then filled with this mixture, in three roughly equal layers. After the addition of each layer, the mould was tapped to remove any air trapped in the soil. When the final layer was tapped, the excess soil was removed from the top and the edge of the mould, leaving a smooth flat surface. The mould containing the soil sample was then placed in a shaded area to dry for seven days. The mould was protected from rain throughout the drying time and the procedure was repeated three times. The percentage linear shrinkage (LS) of the soil was calculated using equation (iii), (AS 1289, CA.1- 1977) and the mean value was calculated as the linear shrinkage.

$$LS\ (\%) = \frac{L}{L} * 100 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \text{(iii)}$$

Where: LS = Linear Shrinkage of the Soil

L = Length of mould (mm)

Ls = Change in Length of the soil (mm)

3.1.3: Aggregate Grading (Sieve Analysis Test)

Dry sample of weight 1kg was measured The sieves were stacked in order of decreasing size, the 5mm sieve at the top of the stack and the collector (pan) at the bottom. The weighed soil sample was then broken by hand and re-weighed. The soil was poured into a set of sieves was then shaken until no more material passes from one sieve to the next. The sieves apertures were lightly brushed with a soft rush to unblock apertures with trapped soil particles. The soil particles lying on top of each sieve was carefully removed and weighed, remembering to brush the material from any blinded holes. The mass on each sieve was converted to a percentage of the total mass using equation (iv) (BS EN 771-1:2011).

$$\% \text{ Passing} = \frac{m \quad r \quad o \quad s}{\sum t \quad m \quad o \quad s \quad sa} * 100 \qquad \text{(iv)}$$

3.2 Properties of Hydraform Blocks

The physical and mechanical properties of the hydraform blocks were determined in accordance with the appropriate section of BS codes.

3.2.1: Water Absorption

The water absorption test was carried out as descried in BS EN 771-1:2011.The procedure carried out was by selecting three dried hydraform blocks at random, weighed individually and immersed completely in water at room temperature for 48hours. The blocks were brought out of the water, then allowed to surface dry for 20 minutes before weighed again. The absorption capacities of the blocks were computed using equation (v)

$$\text{Absorption Capacity} = \frac{W \quad h\,o \quad w \quad B \quad - w \quad ht\,o \quad D \quad B}{w \quad ht\,o \quad D \quad B} * 100 \qquad \text{(v)}$$

3.2.2 Wet Compressive Strength Test

The wet compressive strength test was carried out as descried in BS EN 772-1: 2011. The procedure carried out states that for masonry units with frogs that have a net loaded area of more than 35% of the end face, crush them without removing or filling the frogs. Three specimens were selected at random and placed in water for 24 hours, removed and allowed to surface dry for 20minutes before they are placed in the compressive testing machine. The blocks were loaded gently until the edges of the frogs splinted. The failure load was read and recorded. The wet compressive strength was computed using equation (vi).

Compressive Strength N/mm^2 = $\frac{m \quad f \quad lt}{s \quad a \quad o \; lt \quad a}$ ________________________ (vi)

3.2.3 Dry Compressive Strength Test

The dry compressive strength test was carried out as descried in BS EN 772-1: 2011. Three specimens were selected at random and placed in the compressive testing machine. The blocks were loaded gently until the edges of the frogs splits. The failure load was read and recorded. The dry compressive strength was computed using equation (vi).

3.3 Chemical Analysis of Cement, Laterite and NPK Fertilizer

The chemical analysis for the materials (soil, cement and NPK) were analysed in Center for Energy Research Laboratory, A. B. U. Zaria. The Mini pal 4 version, is a compact Energy X-ray spectrometer designed for the elemental analysis of a wide range of samples. The system is controlled by a PC running the dedicated Mini pal analytical software, which uses a PW 4030 X-ray Spectrometer. This is an energy dispersive microprocessor controlled analytical instrument designed for the detection and measurement of elements in a sample (solid, powders and liquids), from sodium to uranium.

The sample for analysis was weighed and grounded in an agate mortar and a binder (PVC dissolved in Toluene) was added to the sample, carefully mixed and pressed in a hydraulic press into a pellet.

The pellet was loaded in the sample chamber of the spectrometer and voltage (30kV maximum) and a current (1mA) maximum) was applied to produce the X-ray to excite the sample for a preset time (10 minutes). The spectrum from the sample was then analysed to determine the concentration of the elements in the sample by multiplying with the values given in appendix II.

3.4 Hydraform Experiental Procedure

The test specimens comprises of hydraform blocks which were used to determine the compressive strengths of the blocks after immersion in a solution containing NPK fertilizer.

3.4.1 Preparation of NPK Fertilizer Solution

The saturated solution was prepared in Institute for Agricultural Research (I.A.R) A.B.U Zaria. The saturated solution of NPK was prepared by determining the solubility of the NPK in water. A 0.2g of NPK was poured in 50ml of distilled water, shook for 1 minute and allowed to settle for 15-30 minutes. A 0.5-1ml of the solution was poured into a 25ml volumetric flask with a developer. The developer was a solution of Ammonium molybdate and nitric acid. The volumetric flask was filled to the 25ml mark with distilled water and allowed to form a colour (yellowish) within 15-30 minutes.

The quantity of NPK to prepare a saturated solution was 4g/l, which was used as the basis and margin to establish different concentrations of the NPK solution. The concentrations were taken below and above the saturated value at s.t.p (standard temperature and pressure) obtained from the laboratory.

3.4.2 Compressive Strength Test after Exposure to NPK Solution

The different concentrations of NPK solutions used were 2.5g/l, 5g/l, 10g/l, 15g/l and 20g/l respectively. The solutions were prepared in 100l of water with NPK at 0.25kg/l, 0.5kg/l, 1kg/l, 1.5kg/l and 2kg/l respectively. Another solution without the NPK (i.e. water or zero concentration) was used as the control. Three samples of the hydraform blocks were taken at random and placed gently into the various solutions and covered. They were allowed to remain in the solutions for 7, 14, 21, 28, 56 and 90 days respectively. After each period, three samples were taken at random and crushed using the compressive strength testing machine to determine the failure load of the hydraform blocks. The compressive strengths were determined using equation (vi).

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSIONS

4.1 Data Presentation and Analysis

The results presented in this chapter were based on the tests carried out on the properties of soil, hydraform blocks, cement and NPK for the study. The properties of the soil used to produce the hydraform blocks were studied in order to determine the suitability of the soil for hydraform block production. Shrinkage test and sieve analysis tests to determine the cement content required to stabilise the soil and sieve analysis to determine the grading of the soil.

4.2 Properties of Soil

The properties of the soil used for the production of the Hydraform blocks tested in accordance to the relevant standards, and the results obtained are discussed as follows.

4.2.1 Shrinkage Test

The linear shrinkage test carried out based on the Standards Association of Australia, AS 1289, CA.1- 1977, shows that the mean linear shrinkage computed was 5.8% cement content (Table 4.1). Therefore, to increase the strength and durability of the hydraform blocks, the cement content can be increased up to 18% by weight according to soil type (Adam & Agib, 2001).

Table 4.1: Linear Shrinkage Test

Sample	Mould Length L (mm)	Shrinkage Length Ls (mm)	Linear Shrinkage LS (%)
1	600	31.2	5.2
2	600	38.4	6.4
3	600	35.5	5.9
	Mean	35.0	5.8

Source: Laboratory Work (2013)

4.2.2 Result of Aggregate Grading (Sieve Analysis Test)

The sieve analysis carried out for this study was based on BS 812-103(1990). The result for the test presented in table 4.2 shows the percentage of silt and clay as 0.95%, which is less than the minimum (10%) stated in the Hydraform guide to soil selection for block production (Hydraform Manual, 2004). The Hydraform manual (2004) also stated that, “Generally soils with low clay and silt portions, below 10%, will be difficult to handle when coming out the machine”. The soil can also be improved by additional cement content or grading with other soil (Hydraform Manual, 2004).

Table 4.2: Sieve Analysis

Sieve Sizes(mm)	Mass Retained (g)	% Passing
10mm	Nil	Nil
5mm	131.5	13.15
600nm	518	51.8
300nm	341	34.1
150nm	4.5	0.45
0nm	5	0.5

Source: Laboratory Work (2013)

4.3 Properties of Hydraform Blocks

The properties of the blocks i.e. dry compressive strength, wet compressive strength and moisture absorption test are discussed as follows:

4.3.1 Moisture Absorption Test

The moisture absorption test carried out in this study is tabulated in table 4.3. The moisture absorption mean value obtained in this research was 12.21%, which is lower than the maximum value 15% - 20% (Hydraform Manual, 2004).

Table 4.3: Moisture Absorption Test.

Sample	Dry Weight (kg)	Wet Weight (kg)	Moisture Absorption (%)
1	11.06	12.06	9.04
2	9.98	11.22	12.43
3	9.90	11.40	15.15

Source: Laboratory Test (2013)

4.3.2 Dry Compressive Strength

The method used to test the blocks was center loading of the block as shown in appendix I and plate IV. According to Hydraform manual (2004), this method of crushing has the lowest compressive strength (normalised strength factor of value 0.6) compared to load applied across the gross area of the block, load applied across the shoulders of the block and testing of cubes. The results for the dry compressive strength shown in table 4.4 has a mean compressive strength of 2.3N/mm^2. When the normalized strength factor value of 0.6 was multiplied and added to the dry compressive strength. It was less than the recommended minimum compressive strength of 4N/mm^2 for blocks produced on site (Hydraform Manual, 2004).

Table 4.4: Dry Compressive Strength of Hydraform Blocks Loaded across the Tongue

Sample	Tongue Area(mm^2)	Failure Load (N)	Compressive Strength(N/mm^2)
1	22000	50000	2.27
2	22000	50000	2.27
3	22000	50000	2.27
	Average		2.27

Source: Laboratory Test (2013)

4.3.3 Wet Compressive Strength

The wet compressive strength was carried out using BS EN 772-1: 2011 as stated earlier. Table 4.5 shows that the mean compressive Strength computed was 1.8N/mm^2, which is 78% of the dry compressive strength. The BS EN 772-1: 2011 also states that the wet compressive strength should not be less than 80% of the dry compressive strength. The drop in wet compressive strength can also be attributed to the high content of Potassium ion (K^+) present in the soil (Table 4.7), which is readily soluble in water.

Table 4.5: Wet Compressive Strength of Hydraform Blocks Loaded across the Tongue.

Sample	Tongue Area(mm^2)	Failure Load (N)	Compressive Strength(N/mm^2)
1	22000	40000	1.82
2	22000	50000	2.27
3	22000	30000	1.36
	Average		1.82

Source: Laboratory Test (2013)

4.4 Chemical Analysis

4.4.1 Chemical Composition Analysis of Dangote Ordinary Portland Cement

Table 4.6 shows the chemical composition present in the cement used for the production of the Hydraform blocks, which has a total percentage of chemicals from the test as 82.92%. It was assumed that the remaining 17.08% contains other elements including the harmful oxides of cement. These oxides and other compounds and elements of cement were not seen on table 4.6 due to the inability of the Mini Pal 4 Version X-ray spectrometer to detect other elements.

Table 4.6 Chemical Composition of Ordinary Portland Cement (Dangote Cement)

Oxide	Common Name	Content (%)
Al_2O_3	Alimina	1.00
SiO_2	Silica	1.54
SO_3	Sulfuric anhydride	3.54
CaO	Lime	70.82
Fe_2O_3	Iron	6.02
Total		82.92

Source: Laboratory Test (2013)

4.4.2 Chemical Composition Analysis of Laterite

Table 4.7 shows the chemical composition analysis result obtained for the laterite used in this study with the total percentage of elements detected in the result as 98.99%. According to BS EN 771-1:2011, the active soluble salts Sodium (Na^{+}), Potassium (K^{+}) and Magnesium (Mg^{+}) ions in the laterite should not exceed 0.17% and 0.08% by mass respectively. Although, Na^{+} and Mg^{+} are not represented on the result for this research. This could be as a result of their absence or the inability of the Mini Pal 4 X-ray spectrometer to detect them. However, K^{+} present have exceeded the maximum value (0.17), which is 2.35% by mass of its oxide (see appendix V for multipliers of oxides to elements).

Table 4.7 Chemical Composition of Laterite

Oxide	Common Name	Content (%)
Al_2O_3	Alimina	16.60
SiO_2	Silica	49.40
K_2O	Potassium Oxide	2.83
CaO	Lime	2.32
Fe_2O_3	Iron	26.12
TiO_2	Titanium Oxide	1.35
V_2O_5	Vanadium Oxide	0.09
Cr_2O_3	Chromium Oxide	0.08
MnO	Manganese Oxide	0.03
NiO	Nickel Oxide	0.09
CuO	Copper Oxide	0.05
ZnO	Zinc Oxide	0.03
Total		98.99

Source: Laboratory Test (2013)

4.4.3 Chemical Composition Analysis of NPK

Table 4.8 shows the chemical composition of NPK fertilizer 15-15-15 with the total percentage of elements detected as 97.85% of the major or macro elements. Other micro elements likely present are assumed to be present in the remaining 2.15%. Although, the Mini pal 4 X- ray spectrometer was unable to detect Nitrogen element and other elements that could be present. For this reason, another laboratory was involved in estimating the amount of Nitrogen present (appendix VII). The quantity was deducted from the 41.09% of Sulfur, which is reduced to 25.79% as seen in table 4.6. Potassium appears to be higher 19.15% by mass than Phosphorus 6.8% and Nitrogen 15.3%.

Table 4.8 Chemical Composition of NPK Fertilizer

Oxide	Common Name	Content (%)
P_2O_5	Phosphorous pentoxide	15.60
K_2O	Potassium Oxide(alkali)	23.08
S	Sulfur	25.79
Cl^-	Chlorine	18.08
N^-	Nitrogen	15.30
Total		97.85

Source: Laboratory Test (2013)

4.5 Compressive Strength Test Results

Figure 1 shows the combined compressive test results for the separate NPK solutions (2.5g/l, 5g/l, 10g/l, 15g/l and 20g/l). Figure 2, 3, 4, 5 and 6 shows the Zero NPK and the different NPK concentrations respectively.

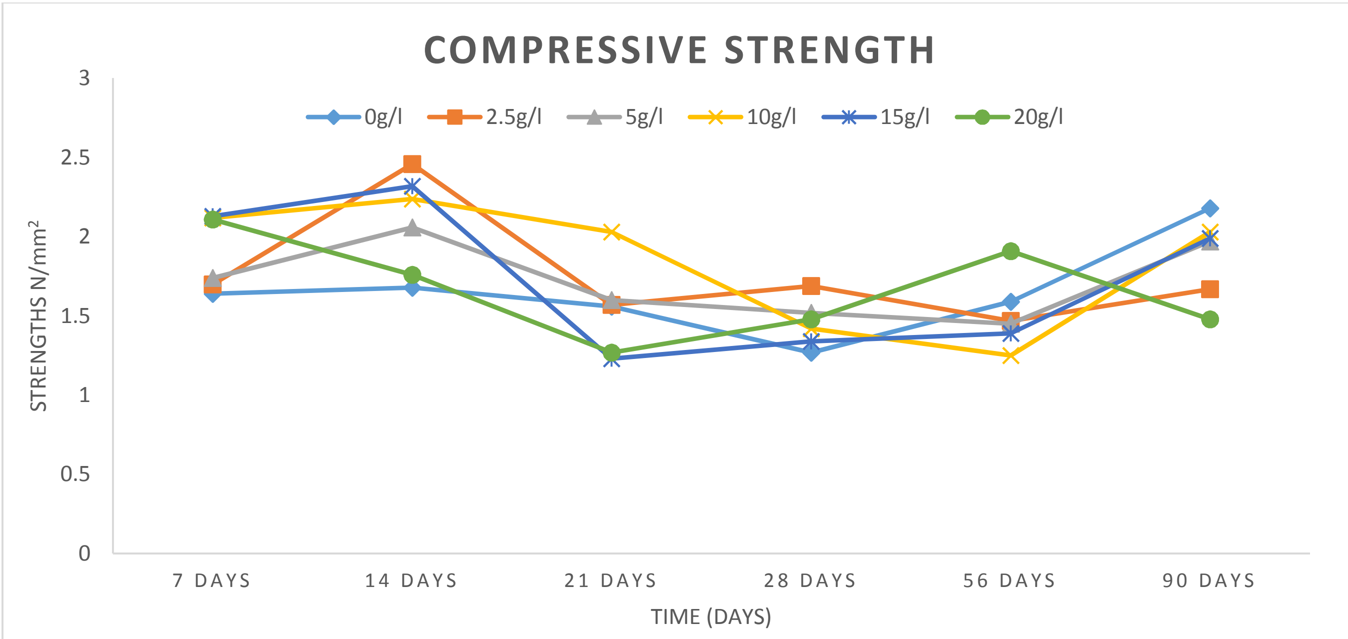

Figure 1 Variation of Compressive Strength of SCB with Age of Curing [Laboratory Work (2013)]

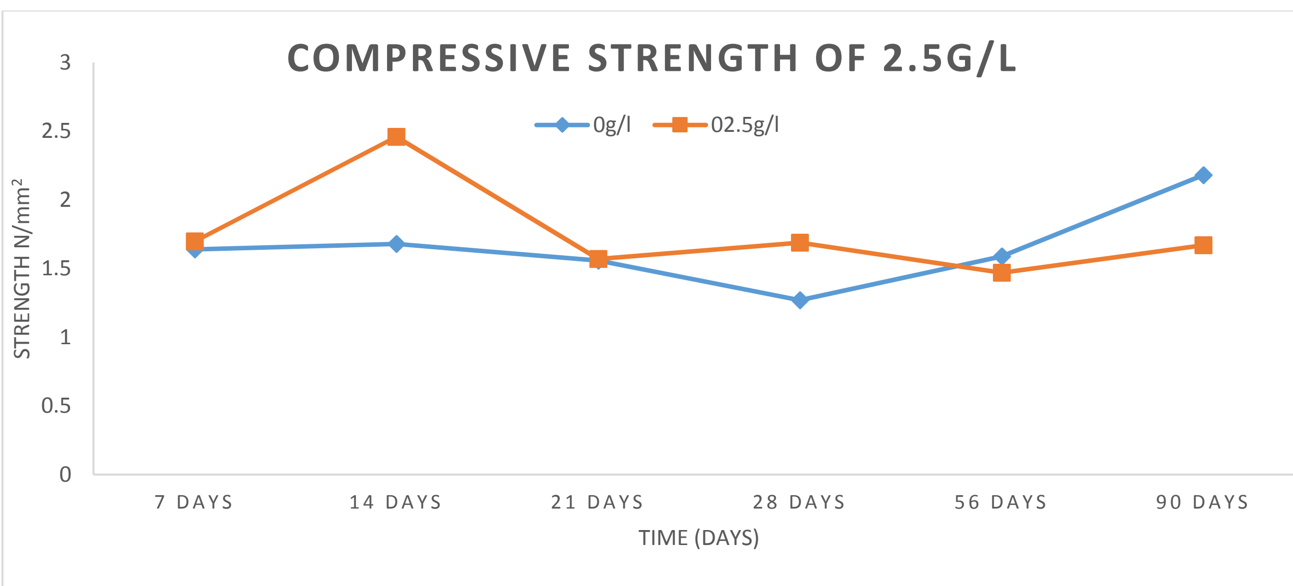

Figure 2 Compressive Strength Test Results (2.5g/l) [Laboratory Work (2013)]

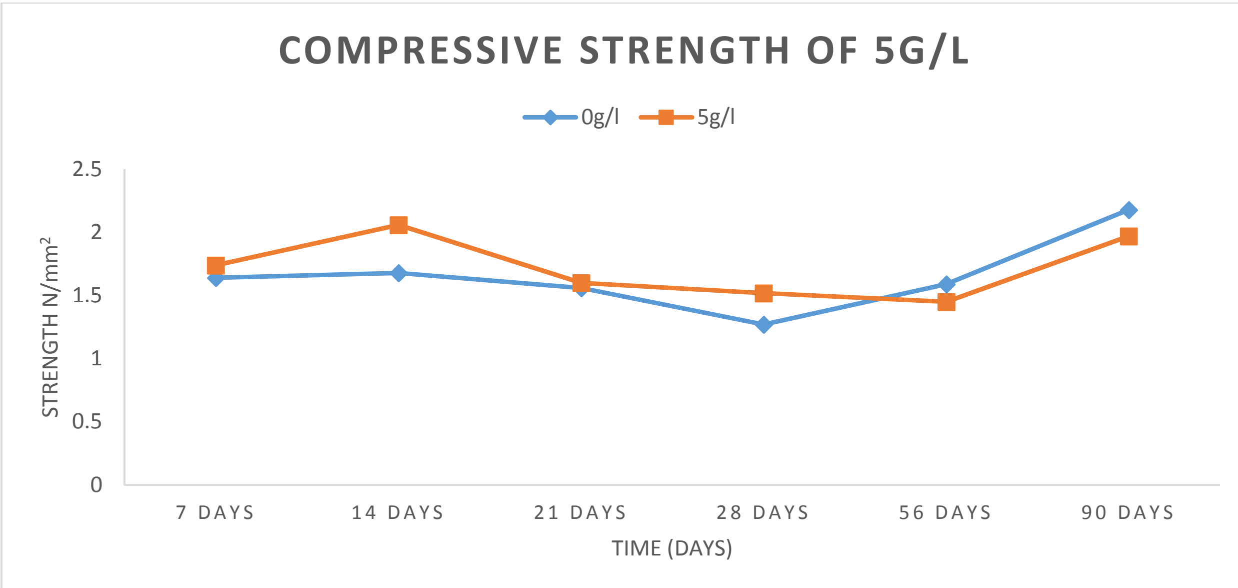

Figure 3 Compressive Strength Test Results (5g/l) [Laboratory Work (2013)]

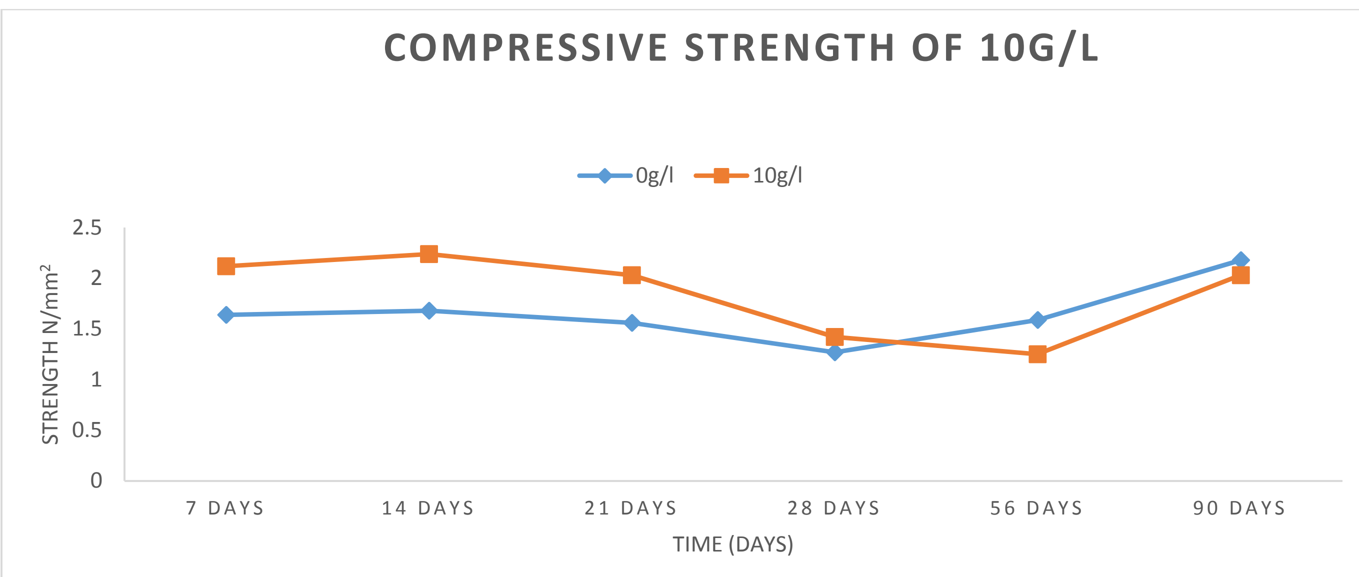

Figure 4 Compressive Strength Test Results (10g/l) [Laboratory Work (2013)]

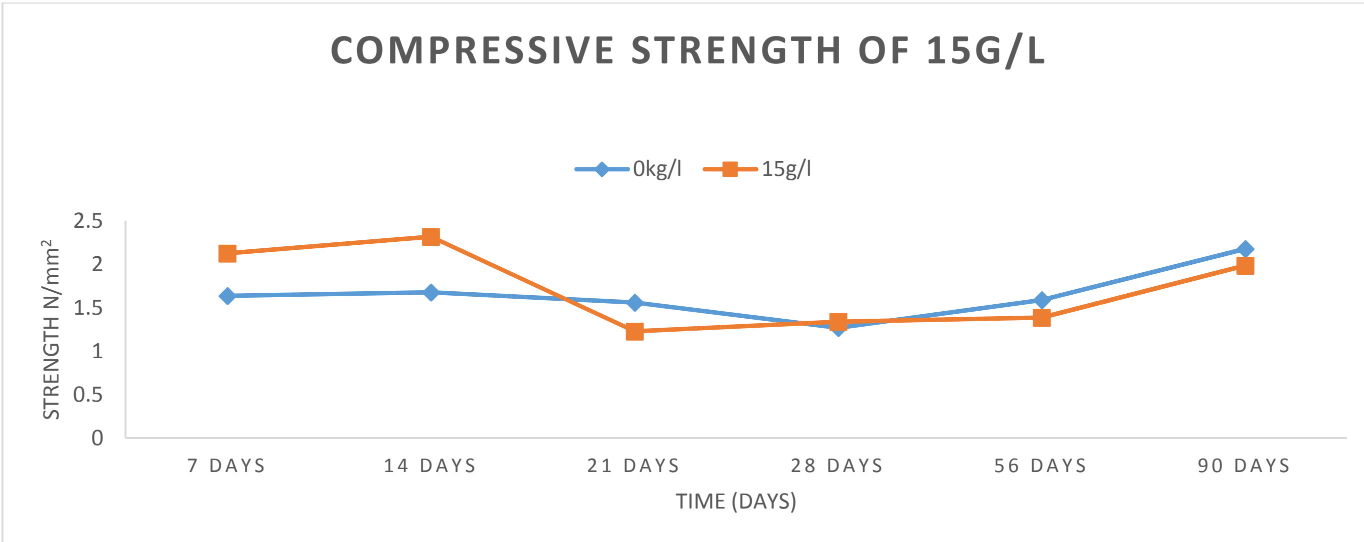

Figure 5 Compressive Strength Test Results (15g/l) [Laboratory Work (2013)]

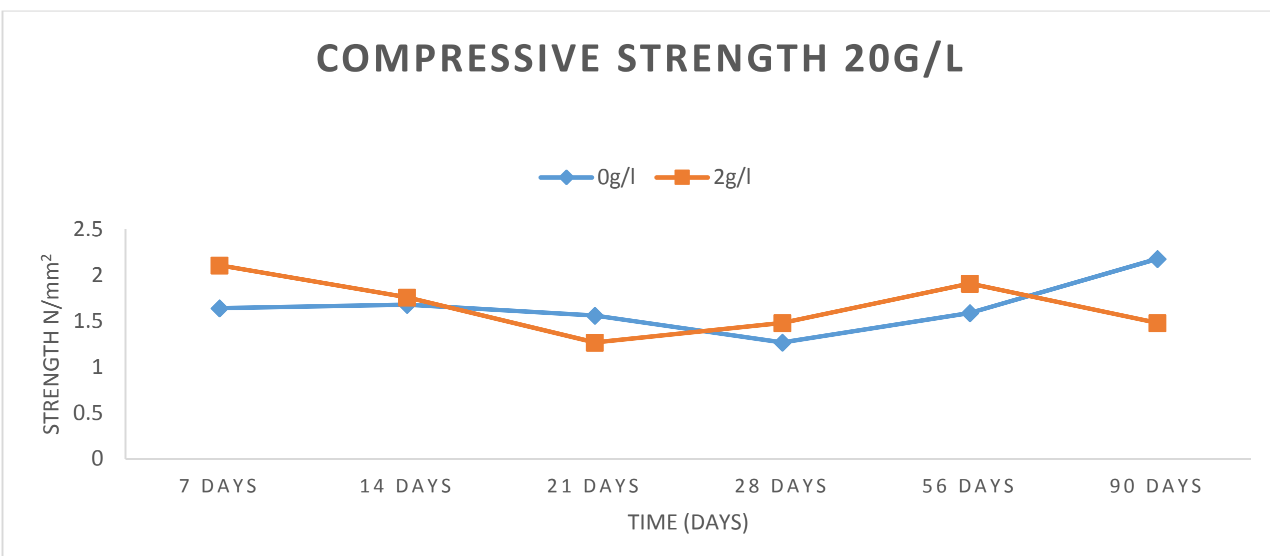

Figure 6 Compressive Strength Test Results (20g/l) [Laboratory Work (2013)]

The figures (1 to 6) shows that the compressive strength of zero concentration is lower 1.64N/mm^2 than those placed in the solutions of NPK with different concentrations. Therefore, the figures can be seen to behave in different patterns. The zero NPK concentration is said to experience leaching out of soluble salts, elements and compounds, while the NPK concentrations experienced the crystallization and accumulation of reaction products, which increases the volume of the blocks within the pore structure (Moskvin 1983; Kerali 2001).

The graph of zero NPK solution showed an almost linear (horizontal) curve in the presence of water. According to Ekstrom (2001), water may not only be good for hydration of cement, it can also start to dissolve free hydration products [$Ca(OH)_2$] in cement. When the free $Ca(OH)_2$ dissolves in water, the solution becomes agitated. To keep the solution within the blocks and the surrounding water at equilibrium, the dissolved products diffuses. When all the free $Ca(OH)_2$ have dissolved, hydrolysis of calcium silicate and aluminate hydrates follows with a release of $Ca(OH)_2$ (Moskvin 1983). Due to the low content of cement (less than 10%) and leaching, hydration by immersion shows small increase in the compressive strength of the blocks from 7days to 14days (1.64 N/mm^2 to 1.68 N/mm^2). After 56 days, the block had the highest compressive strength at 90days (2.18 N/mm^2) after the water with dissolved $Ca(OH)_2$ has remained at equilibrium.

The graphs of blocks immersed in NPK solution displayed the crystallization and accumulation of reaction products associated with ion exchange deterioration (Moskvin, 1983). In this case, the calcium hydroxide formed does not diffuses into the surrounding water due to the presence and concentrations of other monomers in the surrounding water or solution of the NPK. When this monomers penetrate into the pores and polymerize causing increase in volume, the decomposition of the hardened cement develops with the dissolution of its constituents and products of the exchange reactions. At the initial stage, the blocks will be denser owing to a gradual accumulation of salts in its pores. Ones this happens, the filling of pores and voids in the blocks with new crystalline formations and consequent solidification of the blocks gives an indication of increase in strength (Moskovin, 1980), as seen in figure 1 to figure 6 (7days to 21days). This process occurs slowly, which results to the increase in strength at the early stage (1.7N/mm^2, 1.74N/mm^2, 2.12N/mm^2, 2.13N/mm^2 and 2.11N/mm^2 respectively). However, in the case of figure 6, the strength dropped instantly due to rapid dissolution of hardened cement and formation of crystalline salts as seen in plate 5. The white crystalline layer formed appeared after 56days and 90 days immersion in NPK solution with concentrations 15g/l and 20g/l respectively.

Plate V: White layer deposit within Hydraform block after crushing

[Laboratory Work (2013)]

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

1. The cement content established from the mean linear shrinkage test was 5.8% by weight. Soil and SCB properties can be improved by adding more cement.

2. The silt and clay content was 0.95% less than the maximum 35%. Therefore, the soil can be improved by adding more cement content or grading with other soil as stated in the Hydraform Manual (2004).

3. The moisture content was 12.21%, which is less than the maximum stated 15% to 20% (Hydraform Manual, 2004)

4. The dry compressive strength 2.3N/mm^2 when the normalized factor of 0.6 was applied, the strength 3.68N/mm^2 is less than the recommended minimum compressive strength of 4N/mm^2 for blocks produced on site (Hydraform Manual, 2004).

5. The wet compressive strength was 1.8N/mm^2 and it is 78% of the dry compressive strength 2.27N/mm^2, less than the minimum 80% stated in BS EN 772-1: 2011.

6. Hydration of OPC occurs simultaneously with leaching of the products of hydration, to form an equilibrium solution of calcium hydroxide within and around the SCB. Further disintegration of the SCB is due to dissolution of potassium salts present in the laterite soil.

7. Ion exchange takes place leading to the formation of crystals in pore, which increases the volume of the blocks and consequently a false increase in the strength of the SCB.

5.2 Conclusions

1. The soil properties showed low shrinkage and low amount of silt and clay. Therefore, to improve the strength and permeability of the SCB, more cement content needs to be added.

2. The properties of the hydraform blocks i.e. wet compressive strength less than 80% (78%) of dry compressive strength are below the standards in BS EN 771 and BS EN 772.

3. Soil cement blocks with cement as the stabilizing agent under goes hydration when immersed in water. Leaching, which occurs simultaneously when immersed in water, leads to disintegration of SCB as a result of dissolution of the byproduct of hydration.

4. Soil cement blocks with cement as the stabilizing agent under goes ion exchange reaction producing crystalline solid, which fill pores and voids gradually. Therefore leading to increase strength and disintegration.

5. Soil cement blocks can be used to construct ware houses for storage of NPK fertilizer.

5.3 Recommendations

5.3.1 Recommendations from Findings

Based on the findings of this study, the following recommendations are made:

1. The shrinkage test and sieve analysis indicates that the cement quantity should be increased to improve the SCB properties.
2. Chemical test to determine the chemical composition of soil, should be carried out as part of the tests to determine the suitability of soil for SCB.

3. The SCB should be protected from water and moisture by coating. Coatings of Acronal S400 and Masterseal 550 over blocks have been found to improve water proofing qualities (Ipinge, 2012).
4. Government should enact laws to monitor the standards and codes of practices in the selection of materials and production of soil cement blocks.
5. Testing of materials for academic purposes should not be confined to certain Institute or Departments. E.g. Chemistry Department are not to carry out any test on NPK fertilizer.
6. Government should provide tertiary institutions with state-of-the-art equipment for chemical analysis, chemical testing of materials and Hydraform Block machine.

5.3.2 Recommendations for Further Research

1. Further chemical studies should be carried out using lime and cement as stabilising agent.
2. Chemical test of other fertilizers such ammonium nitrate, fungicide and pesticides should be carried out.

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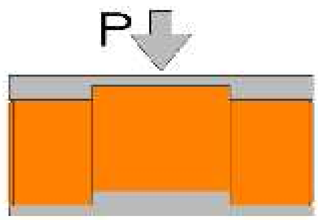
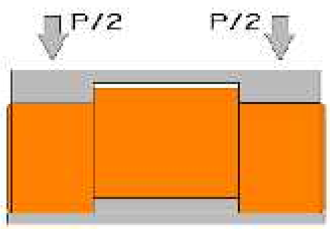
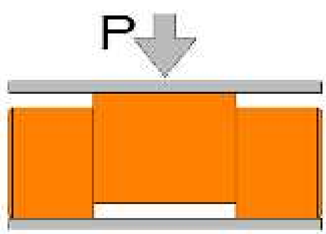
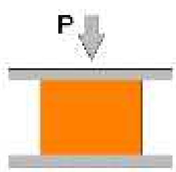
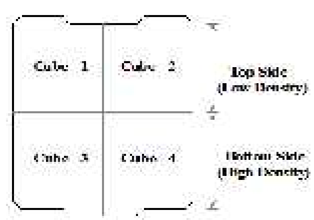
Appendix I

Table 2.2: Methods of load application for irregular shaped Hydraform block and resulting failure patterns

Method of Load Application		Load Regime	Failure Pattern/ Cube Loading Arrangement
1	Load application across the gross area of the block		
2	Load application across the shoulders of the block		
3	Load application across the Tongue of the block		
4	Testing of Cubes		
		ColourScheme: Brown–Hydraform Block Grey -Platen	

Source: Pave (2007)

Appendix VIII

Compressive Strength Test

Duration (Days)	Water	2.5g/l	5g/l	10g/l	15g/l	20g/l
7	1.64	1.7	1.74	2.12	2.13	2.11
14	1.68	2.46	2.06	2.24	2.32	1.76
21	1.56	1.57	1.6	2.03	1.23	1.27
28	1.27	1.69	1.52	1.42	1.34	1.48
56	1.59	1.47	1.45	1.25	1.39	1.91
90	2.18	1.67	1.97	2.03	1.99	1.48

Source Laboratory Work (2013)